EFFECT OF CUTTING PARAMETERS ON MRR, SURFACE ROUGHNESS AND DIMENSIONAL DEVIATIONS IN DRY TURNING OF SS304

A project report submitted in partial fulfillment of the requirements

for the award of the Degree of

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(2015-2019)
In

MECHANICAL ENGINEERING

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LIST OF CONTENTS

LIST OF FIGURES Pg.No.

LIST OF TABLES Pg.No.

NOMENCLATURE

v	Cutting Speed, Rpm
f	Feed, mm/rev
d	Depth of Cut, mm
r	Tool Nose Radius
MRR	Material Removal Rate, cm^3/min
R_a.	Arithmetic Surface Roughness Average, µm
R_z.	Ten Point Average Roughness, µm
CNC	Computerized Numerical Control
DOE	Design of Experiments
OA	Orthogonal Array
S/N	Signal-to-Noise Ratio
ANOVA	Analysis of Variance
DF	Degree of Freedom
SS	Sum of Squares
MS	Mean Square
F	Variance Ratio
P	Probability of Significance
S	Variance
$R^{2.}$	Coefficient of Determination
R^2 (Adj)	Adjusted R^2
$P_{i.}$	Individual Utility
U	Overall Utility
η_m	Total Mean Value

ABSTRACT

The present work is to investigate the effect of cutting parameters on the multiple performance characteristics in dry turning of SS304. The work material has a wide range of applications in food processing units, kitchen utensils, heat transfer equipments, medical offices and surgical offices, screws and machinery parts, cookware, etc. A series of experiments were carried out using coated tungsten carbide tools on CNC turret lathe. Taguchi's mixed L18 orthogonal array has been followed by taking speed, feed, depth of cut and nose radius as the controllable parameters. The multiple responses of material removal rate (MRR) and surface roughness characteristics (R_a) are analyzed using Taguchi based utility and AHP methods. From the results, the optimal combination for achieving the high material removal rate and low surface roughness characteristics simultaneously is obtained at the speed of 60 m/min, feed of 0.15 mm/rev, depth of cut of 1.5 mm and nose radius of 0.8 mm. Finally, the analysis of variance (ANOVA) is employed to find the influence of cutting parameters on the multi response value. From ANOVA it is concluded that feed is the most influencing parameter on the multi response and followed by depth of cut,speed and nose radius respectively. Finally, the model for the multi response based on the estimated averages is predicted and it is found to be more accurate and adequate.

CHAPTER 1

INTRODUCTION

1.1. Turning Operation

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specifieddimension, and to produce a smooth finish on the metal. Often the work piece will beturned so that adjacent sections have different diameters.

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

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

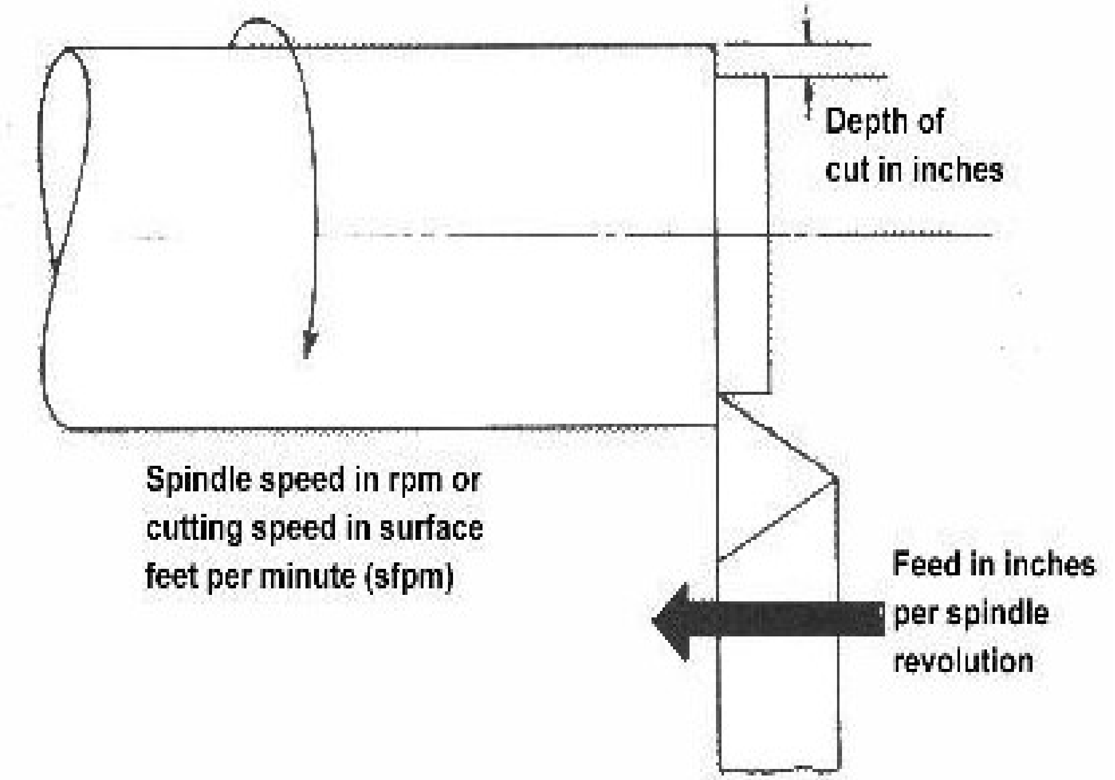

Figure 1.1.Turning Operation

1.1.1.Adjustable Cutting Factors In Turning

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

Speed:

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

$V = \pi DN/1000$; m/min

Here, v is the cutting speed in turning, $D$is the initial diameter of the work piece in mm,and N is the spindle speed in RPM.

Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances alongits cutting path. On most power-fed lathes, the feed rate is directly related to the spindlespeed and is expressed in mm (of tool advance) per revolution (of the spindle), ormm/rev.

$F_m = f.N$ mm/min

Here, $F_m$is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speedin RPM.

Depth of Cut:

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

$D_{cut} = (D-d)/2$, *mm*

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

1.2. CUTTING TOOLS FOR LATHES: TOOL GEOMETRY

Tool Geometry:

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

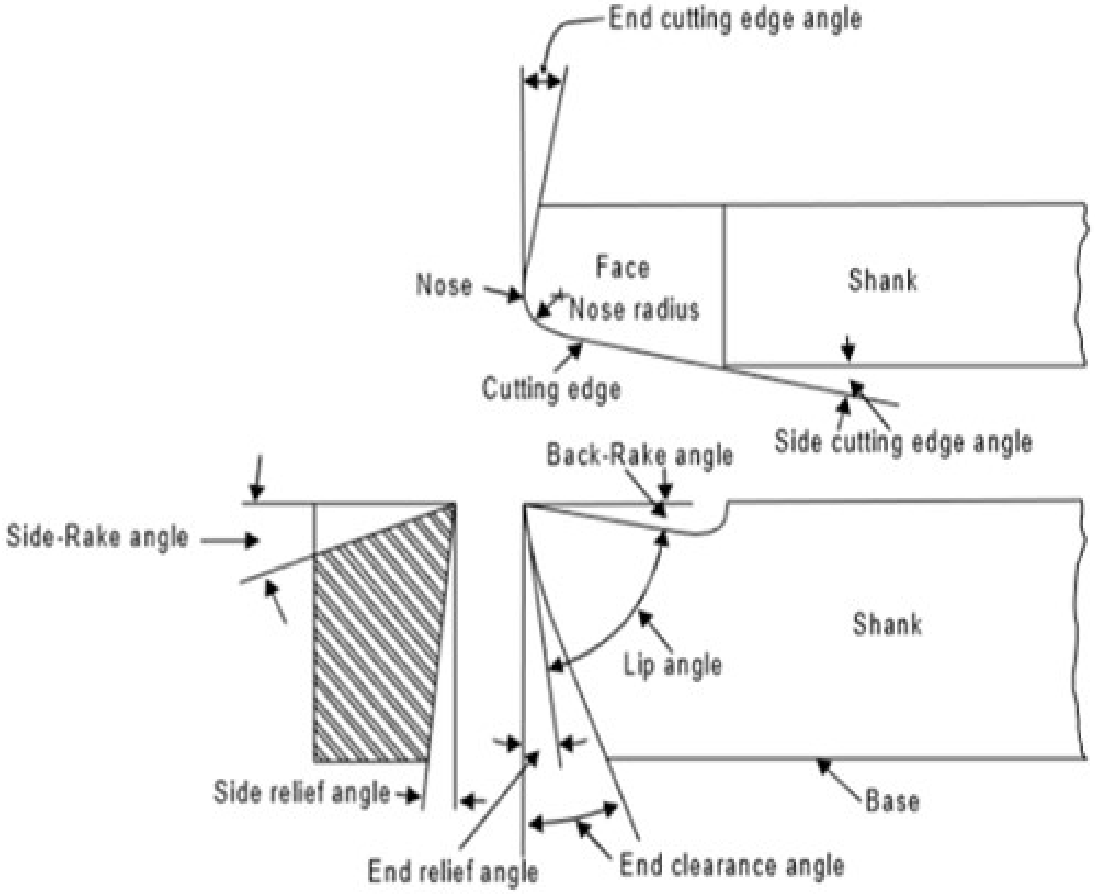

Figure 1.2. Cutting Tool Nomenclature

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 flankpasses over the newly machined surface.

Face:

The flat surface of a single point tool through which, the work piece rotates duringturning operation. 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 theface of the tool and a line parallel to the floor. A positive back rake angle tilts the toolface back, and a negative angle tilts it forward and up.

Side Rake Angle:

If viewed behind the tool down the length of the tool holder, it is the angle formed by theface of the tool and the centerline of the work piece. A positive side rake angle tilts thetool face down toward the floor, and a negative angle tilts the face up and toward thework piece.

Side Cutting Edge Angle:

If viewed from above looking down on the cutting tool, it is the angle formed by the sideflank of the tool and a line perpendicular to the work piece centerline. A positive sidecutting edge angle moves the side flank into the cut, and a negative angle moves the sideflank 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 endflank of the tool and a line parallel to the work piece centerline. Increasing the endcutting 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 theside flank of the tool and a vertical line down to the floor. Increasing the side relief angletilts 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 endflank of the tool and a vertical line down to the floor. Increasing the end relief angle tiltsthe 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 radiuscreates 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 withdimensions that shift the angle of an insert, the lead angle takes this change intoconsideration.The back rake angle affects the ability of the tool to shear the work material and form thechip. It can be positive or negative. Positive rake angles reduce the cutting forcesresulting in smaller deflections of the work piece, tool holder, and machine. If the backrake angle is too large, the strength of the tool is reduced as well as its capacity to conduct heat. In machining hard work materials, the back rake angle must be small, even negative for carbide and diamond tools. The higher the hardness, the smaller will be the back rake angle. For high-speed steels, back rake angle is normally chosen in the positiverange.

1.3. CUTTING TOOL MATERIALS

The classes of cutting tool materials currently in use for machining operation are highspeedtool steel, cobalt-base alloys, cemented carbides, ceramic, polycrystalline cubicboron nitride and polycrystalline diamond. Different machining applications require different cutting tool materials. The Ideal cutting tool material should have all of thefollowing 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 specificinformation 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. However carbon steelsstart to soften at a temperature of about 180oC. This limitation means that such tools arerarely 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 forwoodworking and they can be used in a router to machine aluminium sheet up to about3mm thick.

High Speed Steels (HSS):

HSS tools are so named because they were developed to cut at higher speeds. Developedaround 1900 HSS are the most highly alloyed tool steels. The tungsten (T series) wasdeveloped first and typically contains 12 - 18% tungsten, plus about 4% chromium and 1

7- 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 formost of the tungsten resulting in a more economical formulation which had betterabrasion 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 contain5 - 10% molybdenum, 1.5 - 10% tungsten, 1 - 4% vanadium, 4% Chromium and manygrades contain 5 - 10% cobalt.

HSS tools are tough and suitable for interrupted cutting and are used to manufacture toolsof complex shape such as drills, reamers, taps, dies and gear cutters. Tools may also becoated to improve wear resistance. HSS accounts for the largest tonnage of tool materialscurrently 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 of55 - 64 Rc. They have good wear resistance but are not as tough as HSS but can be usedat somewhat higher speeds than HSS. Now only in limited use.

Carbides:

Also known as cemented carbides or sintered carbides were introduced in the 1930s andhave high hardness over a wide range of temperatures, high thermal conductivity, highYoung's modulus making them effective tool and die materials for a range ofapplications. The two groups used for machining are tungsten carbide and titaniumcarbide; both types may be coated or uncoated. Tungsten carbide particles (1 to 5 micrometer) are bonded together in a cobalt matrix using powder metallurgy. The powderis pressed and sintered to the required insert shape. Titanium and niobium carbides mayalso be included to impart special properties. A wide range of grades are available fordifferent applications. Sintered carbide tips are the dominant type of material used inmetal cutting. The proportion of cobalt (the usual matrix material) present has asignificant effect on the properties of carbide tools. 3 - 6% matrix of cobalt gives greater8hardness while 6 - 15% matrix of cobalt gives a greater toughness while decreasing thehardness, wear resistance and strength. Tungsten carbide tools are commonly used formachining steels, cast irons and abrasive non-ferrous materials. Titanium carbide has ahigher wear resistance than tungsten but is not as tough. With a nickel-molybdenum alloyas the matrix, TiC is suitable for machining at higher speeds than those which can beused for tungsten carbide. Typical cutting speeds are: 30 - 150 m/min or 100 - 250 whencoated.

Coatings:

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

Cermets:

Developed in the 1960s, these typically contain 70% aluminium oxide and 30% titaniumcarbide. Some formulation contains molybdenum carbide, niobium carbide and tantalumcarbide. Their performance is between those of carbides and ceramics and coatings seemto 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 highpurity aluminium oxide ($Al2O3$) and silicon nitride ($Si3N4$) are pressed into insert tipshapes and sintered at high temperatures. Additions of titanium carbide and zirconiumoxide ($ZrO2$) may be made to improve properties. But while $ZrO2$ improves the fracturetoughness, 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 chemicalstability compared to HSS and carbides means they are less likely to adhere to the metalsduring cutting and consequently have a lower tendency to form a built up edge. Their main weakness is low toughness and negative rake angles are often used to avoidchipping 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 topremature 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 alsocontain 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 theelements: silicon, aluminium, oxygen and nitrogen. This has higher thermal shock resistance than silicon nitride and is recommended for machining cast irons and nickelbased 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 thicklayer 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 choicefor machining alloy and tool steels with a hardness of 50 Rc or higher. Typical cuttingspeeds: 30 - 310 m/min.

Diamond:

The hardest known substance is diamond. Although single crystal diamond has been usedas a tool, they are brittle and need to be mounted at the correct crystal orientation toobtain optimal tool life. Single crystal diamond tools have been mainly replaced bypolycrystalline diamond (PCD). This consists of very small synthetic crystals fused by ahigh 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 orientationof 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 cutsat almost any speed and is mainly used for very high speed machining of aluminium -silicon alloys, composites and other non - metallic materials. Typical cutting speeds: 200- 2000 m/min.To improve the toughness of tools, developments are being carried out with whiskerreinforcement, 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 ceramicsand other super hard materials.High-speed steels cut four times faster than the carbon steels they replaced. There areover 30 grades of high-speed steel, in three main categories: tungsten, molybdenum, andmolybdenum-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-speedsteels. Cemented carbide is a powder metal product consisting of fine carbide particlescemented together with a binder of cobalt. The major categories of hard carbide includetungsten 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 typesof ceramic cutting tools are available: the alumina-based and the silicon nitride-basedceramics. The alumina-based ceramics are used for high speed semi- and final-finishingof ferrous and some non-ferrous materials. The silicon nitride-based ceramics aregenerally used for rougher and heavier machining of cast iron and the super alloys.

1.4. OUTPUT CHARACTERISTICS

1.4.1. Material Removal Rate (MRR)

The material removal rate (MRR) in turning operations is the volume of material/metalthat is removed per unit time in mm3/min. For each revolution of the work piece, a ringshapedlayer of material is removed.

$$MRR = (v.f.d \times 1000) in mm^3 / \mathrm{min}$$

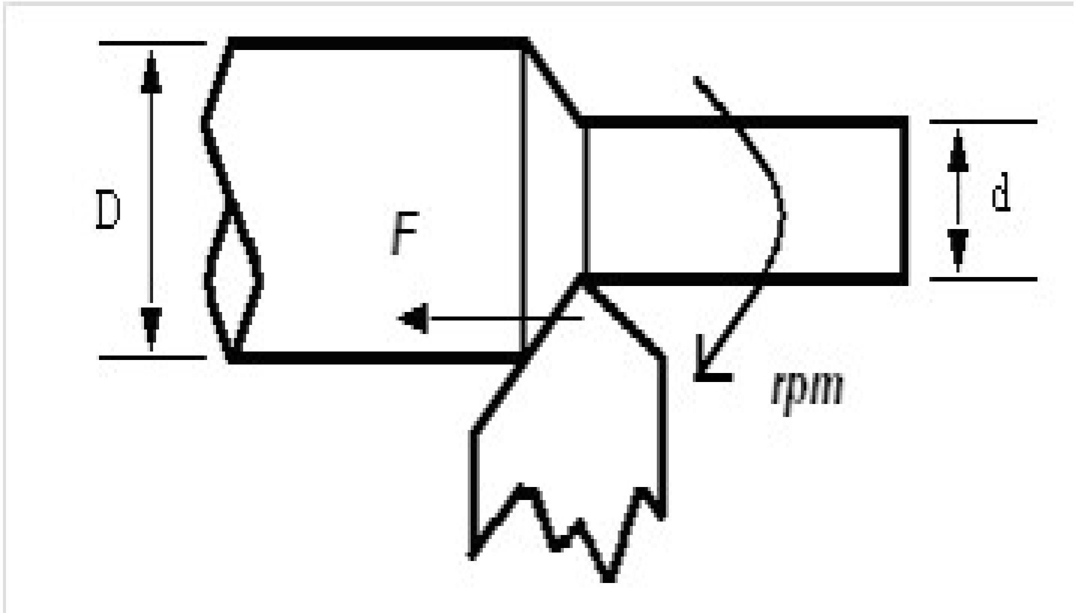

Figure 1.3 Material Removal Rate (MRR)

1.4.2. Surface Structure and Properties

Surface roughness is an important measure of product quality since it greatly influencesthe performance of mechanical parts as well as production cost. Surface roughness has animpact on the mechanical properties like fatigue behavior, corrosion resistance, creep life,etc. It also affects other functional attributes of parts like friction, wear, light reflection,heat transmission, lubrication, electrical conductivity, etc. Before surface roughness, it isalso necessary to discuss about surface structure and properties, as they are closelyrelated.Upon close examination of the surface of a piece of metal, it can be found that itgenerally consists of several layers. The characteristics of these layers arebriefly outlined here:

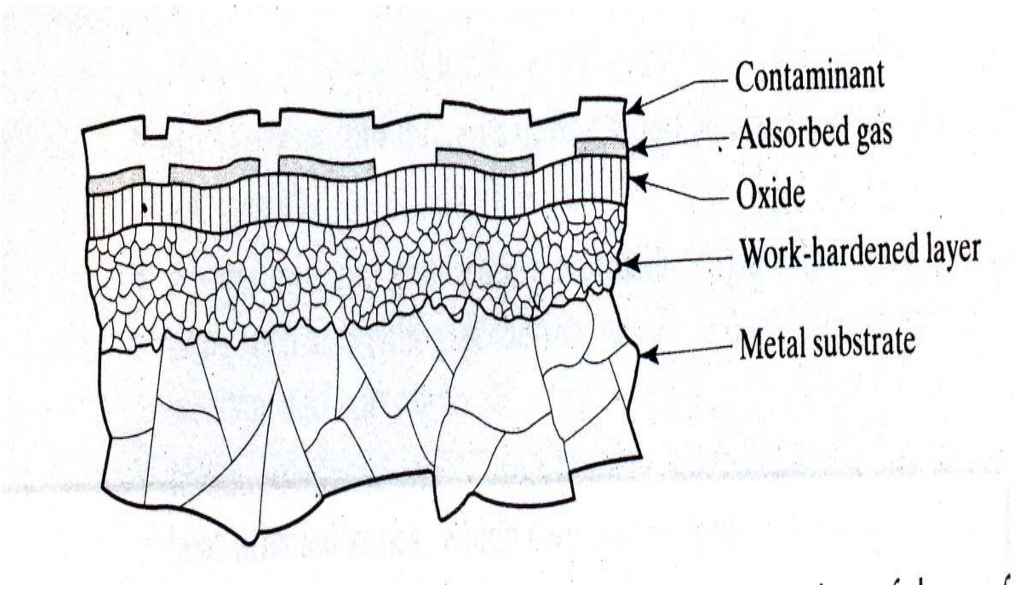

Figure 1.4 Schematic of a Cross-Section of the Surface Structure of Metals

1. The bulk metal, also known as the metal substrate, has a structure that depends onthe composition and processing history of the metal.

2. Above this bulk metal, there is a layer that usually has been plastically deformedand work-hardened to a greater extent during the manufacturing process. Thedepth and properties of the work-hardened layer (the Surface Structure) dependon such factors as the processing method used and how much frictional sliding thesurface undergoes.The use of sharp tools and the selection of appropriate processing parametersresult in surfaces with little or no disturbance. For example, if the surface isproduced by machining using a dull and worn tool, or which takes place underpoor cutting conditions, or if the surface is ground with a dull grinding wheel, thesurface structure layer will be relatively thick. Also, non-uniform surfacedeformation or severe temperature gradients during manufacturing operationsusually cause residual stresses in the work-hardened layer.

3. Unless the metal is processed and kept in an inert (oxygen-free) environment, oris a noble metal such as gold or platinum, an oxide layer forms over the workhardenedlayer.
a. Iron has an oxide structure with FeO adjacent to the bulk metal, followed by a layer of Fe3O4 and then a layer of Fe2O3, which is exposed to theenvironment.
b. Aluminum has a dense, amorphous (without crystalline structure) layer ofAl2O3, with a thick, porous hydrated aluminum-oxide layer over it.

4. Under normal environmental conditions, surface oxide layers are generallycovered with absorbed layers of gas and moisture. Finally, the outermost surfaceof the metal may be covered with contaminants such as dirt, dust, grease,lubricant residues, cleaning-compound residues, and pollutants from theenvironment.

Thus, surfaces have properties that generally are very difficult from those of thesubstrate. The oxide on a metal surface is generally much harder than the base metal.Consequently, oxides tend to be brittle and abrasive. This surface characteristic hasseveral important effects on friction, wear, and lubrication in materials processing, and onproducts.

Surface Integrity

Surface integrity is the sum of all the elements that describes all the conditions exiting onor at the surface of a work piece. Surface integrity has two aspects. The first is surfacetopography which describes the roughness, 'lay' or texture of this outermost layer of thework piece, i.e., its interface with the environment. The second is surface metallurgywhich describes the nature of the altered layers below the surface with respect to the baseof the matrix material. This term assesses the effect of manufacturingprocesses on the properties of the work piece material.

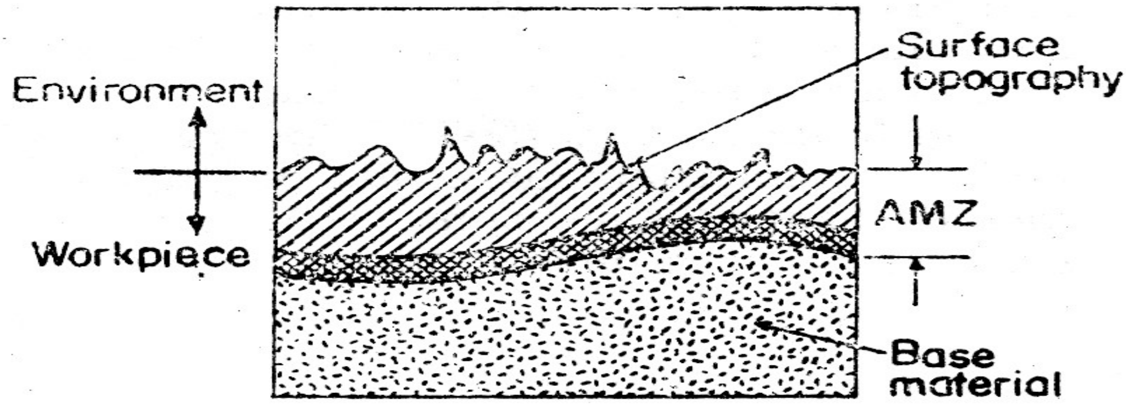

Figure 1.5 Various Layers of a Surface

Surface integrity describes not only the topological (geometric) features of surfaces andtheir physical and chemical properties, but their mechanical and metallurgical properties and characteristics as well. Surface integrity is an important consideration in manufacturing operations because it influences properties, such as fatigue strength,resistance to corrosion, and service life.

Surface Topography

Outermost layers of all machined surfaces display a great number of both macrogeometricaland micro-geometrical deviations from the ideal geometrical surface. Surfaceroughness refers to deviation from the nominal surface of the third up to sixth order.Order of deviation is defined in international standards. First and second-order deviationsrefer to form, i.e. flatness, circularity, etc. and to waviness, respectively, and are due tomachine tool errors, deformation of the work piece, erroneous setups and clamping,vibration and work piece material inhomogeneities. Third and fourth-order deviations referto periodic grooves, and to cracks and dilapidations, which are connected to the shape and condition of the cutting edges, chip formation and process kinematics. Fifth andsixth-order deviations refer to work piece material structure, which is connected tophysical-chemical mechanisms acting on a grain and lattice scale (slip, diffusion,oxidation, residual stress, etc.).

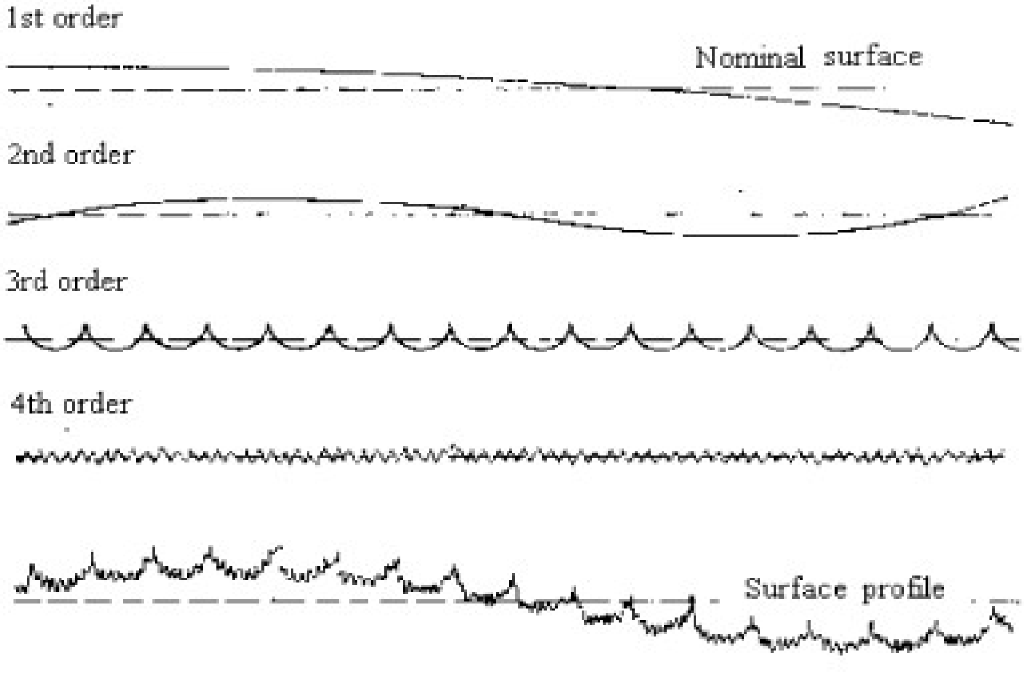

Figure 1.6 Surface form Deviations

The principal elements of surfaces are discussed below:

Surface:

The surface of an object is the boundary which separates that objectfrom another substance. Its shape and extent are usually defined by a drawing ordescriptive specifications.

Profile: It is the contour of any specified section through a surface.

Roughness:

It is defined as closely spaced, irregular deviations on a scale smallerthan that of waviness. Roughness may be superimposed on waviness. Roughnessis expressed in terms of its height, its width, and its distance on the surface alongwhich it is measured.

Waviness:

It is a recurrent deviation from a flat surface, much like waves on thesurface of water. It is measured and described in terms of the space betweenadjacent crests of the waves (waviness width) and height between the crests andvalleys of the waves (waviness height). Waviness can be caused by,

(i) Deflections of tools, dies, or the work piece,

(ii) Forces or temperature sufficient to cause warping,

(iii) Uneven lubrication,

(iv) Vibration, or

(v) Any periodic mechanical or thermal variations in the system duringmanufacturing operations.

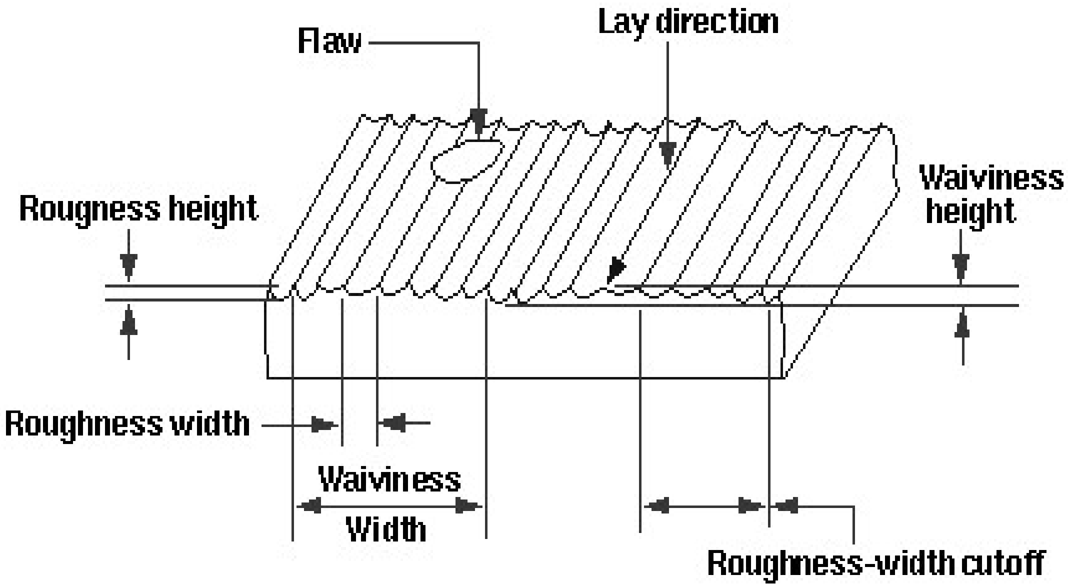

Figure 1.7 Surface Characteristics

Flaws:

Flaws, or defects, are random irregularities, such as scratches, cracks,holes, depressions, seams, tears, or inclusions.

Lay:

Lay, or directionality, is the direction of the predominant surface pattern andis usually visible to the naked eye.

Surface Finish In Machining

The resultant roughness produced by a machining process can be thought of as thecombination of two independent quantities:

a. Ideal roughness, and

b. Natural roughness.

a. Ideal roughness:

Ideal surface roughness is a function of feed and geometry of the tool. It represents thebest possible finish which can be obtained for a given tool shape and feed. It can beachieved only if the built-up-edge, chatter and inaccuracies in the machine toolmovements are eliminated completely. For a sharp tool without nose radius, themaximum height of unevenness is given by:

$R_{max} = f/(\text{Cot } \varphi + \cot \beta)$

Here *f* is feed rate, φ is major cutting edge angle and β is the minor cutting edge angle.

The surface roughness value is given by, $R_a = R_{max}/4$

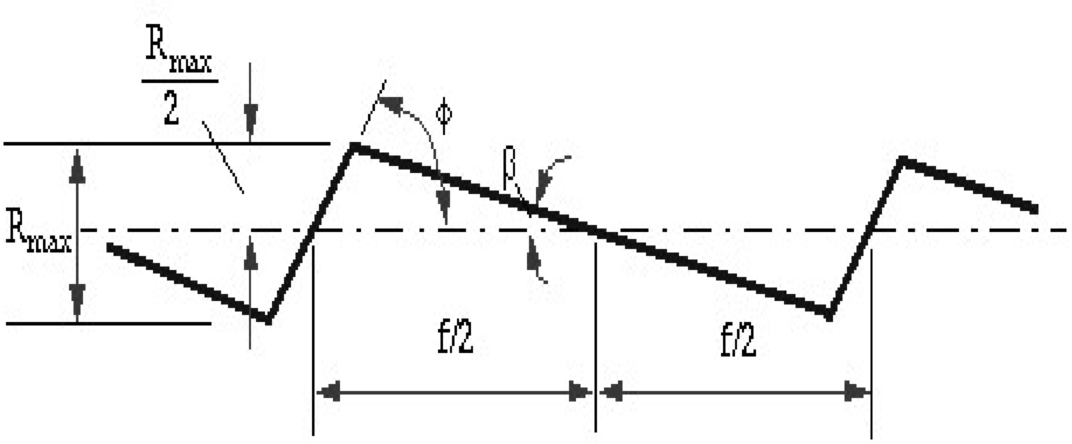

Figure 1.8 Idealized Model Of Surface Roughness

Practical cutting tools are usually provided with a rounded corner, and figure belowshows the surface produced by such a tool under ideal conditions. It can be shown thatthe roughness value is closely related to the feed and corner radius by the followingexpression:

$R_a = 0.0321f^2/r$

where r is the corner radius.

b. Natural Roughness:

In practice, it is not usually possible to achieve conditions such as those described above,and normally the natural surface roughness forms a large proportion of the actualroughness. One of the main factors contributing to natural roughness is the occurrence ofa built-up edge and vibration of the machine tool. Thus, larger the built up edge, therougher would be the surface produced, and factors tending to reduce chip-tool frictionand to eliminate or reduce the built-up edge would give improved surface finish.

Factors Affecting the Surface Finish

Whenever two machined surfaces come in contact with one another the quality of themating parts plays an important role in the performance and wear of the mating parts. Theheight, shape, arrangement and direction of these surface irregularities on the work piecedepend upon a number of factors such as:

A) The machining variables which include
a) Cutting speed
b) Feed, and
c) Depth of cut.
B) The tool geometry
Some geometric factors which affect achieved surface finish include:
a) Nose radius
b) Rake angle
c) Side cutting edge angle, and
d) Cutting edge.
C) Work piece and tool material combination and their mechanical properties
D) Quality and type of the machine tool used,
E) Auxiliary tooling, and lubricant used, and
F) Vibrations between the work piece, machine tool and cut

CHAPTER 2

LITERATURE REVIEW

Numerous investigations have been carried out in the fields of optimization of working parameters of CNC lathe by considering different input parameters like cutting speed, feed and depth of cut to optimize and getting better output characteristics like Material Removal Rate (MRR), Surface Roughness (R_a), Tool Wear and Dimensional Accuracy etc, some of them were discussed in this chapter.

C.J.Rao, et al. [1] investigated the influence of speed, feed, and depth of cut on Surface Roughness and Cutting forces during machining of AISI 1050 steels (hardness of 484HV) on CNC lathe with ceramic (Al2O3+TiC matrix) tool. The experiments were conducted by using Taguchi method (L27 design with 3 levels and 3 factors). The results indicated that feed rate has most influence on both Cutting forces as well as Surface Roughness. Depth of cut has a significant influence on Cutting force, but has an insignificant influence on Surface roughness. The interaction of feed and depth of cut and the interaction of all the three cutting parameters have significant influence on cutting forces, whereas none of the interaction effects are having significant influence on the Surface Roughness produced.

Harish Kumar, et al. [2]were conducted experiments on MS 1010 using HSS tool on CNC lathe under dry condition. They have taken speed, feed and depth of cut taken as input parameters and Surface Roughness as output characteristic for the analysis. They analyzed the data using Taguchi methodology and ANOVA. They found that for MS1010 speed is the most significant parameter for Surface Roughness and least significant parameter is DOC.

M. Kaladhar, et al. [3] have conducted experiments on turning of AISI 304 austenitic stainless steel with Physical Vapour Deposition (PVD) coated insert for optimizing Material Removal Rate and Surface Roughness by using Taguchi L16 orthogonal array and ANOVA. They found that feed is the most significant parameter and followed by nose radius for Surface Roughness. Similarly,depth of cut is most significant parameter followed by feed for Material Removal Rate.

N.E. Edwin Paul, et al. [4] have conducted experiments on EN8 material using CNC lathe on Taguchi L9 Orthogonal array. Signal to Noise ratio and ANOVA used for analyzing the data. The results concluded that the feed has greater influence on the Surface Roughness followed by the cutting speed and the depth of cut has least influence.

Upinder Kumar Yadav, et al. [5] investigated the significance of machining parameters on Surface Roughness in CNC turning of medium carbon steel AISI 1045 by using Taguchi L27 orthogonal array and Analysis of variance (ANOVA). The results concluded that feed rate is the most significant factor for Surface Roughness next to depth of cut. Cutting speed is the least significant factor affecting Surface Roughness.

Sunil J Raykar, et al. [6] investigated on the effect of process parameters on R_a, R_z, R_q parameters of surface topology in dry machining of EN8 steel by using Taguchi L27 orthogonal array and Regression analysis. Results concluded that feed has greatest influence on surface finish of all three surface topology parameters R_a, $R_q$and R_z next is to cutting speed and depth of cut has least significance. Regression models were prepared and a good correlation is found between Surface Roughness and cutting parameters and hence the models were used for predict the Surface Roughness within the range of cutting parameters under investigation.

A Mahamaniet.al.[7]studied the influence of machining parameters on cutting force and surface roughness in hard turning of AA2219-TiB2/ZrB2 in-situ metal composites with uncoated tungsten carbide tool by using Taguchi L27 orthogonal array and Regression analysis. The results concluded that the feed rate has strongest effect on both Cutting force and Surface Roughness. Regression models also developed between the machining parameters and responses.

H.K. Dave et al.[8]done an experimental investigation to optimize responses in the machining of EN materials using different TiN coated cutting tools. Taguchi method and ANOVA are employed for the analysis of material removal rate and surface roughness. They found that the depth of cut has a significant role for producing high material removal rate and insert has significant role for producing lower surface roughness.

M. Kaladhar et al.[9]applied Taguchi method to determine the optimal process parameters for turning of AISI304 steel using CVD coated carbide tools of 0.4 and 0.8 nose radii. The results of material removal rate and surface roughness are analyzed using Taguchi and ANOVA methods. From the results they found that cutting speed has a significant effect on surface roughness followed by nose radius. Similarly, for material removal rate, depth of cut is the most affecting parameter followed by cutting speed.

M. Kaladhar et al. [10]investigated the effect of process parameters on surface finish and material removal rate using Taguchi method. Analysis of variance is used to analyze the influence of cutting parameters during machining of AISI 304 steel using PVD coated cermet inserts (TiCN-TiN) of 0.4 and 0.8 mm nose radii. Finally they found that feed and nose radius are the most significant factors for surface roughness. Depth of cut and feed are the significant factors for material removal rate.

K. Adarsh Kumar et.al. [11]directed trial to investigate the impact of cutting parameters on surface roughness in turning of EN-8 utilizing established carbide embed. They presumed that the feed is the most affecting parameter on surface roughness.

G Shivam et al. [12]directed analyses on CNC machine by taking cutting speed, feed and depth of cut as process parameters and MRR and SR as yields. The Cutting speed and depth of cut are the most affecting parameters on surface roughness and material expulsion rate separately. Analysis of variance (ANOVA) is added to the Taguchi method to find the influence of cutting parameters on the responses.

Milan Kumar Das et al. [13]made an endeavor to upgrade the procedure parameters for material removal rate and surface roughness in plasma circular segment cutting of EN31 steel utilizing the weighted principal component analysis. The trials are arranged according to taguchi's L27 OA. ANOVA is directed and the outcomes demonstrated that the gas pressure is the most noteworthy factor followed by arc current.

Upinder Kumar et al. [14]conducted an experiment to optimize the surface roughness and material removal rate simultaneously using grey relational analysis. The L9 OA is used for machining of AISI 1045 steel. The optimal combination of the combined response is found at cutting speed of 188 m/min, feed rate of 0.2 rev/min and depth of cut of 1.5 mm.

C Ibrahimet.al. [15]conducted experiments to find the effect of cutting parameters on surface roughness in the machining of AISI304 and AISI316 steels using CVD multi-layer coated cemented carbide tools. The results showed that the cutting speed has high significance on surface roughness.

F Vishal et.al.[16]employed Taguchi method and Analysis of variance to find out the influence of cutting parameters on material removal rate and surface roughness. Feed rate is found to be the most influencing parameter on the surface roughness.

Y Sahijpaulet.al. [17] analyzed the effect of cutting parameters on surface roughness while turning of EN8 steel. They concluded that the feed rate is the most influencing parameter on the surface roughness.

S R Bheem et al. [18]investigated the effect of cutting parameters on surface roughness and material removal rate during the turning of metal matrix composite. Results revealed that the feed is the most influencing parameter on surface roughness followed by the depth of cut and speed.

G Shivamet.al. [19]conducted experiments on CNC lathe by taking cutting speed, feed and depth of cut as process parameters and MRR and SR as outputs. The Cutting speed and depth of cut are the most influencing parameters on surface roughness and material removal rate respectively.

S Devendra et al. [20]conducted a study to investigate the effect of nose radius on surface roughness in CNC turning of Aluminium 6061 in dry condition. Nose radius is identified as the most influencing parameter on surface roughness.

Shreemoy Kumar Nayak, et al. [21] Conducted experiments by using multi objective Grey relational analysis for optimization of cutting process parameters in dry turning of AISI 304 austenitic stainless steel, and machinability characteristics of material removal rate, cutting force and surface roughness were studied. Experiments were conducted as per Taguchi L27 orthogonal array. From the mean of the overall Grey relational grade it is concluded that feed has high significance on Material Removal Rate (MRR), cutting forces and Surface roughness together followed by speed and depth of cut has least significance.

DiptiKanta Das et al. [22]Investigated for finding the optimal combination of cutting process parameters during hard machining of EN 24 steel with coated carbide insert by using Grey based Taguchi(L9 orthogonal array) and Regression methodology for minimum Surface quality characteristics R_a and R_z. The results concluded that the feed is considered to be the most dominant parameter for both Surface Roughness parameters R_a and R_z. The prediction models have been developed using regression analysis for surface Roughness and they are adequate and significant.

M. Kaladhar et al. [23] had optimized multi-characteristics response for turning of AISI 202 austenitic stainless steel using a CVD coated cemented carbide tool on CNC TC based on Taguchi and Utility concept. They have used this concept for optimize process parameters such as speed, feed, depth of cut, and nose radius and selected multiple performance characteristics, namely, surface roughness and material removal rate. Taguchi’s L8 orthogonal array was selected for experimental planning. The experimental result analysis showed that the combination of higher levels of cutting speed, depth of cut, and nose radius and lower level of feed is essential to achieve simultaneous maximization of MRR and minimization of Ra. They have performed ANOVA for individual quality parameters as well as for multi response case. Based on the ANOVA, the most statistical significant and percent contribution of the process parameters for multiple performances were depth of cut, cutting speed whereas feed and nose radius were less effective.

Bharat Chandra Routara et al. [24] had studied highlights a multi-objective optimization problem by applying utility concept coupled with Taguchi method through a case study in CNC end milling of UNS C34000 medium leaded brass. Utility theory has been adopted to convert a multi-response optimization problem into a single response optimization problem; in which overall utility degree serves as the representative single objective function for optimization. They have been used combination of utility concept and Taguchi methodology for predicting optimal setting of process parameters. Finally the optimal setting has been verified by confirmation runs.

B.Singarvel et al. [25] had done experimental analysis the optimum machining parameters were evaluated using Taguchi based utility concept coupled with Principal Component Analysis (PCA) on turning of EN25 steel with CVD and PVD coated carbide tools. This strategy has been utilized for simultaneous minimization of surface harshness, cutting power and maximization of material removal rate. They found that • The results of ANOM shown that a combination of machining parameters for this investigation were cutting speed of 244 m/ min, feed rate of 0.10 mm/rev and depth of cut of 1.0 mm with CVD coated tool. The result of ANOVA showed that the coated tool was the most significant parameter followed by cutting speed. The prediction error (i.e) the difference between the predicted SN ratio and multi objective SN ratio was within the confidence level.

Hari Vasudevan et al. [26] had studied a hybrid multiobjective optimization algorithm involving utility and fuzzy coupled with Taguchi methodology. Four process parameters, at three levels were selected for the study viz. tool nose radius, cutting speed, feed and depth of cut and surface roughness, cutting force and material removal rate were chosen as quality performance measures. They used Taguchi L27 orthogonal array to perform experiments. Woven fabric based GFRP/Epoxy tubes produced using hand layup process were finish turned using Poly Crystalline Diamond (PCD) tool. Utility values of the three performance measures were transformed into a single Multi Performance Characteristics Index (MPCI) using Mamdani type fuzzy inference system. Then, MPCI is then optimized using Taguchi analysis. The for multi characteristics the optimal sequence found: tool nose radius of 0.8 mm, cutting speed of 200 m/min, feed rate of 0.05 mm/rev and depth of cut of 1mm. The confirmatory experiment at these settings gives maximum value of MPCI validating the results.

KishanChoudhuri et al. [27]used Taguchi and Utility concept to optimize the process parameters, such as speed, feed, and depth of cut on multiple performance characteristics, namely surface roughness and material removal rate during turning of Aluminium 6061 using a Carbide cutting tool on CNC TC. Taguchi's L9 orthogonal array was selected for experimental planning. The experimental result showed that combination of higher levels of feed, depth of cut, and lower level of spindle speed was essential to achieve simultaneous maximization of MRR and minimization of surface roughness. They have performed ANOVA analysis for individual response characteristic. From ANOVA analysis they found that the depth of cut (65.57%) was most significantly influences the Ra followed by spindle speed (6.344%) and in case of material removal rate, feed (76.109%) was the most significant parameter followed by spindle speed (9.597%).

R. Jayadithya et al. [28] have been conducted experiments using 3 machine parameters such as pulse on time (TON), pulse off time, wire feed and one work piece parameter such as work piece thickness, each at three levels for obtaining the responses like cutting speed, surface roughness, and dimensional deviation. Taguchi's L9 orthogonal array was selected to collect information regarding the process with lesser number of experimental runs. Conventional Taguchi approach is insufficient to solve a multi response optimization problem. In order to overcome this limitation, utility theory has been applied. ANOVA analysis was also carried out to find out the significant effect of the process parameters during WEDM process. Finally confirmation test has been carried out to verify the experimental result.

RavinderKataria et al. [29] had compared different multiple response optimization techniques for turning operation of AISI O1 tool steel. They selected nose radius, speed, feed and depth of cut as input process parameters and material removal rate, surface roughness as quality parameters. Taguchi method was employed for single response optimization. For multi-response optimization, weighted signal-to-noise ratio (WSN), grey relational analysis (GRA), utility concept and technique for order preference by similarity to ideal solution (TOPSIS) method have been utilized and their performance was evaluated. The optimal process parameter settings for WSN, GRA, Utility Concept and TOPSIS were A1B3C2D3, A2B1C1D2, A2B3C3D2 and A2B2C3D3 respectively. Hence, there has been considerable difference among the optimal settings yielded by the methods investigated. Weighted signal-to-noise ratio method has been found to produce best results for multi-response optimization for this study.

Rina Chakravorty et al. [30] had studied the effect of process parameters such as work piece polarity, pulse-on-time, duty factor, open discharge voltage, discharge current, dielectric fluid on different quality parameters such as material removal rate and electrode wear rate in EDM process. The experimental results data of EDM processes were analyzed using the modified PCA-based UT approach and PCA -based PQLR method. The comparison of the optimization performances at the optimal conditions derived by the two methods indicates that the optimal condition derived by the modified PCA-based UT method leads to better optimization performance than PCA-based PQLR method. This suggests that the modified PCA-based UT approach can be a promising method for optimizing correlated responses of EDM process. TarunGoyal et al. [15] have used Utility theory and Taguchi quality loss function for simultaneous optimization of more than one response characteristics for low-pressure cold spray (LPCS) process to deposit copper coatings. They selected coating density and surface roughness as quality characteristics and feed type, substrate material, stagnation pressure, stagnation temperature, standoff distance taken as input process parameters. Utility values based upon these response parameters have been analyzed for optimization by using Taguchi approach. For the experiments they found that the selected quality parameters were significantly improved using Taguchi utility concept and analysis of variance also performed to analyzethe parameters are significantly effect on multi responding parameters.

Yogendra Kumar et al. [31] had performed multi- response optimization in dry turning process using Taguchi and utility concept. They selected nose radius, cutting speed, feed rate and depth of cut as input process parameters and axial force, radial force, main cutting force, material removal rate as quality parameters. They have selected EN47 alloy steel as work material and experiments were performed based on mixed L18 Taguchi orthogonal array. They found that all the four process parameters, namely, nose radius, cutting speed, feed and DOC had significant effect on utility function for multi optimization. The model can be used for optimization of multi-response characteristics that have realistic data.

Nithyanandhan T. et al. [32] have investigated the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of process parameters. And the analysis of Variance (ANOVA) is also used to analyze the influence of cutting parameters during machining. AISI 304 stainless steel work pieces are turned on conventional lathe by using tungsten carbide tool. The results revealed that the feed and nose radius is the most significant process parameters on work piece surface roughness. However, the depth of cut and feed are the significant factors on MRR.

D. Philip Selvaraj et al. [33] have studied the Taguchi optimization method was applied to find the optimal process parameters, which minimizes the surface roughness during the dry turning of AISI 304 Austenitic Stainless Steel. A Taguchi orthogonal array, the signal to noise (S/N) ratio and the analysis of variance (ANOVA) were used for the optimization of cutting parameters. ANOVA results shows that feed rate, cutting speed and depth of cut affects the surface roughness by 51.84%, 41.99% and 1.66% respectively. A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.

Samruddhi Rao et al. [34] presented a detailed overview of Taguchi Method in terms of its evolution, concept, steps involved and its interdisciplinary applications. It could be concluded that this method with its perfect amalgamation of statistical and quality control techniques was one of the effective and efficient methods of its kind to highlight the benefits of designing quality into products upstream rather than inspecting out bad products downstream. It offers a quantitative solution to identify design factorsto optimize quality and reduce cost. Also the application of this method is not confined to a particular domain but also to other fields like product and service sectors. It thus is a powerful method as compared to the other intuitive and more cumbersome methods encompassing a large number of fields in terms of application.

M. Adinarayana et al. [35] have presented in paper the multi response optimization of turning parameters for Turning on AISI 4340 Alloy Steel. Experiments are designed and conducted based on Taguchi's L27 Orthogonal array design. This paper discusses an investigation into the use of Taguchi parameter Design and Regression analysis to predict and optimize the Surface Roughness, Metal Removal Rate and Power Consumption in turning operations using CVD Cutting Tool. The Analysis of Variance (ANOVA) is employed to analyze the influence of Process Parameters during Turning. This paper also remarks the advantages of multi-objective optimization approach over the single-objective one. The useful results have been obtained by this research for other similar type of studies and can be helpful for further research works on the Tool life and Vibration of tools etc.

KompanChomsamutr et al. [36] objective of research is to compare the cutting parameters of turning operation the work pieces of medium carbon steel (AISI 1045) by finding the longest tool life by Taguchi methods and Response Surface Methodology: RSM. This research is to test the collecting data by Taguchi method. The analyses of the impact among the factors are the depth of cut, cutting speed and feed rate. This research found that the most suitable response value; and tool life methods give the same suitable values, i.e. feed rate at 0.10 mm/rev, cutting speed at 150 m/min, and depth of cut at 0.5 mm, which is the value of longest tool life at 670.170 min, while the average error is by RSM at the percentage of 0.07 as relative to the testing value.

Sunil Kumar Sharma et al. [37] have analyzed that Taguchi optimization technique pair with grey relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better, material removal rate higher is better of the AISI 8620 steel during turning on a CNC Lathe Trainer. After identify the optimal process parameters setting for turning operation, ANOVA is also applied for finding the most significant factor during turning operation. In this study it is concluded that the feed rate is the most significant factor for the surface roughness and material removal rate together, as the P-value is less than 0.05. Cutting speed and depth of cut is found to be insignificant from the ANOVA study.

From the above literature review, it has been observed that no much work is reported on Multi objective optimization of Material Removal Rate (MRR) and Surface Roughness (R_a) characteristics in turning of SS304 with a coated tungsten carbide tools. Also very less works are there by considering the nose radius as one of the controlling parameter. In the present investigation, Multi objective optimization of responses was done using Taguchi based utility and AHP methods. The optimal combination of machining parameters (cutting speed, feed, depth of cut and nose radius) in order to attain the maximum Material Removal Rate and minimum Surface Roughness simultaneously has been obtained.

CHAPTER 3

METHODOLOGY

In the present chapter the methodology used for obtaining better response parameters is briefly discussed. In modern industrial environment a numerous kinds of Investigations have been done for the improvement of product quality in the field of manufacturing. Some have few factors to be considered, some have many. While there are others, that demand factors to have mixed levels. A vast majority of experiments however fall in the category where all factors possess the same number of levels. In the conventional technique of varying one factor at a time, lot of experimental data can be obtained. This way of experimentation not only consumes lot of time but also poses a challenge to the investigator for deriving appropriate conclusion from the huge experimental data. Design of Experiments (DOE) is at ever rescue for planning systematic experimentation and arriving at meaningful conclusion without being inundated in huge set of experimental data. DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of factors. There are number of statistical techniques available for engineering and scientific studies. In the present investigation a multi objective optimization method taguchi based utility and AHP is employed for optimizing the control parameters.

3.1 Methodology

Algorithm

- Selection of process parameters and their levels
- Conduct the experiments as per the Taguchi Design of Experiments
- Measure the selected quality characteristics
- Construct preference scale for each quality characteristic from realistic data
- Assign weights to the characteristics based on Analytical Hierarchy Process (AHP)
- Determine the individual utility values and use these values as a response of selected experimental plan
- Find the overall utility index (U) values for the alternatives
- Analyze the results with taguchi method
- Determine the optimal setting of process parameters for optimum utility
- Conduct ANOVA for finding the significance of the factors
- Run the confirmation experiment and compare the predicted optimal values with the actual ones.

3.2. Design Of Experiments (DOE)

Design of Experiments is a powerful statistical technique introduces by R.A. Fisher in England in the 1920’s to study the effect of multiple variables simultaneously. The DOE using Taguchi approach can be economically satisfy the needs of problem solving and product/process design optimization projects. DOE is a technique of defining and investigating all possible combinations in an experiment involving multiple factors and to identify the best combination. In this different factors and their levels are identified. Design of Experiments is also useful to combine the factors at appropriate levels, each with the respective acceptable range, to produce the best results and yet exhibit minimum variation around the optimum results. Therefore, the objective of a carefully planned designed experiment is to understand which set of variables in a process affects the performance most and then determine the best levels for these variables to obtain satisfactory output functional performance in products.

Advantages of Design of Experiments (DOE)

- Number of trails is significantly reduced.
- Important decision variables which control and improve the performance of the product or the process can be identified.
- Optimal setting of the parameters can be found out.
- Qualitative estimation of parameters can be made.
- Experimental errors can be estimated.
- The effect of parameters on the characteristics of the process can be found out.

The DOE techniques used for process parameter optimization

- Full factorial technique
- Fractional factorial technique
- Taguchi orthogonal array
- Response surface method (central composite design).

3.3. Taguchi Optimization Method

Taguchi techniques are statistical methods developed by Genichi Taguchi to improve the Quality of manufacturing goods. Basically, classical experimental design methods are to complex and not easy to use. A large number of experiments have to be carried out when the number of the process parameter increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. In this study, L9 orthogonal array with 3 columns and 9 rows are used as shown in Table 3.3.

Taguchi proposed that engineering optimization of a process or product should be carried out in a three step approach i.e. System design, parameter design and tolerance design. In system design the engineer applies scientific and engineering knowledge to produce a basic functional prototype design, this design including the product design stage and process design stage. In the product design stage the selection of material components tentative product parameter values, etc., are involved as to the process design stage the analysis of processing sequences, the selection of production equipment, tentative process parameter values, etc., are involved. Since system design is an initial functional design it may be far from optimum in terms of quality and cost. Following on from system design is parameter design. The objective of parameter design is to optimize the settings of the process parameter values for improving quality characteristics and to identify the product parameter values under the optimal process parameter values. In addition, it is expected that the optimal process parameter values obtained from parameter design are insensitive to variation in the environmental conditions and other noise factors. Finally, tolerance design is used to determine and analyze tolerances around the optimal settings recommend by parameter design. Tolerance design is required if the reduced variation obtained by the parameter design does not meet the required performance. However based on above discussion, parameter design is the key step in the Taguchi method to achieving high quality without increasing cost. To obtain high cutting performance, the parameter design proposed by Taguchi method is adopted in this project work.

3.4. Taguchi-Utility method

Utility can be defined as the usefulness of a product or a process in reference to the levels of expectations to the consumers. The performance evaluation of any machining process depends on number of output characteristic. Therefore, a combined measure is necessary to gauge its overall performance, which must take into account the relative contribution of all the quality characteristics. Such a composite index represents the overall utility of a product/process. It provides a methodological framework for the evaluation of alternative attributes made by individuals, firms and organizations. Utility refers to the satisfaction that each attributes provides to the decision maker. Thus, utility theory assumes that any decision is made on the basis of the utility maximization principle, according to which the best choice is the one that provides the highest satisfaction to the decision maker.

According to the utility theory, if X_i is the measure of effectiveness of an attribute (or quality characteristics) i and there are n attributes evaluating the outcome space, then the joint utility function can be expressed as

$$U(X_1, X_2, \ldots\ldots X_n) = f\big(U_1(X_1), U_2(X_2)\ldots\ldots U_n(X_n)\big)$$

Here, $U_i(X_i)$ is the utility of the i^{th} attribute.

The overall utility function is the sum of individual utilities if the attributes are independent, and is given as follows:

$$U(X_1, X_2\ldots\ldots X_n) = \sum_{i=1}^{n} U_i(X_i)$$

The overall utility function after assigning weights to the attributes can be expressed as:

$$U(X_1, X_2\ldots\ldots X_n) = \sum_{i=1}^{n} W_i U_i(X_i)$$

The preference number can be expressed on a logarithmic scale as follows:

$$p_i = A\ X\ log\left(\frac{X_i}{X'_i}\right)$$

Here, X_i is the value of any quality characteristic or attribute i, X_i' is just acceptable value of quality characteristic or attribute i and A is a constant. The value A can be found by the condition that if $X_i = X^*$ (where X^* is the optimal or best value), then $P_i = 9$ Therefore,

$$A = \frac{9}{log\frac{X^*}{X'_i}}$$

The overall utility can be expressed as follows:

$$U = \sum_{i=1}^{n} W_i P_i$$

Subject to the condition:$\sum_{i=1}^{n} W_i = 1$

Overall utility index that has been computed treated as a single objective function for optimization. Among various quality characteristics types, viz. Lower-the-Better (LB), Higher-the-Better (HB), and Nominal-the-Best (NB) suggested by Taguchi, the utility function would be higher. In the proposed approach utility values of individual responses are determined to calculate overall utility index. Overall utility index is treated as the single objective function for optimization.

3.5. AHP Method

However in the proposed work, the associate weight for each response required for calculation of overall utility index can be obtained with the help of Analytic Hierarchy Process (AHP).

The analytic hierarchy process (AHP) is a structured technique for dealing with complex decisions that was developed by Thomas L. Saaty in the 1980 year. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. The base of this model is comparing variables by pair wise by Matrix relationship. In this way, pair wise of the effective variables on the concrete Pavement were considered and based on relative weights the output was extent. AHP helps decision makers to find a solution that best suits their goal and their understanding of the problem. It is a process of organizing decisions that people are already dealing with, but trying to do in their heads. The AHP was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem tangible or intangible, carefully measured or roughly estimated, well or poorly-understood anything at all that applies to the decision at hand. Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations. The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques. In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal. Thus, they allow a straightforward consideration of the various courses of action. Steps of AHP method are as follows:

a) Define the objective and identify the Criteria/ Alternatives.

b) A pairwise comparison matrix (A) using the fundamental scale of the Analytic Hierarchy process Saaty has been constructed.

c) The relative normalized weight (W_j) of each criterion has been calculated by the geometric mean method of AHP. The Geometric mean of rows in the comparison matrix can be calculated by

$$GM_j = \left[\prod_{j=1}^{M} b_{ij}\right]^{\frac{1}{M}}$$

$$W_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j}$$

d) The maximum eigen value, λ_{max} can be calculated by the matrix product of the pairwise comparison matrix and weight vectors and adding all elements of the resulting vector.

e)The consistency index (CI) can be determined by

$$CI = \frac{(\lambda_{max} - n)}{n-1}$$

The smaller the value of CI, the smaller is the deviation from Consistency.

f) Consistency ratio (CR) has been calculated by

$$CR = \frac{CI}{RI}$$

where RI is the random index value obtained by different orders of the pairwise comparison matrices. Usually a CR of 0.1 or less is considered as acceptable indicating unbiased judgments made by the decision makers.

CHAPTER 4
EXPERIMENTAL DETAILS

The experimental steps involved in the present work are clearly explained in this chapter. This includes selection of work material, selection of process parameters with their levels and selection of appropriate orthogonal array etc.

4.1. Selection of Work Material

The work material selected for the study is stainless steel of grade SS304. The work specimens are of cylindrical shape are taken and shown in figure 4.1. The work material has a wide range of applications in Heat exchangers, springs, food processing equipments, threaded fasteners, architectural paneling etc. The chemical and mechanical properties of SS304 are given in the tables 4.1and 4.2.

Fig 4.1 SS304 Material

Table 4.1. Chemical Composition of SS304 Steel

Element	C	Mn	Si	P	S	Cr	Ni	N	Fe
Max.	0.08	2	0.75	0.045	0.03	20	10.5	0.10	Remining

Table 4.2. Mechanical Properties of SS304 Steel

Density(Kg/m^3)	Tensile strength (MPa) min	Yield Strength 0.2% proof(MPa) min	Elongation (% in 50mm) min	Poisson's ratio	Hardness (RHN) (HR B) Max	Hardness (BHN) max
8000	515	205	40	0.27-0.30	92	201

4.2. Selection of the Process Parameters and Their Levels

Selection of right combination of process parameters and setting the range of the process parameters is very important step in unconventional process. Small variation in process parameters will effect adversely on the Surface Roughness and accuracy of the machined components. In general the process parameters are of two types.

- Fixed parameters
- Controlled parameters

In this present work the tool geometry, work piece hardness and its mechanical properties and environmental conditions are taken as fixed parameters which will not be changed throughout the investigation, whereas cutting speed, feed depth of cut and nose radius are considered as the controlled parameters are used to change for each experiment by Taguchi approach. The selected process parameters for the experiment with their limits, notations and units are given in table 4.3.

Table 4.3 Process Parameters and Their Levels

	parameter	1	2	3
A	Nose Radius(mm)	0.4	0.8	-
B	Speed(m/min)	45	60	75
C	Feed(mm/rev)	0.05	0.1	0.15
D	Depth of cut(mm)	0.5	1.0	1.5

4.3. Selection of Orthogonal Array (OA)

Taguchi has developed a design called orthogonal array it is used to study the entire design space with a very less number of experiments. For the four parameters with mixed levels taguchi's standard L18 has been chosen and it is given in the table 4.4.

Table 4.4 Taguchi L18 Orthogonal Array

S.No	Nose radius R (mm)	Cutting speed N (m/min)	Feed f (mm/rev)	Depth of cut d (mm)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2

8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

The experiments were conducted on CNC turret lathe it is shown in the figure 4.2. The work pieces are first trued for 0.5 mm to remove the unevenness and the components after machining were shown in the figure 4.3.After machining the finished components were tested for their roughness with SJ-210 tester shown in the figure 4.4.

FIG 4.2 CNC Machine

.

Figure 4.3. Machined Components

Figure 4.4. SJ-210 Roughness Tester

CHAPTER 5

RESULTS & DISCUSSIONS

In this chapter the experimental results of material removal rate (MRR) and surface roughness characteristics (R_a) are analyzed using Taguchi based utility and AHP method. The focus of the work is to identify the optimal combination of process parameters that concurrently maximizes the material removal rate and minimizes the surface roughness characteristics.

5.1. Experimental Results

The measured results of both material removal rate and surface roughness characteristics were tabulated in table 5.1. In the present work in order to determine the weights of each criterion, a pair wise comparison matrix as shown in the table 5.2 is developed using Analytical hierarchy process (AHP). The criterion weights are obtained as W_{MRR} = 0.6369, W_{Ra} = 0.2582 and W_{DD} = 0.1047 respectively. The value of CR is calculated as 0.0192 which is less than the allowed value of CR (=0.1), indicating the fact that there is a good consistency in the judgments made by the decision maker while assigning values in the pair – wise comparison matrix.

Table 5.1 Experimental Results

S.No.	MRR (cm^3/min)	R_a (μm)	DD (mm)
1	0.225	2.441	0.053
2	4.5	1.894	0.42
3	10.125	2.573	0.08
4	1.5	1.672	0.02
5	6	1.579	0.466
6	13.5	2.998	0.06
7	3.75	2.9	0.25
8	11.25	1.556	0.5

9	5.625	2.134	0.225
10	3.375	1.792	0.774
11	2.25	2.104	0.506
12	6.75	0.856	0.112
13	3	2.207	0.87
14	9	1.956	0.26
15	4.5	1.15	0.44
16	5.625	1.328	0.42
17	3.75	1.783	0.52
18	11.25	4.9	0.69

Table 5.2. Pair Wise Comparison Matrix

Criteria	MRR	R_a	R_z
MRR	1	3	5
R_a	1/3	1	3
R_z	1/5	1/3	1

The experimental results of responses were explored to calculate the utility values of individual quality attributes (also called preference number) by using the following equations 1,2,3.

$P_{MRR} = 6.5207 * \log(X_i/2.5133)$………Eq.(1)
$P_{Ra} = -9.0225 * \log(X_i/1.79)$…………Eq.(2)
$P_{DD} = -10.8958 * \log(X_i/8.24)$………...Eq.(3)

The calculated individual utility values are given in the table 5.3. Now, the overall utility index values along with the weights of the attributes can be calculated using the equation 4 and the values obtained and the corresponding S/N ratios (Higher-the-better) are given in the table 5.4.

$U = P_{MRR} * W_{MRR} + P_{Ra} * W_{Ra} + P_{DD} * W_{DD}$……………Eq.(4)

Table 5.3. Individual Utility Values of Responses

S.No.	P_{MRR}	P_{Ra}	P_{dd}
1	0	3.5943	6.6751
2	6.5845	4.9030	1.7372
3	8.3669	3.3227	5.6929
4	4.1698	5.5461	8.9999
5	7.2168	5.8413	1.4893
6	8.9992	2.5341	6.3792
7	6.1838	2.7046	2.9748
8	8.5985	5.9170	1.3213
9	7.0750	4.2876	3.2261
10	5.9522	5.1886	0.2789
11	5.0610	4.3606	1.2928
12	7.4757	8.9995	4.8902

13	5.6933	4.1141	0
14	8.1080	4.7369	2.8812
15	6.5845	7.4766	1.6262
16	7.0750	6.7342	1.7372
17	6.1838	5.2145	1.2277
18	8.5985	0	0.5530

Table 5.4. Overall Utility (U) and S/N Ratios of U

S.No.	Overall Utility (U)	S/N of U
1	1.6269	4.2274
2	5.6415	15.0279
3	6.7828	16.6282
4	5.0300	14.0314
5	6.2605	15.9322
6	7.0538	16.9685
7	4.9485	13.8894
8	7.1425	17.0770
9	5.9509	15.4916

10	5.1598	14.2527
11	4.4846	13.0345
12	7.5970	17.6128
13	4.6883	13.4204
14	6.6887	16.5069
15	6.2944	15.9791
16	6.4267	16.1598
17	5.4134	14.6694
18	5.5343	14.8612

The values of the overall utility are analyzed using taguchi's higher-the-better characteristic and the signal to noise (S/N) ratios were calculated. From the mean values of process parameters given in the table 5.5, the main effect plot has been plotted to identify the optimal combination of process parameters on the multi response. From the main effect plot for mean values of overall utility are shown in figure 5.1. The optimal combination of cutting parameters is obtained at 60 m/min of speed, 0.15 mm/rev of feed, 1.5 mm of depth of cut and 0.8 mm nose radius respectively.

Table 5.5. Mean Values of Overall Utility Values

Level	r	s	f	d
1	5.604	5.215	4.647	4.800
2	5.810	6.003	5.939	5.778

3		5.903	6.536	6.542
Delta	0.206	0.787	1.889	1.742
Rank	4	3	1	2

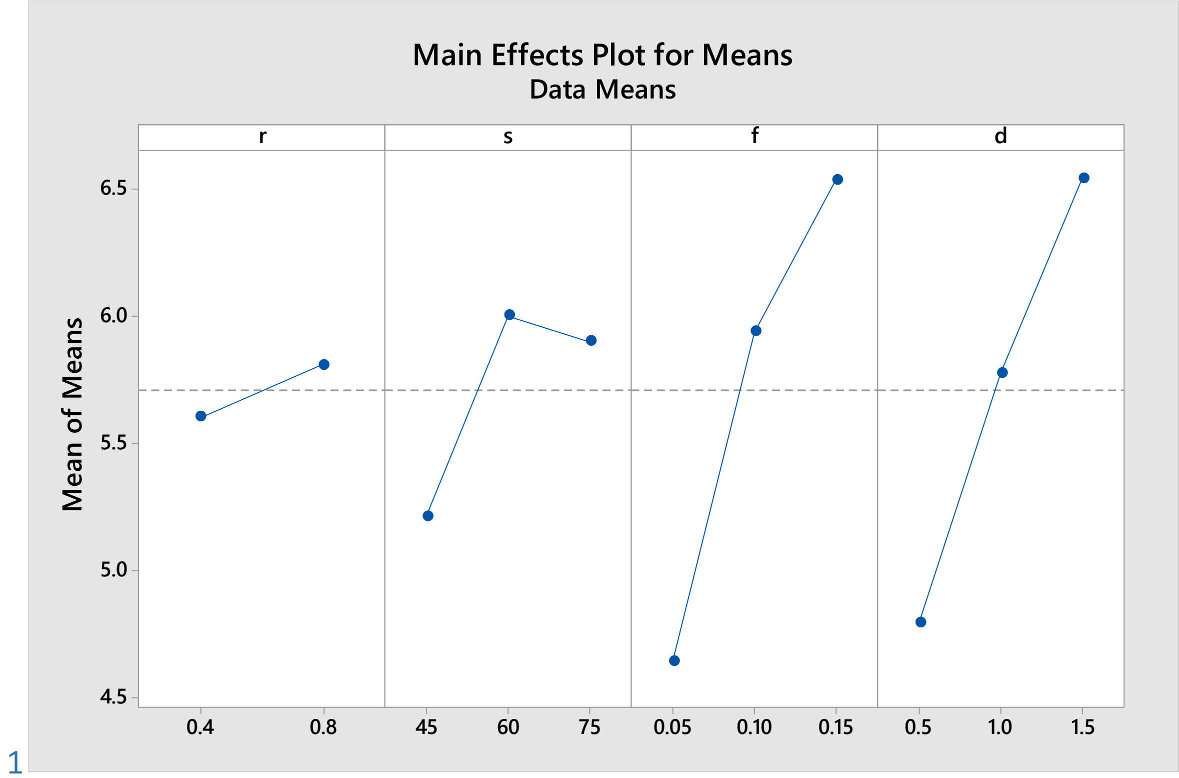

Figure 5.1. Main Effect Plot for Means of Overall Utility (U)

5.2. ANOVA Results

The Analysis of variance is used to investigate the significance of cutting parameters on the performance characteristic. This is accomplished by separating the total variability of the overall utility, which is measured by the sum of squared deviations from the total mean of the overall utility, into contributions by each parameter and the error. The percentage contribution by each factor to the total sum of the squared deviations SST can be used to evaluate the importance of the cutting parameter change on the performance characteristic. In addition, the F-test can also be used to determine which factor has a significant effect on the performance characteristic. Usually, the change of a determined factor has a significant effect on the performance characteristic when the F value is large. From the results of table 5.6, it is clear that the nose radius is the most influencing parameter and followed by the depth of cut, speed and feed respectively.

Table 5.6. Anova Results

Source	DF	Adj SS	Adj MS	F-value	P
R	1	0.1901	0.1901	0.22	0.650
S	2	2.2039	1.1020	1.27	0.323
F	2	11.1855	5.5928	6.43	0.016
D	2	9.1534	4.5767	5.26	0.027
Error	10	8.6958	0.8696		
Total	17	31.4287			

$S = 0.440822$, $R^2 = 96.57\%$, R^2 (adj) $= 89.70\%$

From the residual plots of figure 5.2, it is observed that all the errors are following the normal distribution as all the residuals are laying near to the straight line in the normal probability plot. Versus fits and order plots are implying that the errors are distributed on both the sides of mean line i.e. they are not following any regular pattern hence maintaining the constant variance.

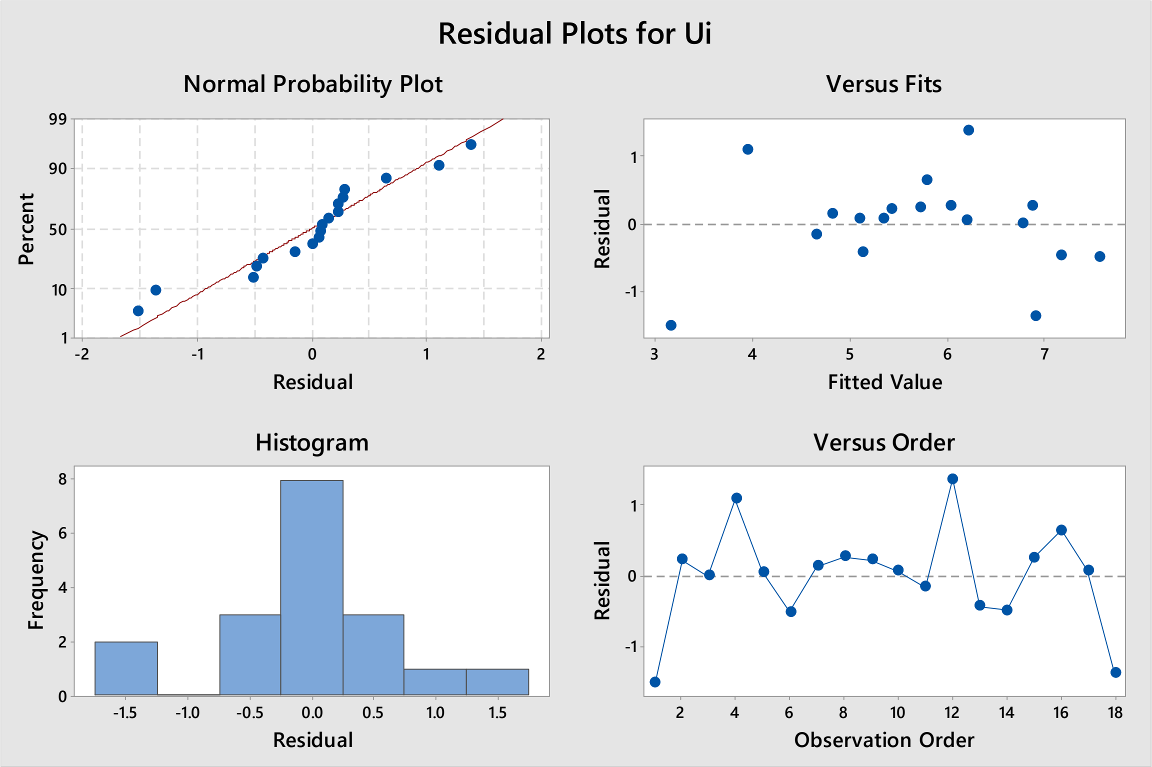

Figure 5.2 Residual Plots for Overall Utility

5.3. Prediction of Optimal Design for Overall Utility

Performance of overall utility (U) when the two most significant factors (nose radius and depth of cut) are at their best levels

μ_{A1B3} = A1 + B3 – T

= 6.536 + 6.542 – 5.707 = 7.371

$$CI = \sqrt{\frac{F_{95\%,1,DOFerror} * V_{error}}{\eta_{efficiency}}}$$

where, $\eta_{efficiency} = \frac{N}{(1+dof)}$ = 18/(1+1+3)

= 18/5 = 3.6

V_{error} = 0.8696

$F_{95\%,1,5}$ =4.9646

$$CI = \sqrt{\frac{4.9646 * 0.8696}{3.6}} = 1.0951$$

The predicted optimal range of overall utility (U) at 95% (α = 0.05) of confidence level is obtained as

$\mu_{A4B3} - CI \leq \mu_{A4B3} \leq \mu_{A4B3} + CI$

$7.371 - 1.0951 \leq \mu_{A4B3} \leq 7.371 + 1.0951$

$6.2759 \leq \mu_{A4B3} \leq 8.4661$

The model predicted is more accurate and adequate for the prediction of multiple responses.

CHAPTER 6

CONCLUSIONS

The present work discussed an application of taguchi based Utility method for investigating the effects of turning parameters on material removal rate and surface roughness characteristics in turning of SS304 Steel. From the results of Utility analysis and ANOVA the following conclusions can be drawn:

- From the Utility analysis, the optimal combination of cutting parameters is obtained at 60m/min of speed, 0.15 mm/rev of feed, 1.5 mm of depth of cut and 0.8 mm nose radius respectively.
- ANOVA results concluded that the feed is the most influencing parameter and followed by the depth of cut, speed and nose radius on the multi-response.
- The errors are distributed normally and they are not following any regular patterns hence following the assumptions normality and constant variance of ANOVA.
- The model prepared for the overall utility is best fit and it can be accurately used for the prediction of multiple responses.

Scope of Future Work

In the present work, optimization of cutting process parameters in dry turning of SS304 Steel with a PVD coated tungsten carbide tool on CNC lathe has been done by using Taguchi based utility method and anova. For further extension of the work we can conduct the experimentation with different types of tool shapes (C-type, round type etc.) and with multi-layer coated tools or by changing the coating material type of the tool and for different material grades or composites by employing various multi objective optimization methods.

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