ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School Of Mechanical Chemical and Material Engineering

Program Of Mechanical Design And Manufacturing Engineering

EFFECT OF CUTTING PARAMETERS ON SURFACE ROUGHNESS IN A TURNING OPERATION

A Thesis submitted in partial fulfillments of the required for the award of the degree of

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In

Manufacturing Engineering

By

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Advisor: Dr. Guteta Kabeta

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Adama, Ethiopia

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OPTIMIZATION OF TURNING PARAMETERS FOR EN-9 STEEL MATERIAL USING TAGUCHI METHOD

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Gemeda Leliso Geleto

Approval by Board of Examines

Chair, department Graduate committee Signature Date

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Advisor Signature Date

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Candidate Declarations

I hereby declare that the work which is being present in this thesis entitled"**Optimization of turning parameters for EN-9 steel material using Taguchi method**" in partial fulfillment of the requirements for the award of the degree of masters of Science in Manufacturing Engineering is an authentic record of my own work carried out September to August 2018 under the supervision of **Dr.Guteta Kabeta**, Mechanical Design and Manufacturing Engineering Program, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in the thesis has not been submitted by me for the award of any other degree or diploma. All relevant resource of information used in this thesis have been duly acknowledged.

Candidate	Signature	Date
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This is to certify that the above declaration made by the candidate is correct to the best my knowledge and believe. This thesis has been submitted for examination with our approval.

Dr. Guteta Kabeta	___________	_____/____/_____
Advisor	Signature	Date

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Abstract

In any machining process, it is most important to determine the optimal machining parameters to achieve the desired product quality. This paper, the work aims to optimize the cutting parameters such as cutting speed, feed rate and depth of cut on surface roughness produced on the machined part on the lathe machine. The data for turning are generated on a lathe machine, model of CU582 by dry turning operation and presents an experimental study to investigate the effects of cutting parameters on surface roughness of EN-9 steel with inserted carbide. The surface roughness of the workpiece is measured using a surface roughness tester. Optimum machining parameters of turning operations are greatly influenced by concern along with manufacturing environment.

In this experimental work, turning parameters are greatly influenced by response parameters like surface roughness and metal removal rate. Mainly surface roughness were investigated employing L9 orthogonal array using Taguchi's design of experiments with different cutting parameters of EN-9 of turning parameters and optimized by signal to noise (S/N) ratio and analyzed by Analysis of variance (ANOVA's). The experimental investigation was conducted under varying input influential process parameters while taking other parameters constant cutting parameters for resulted surface roughness test were done. The ranges of cutting parameters process in the present study are limited to: cutting speed (31, 33,35m/min), depth of cut (0.5, 1.5, 2.5mm), feed rate (0.2, 0.4, 0.6mm/rev). Through this study, not only can the optimal cutting parameters for turning operations be obtained, but also the main cutting parameters that affect the cutting performance in turning operations were found. In this study, S/N ratio revealed that the optimum surface roughness condition is achieved at 35m/min of cutting speed, 0.2mm/rev of feed rate and 2.5mm of depth of cut.The level of significance of each parameter was determined by the help of analysis of variance. So that, from the analysis of variance Cutting speed is a dominating or significant parameter of turning process.

Key words: Turning parameters ,EN-9, Taguchi DOE, S/N ratio, ANOVA

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Abbreviations and Acronyms

μ Mean

ANOVA Analysis of variance

ASMT American Society of Testing materials

AISI American Iron and Steel institute

BUE Build-up edge British

BS Standard

D Distance between two successive peaks

DOE Design of experiment

Db deci Bell

ECEA End cutting edge angle

EN European norm

f Feed rate

HRC Rockwell Hardness scale measure on C

HSS High Speed Steel

HV Vickers hardness

ISO International Standard Organization

JIS Japanese Industrial Standard

n Rotational speed

OA Orthogonal Array

PM Powder metallurgy

PCA Principal component analysis

r Tool nose radius

Ra Arithmetic mean deviation

RSM Response surface methodology

RP Rapid prototype

Rz Average height profile

s Ultimate strength

S Yield strength

SCEA Side cutting edge angle

SD Standard deviation

SRA Side relieve angle

S/N Signal to Noise ratio

t Depth of cut

VB Flank wear land

Vc cutting speed

CHAPTER ONE
INTRODUCTION

1.1. Background of the study

Machining is still the most commonly used method of product formation of all manufacturing technologies. It's a basic production operation, predicted to improve or at least maintain its position in the engineering industry; especially if precision is involved. Turning is one of the widely used machining processes. It's the machining operation that produces cylindrical parts. In turning, a single-point cutting tool removes material from the surface of a rotating cylindrical workpiece. In its basic form, it can be defined as the machining of an external surface: With the workpiece rotating, by a single-point cutting tool, and With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work [1]. In the turning operations, roughness is mainly a result of the kinematical tool representation; additionally it is dependent on the unremoved fragment of the material, the tool run out, and, finally, the tool wear. Turning is the primary operation in most of the production process in the industry, or surface finish of turned components has a great impact on the quality of the product.

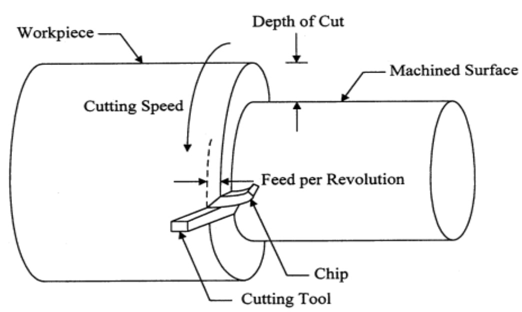


Figure 1.1 Basic Turning Operation [1]

In machining of parts, surface quality is one of the most specific customer requirements where the major indication of surface quality on machined parts is surface roughness value. The performance and service life of the machined component are often affected by its surface finish, surface nature and extent of residual stresses and the presence of surface or sub-surface microcracks, particularly when that component is to be used under dynamic loading or in conjugation with some other mating parts. Surface roughness also determine how a real object interacts with its environment. Rough surfaces usually wear more quickly and have a high frictional coefficient than smooth surfaces. Roughness is a good predictor of performance of mechanical components, since irregularities in the surface may form nucleation sites for cracks and corrosion, although roughness is undesirable; it is complex and expensive to control in manufacturing. The three primary input control parameters in turning operation are cutting speed, feed rate and depth of cut; where cutting speed is the relative velocity between cutting tool and the surface of the workpiece that it is operating on, feed rate is the relative velocity at which the cutter is advanced along the workpiece, its vector is perpendicular to the vector of cutting speed. The depth of cut is the thickness of the material that can be removed by one pass of cutting tool over the workpiece [2]. Surface roughness is one of a vital attribute to achieve the desired product quality. In the metal cutting and manufacturing industries, the surface finish of a product is very significant in determining the quality. Good surface finish not only assures quality, but also reduces manufacturing cost. Surface finish is important in terms of tolerances, it reduces assembly time and avoids the need for the secondary operation, thus reduces operation time and leads to overall cost reduction.

The desired value of surface roughness of a product is generally defined to achieve the required fatigue strength, corrosion resistance, precision fits, tribological and aesthetic requirements [3]. Today the standard procedure to find a better surface roughness during machining is by careful planning of the cutting parameters. Machining parameters are selected and determined during manufacturing (cutting) process; which is influenced by many factors such as machine structure, tool type, work material, etc. The composition of machining is complicated. In a turning operation, it is an important task to select cutting parameters for achieving high cutting performance, high surface qualities, less tool wear, economical in machining and high performance of the product [4].

The aim of this research is to investigate the effects of cutting parameters on the resulting surface roughness in the dry turning operation of medium carbon steel (EN9). The specific products from this steel are shafts, cam, bolt, and stud, gear and etc. it very important to optimization on this material due quick wear of component under dynamic load. On this material, an experiment is carried or different trial with different parameters level and finally, confirmation test is was conducted to verify the predicted value bas on experiment. To achieve such objective, the research has completed a fractional experimental design that allows considering at different levels of the cutting parameters (cutting speed, feed rate, depth of cut and tool length) on the measured dependant variables (surface roughness). The ability to control the process for better quality of the product is significant [5]. Surface roughness is a significant factor to determine cracks, creep, cavities, Build-up-edges (BUE) which nucleate on the surface of the component thereby influencing its performance. Cutting parameters may be specified according to hardness of materials and roughness of the surface of a workpiece. The ability of a manufacturing operation to produce a desired roughness (surface finish) depends on various parameters; such as machining parameters, cutting tool and workpiece material properties and cutting conditions. All these parameters have been studied in terms of depth of cut (t), feed rate (f), and cutting speed (Vc). In this present study, the influence of different machining parameters on surface roughness has been analysed. This parameter is Ra (arithmetic mean deviation) [6].

1.2. Overview of the surface roughness

Surface-is a boundary that separates an object from another object, substance or space. Roughness is comprised of an irregularity that occurs due to the mechanism of the material removal process; tool geometry, and wheel grit [7]. According to (M.Nalbant et al.) "Surface roughness can be defined as the measure of the quality of a product and also it is the factor that significantly affects manufacturing cost. It can further also be describes the geometry of the machined surfaces that combined with the texture of the surface. Surface properties such as roughness are judicious to the purpose, competence of machine components. Surface roughness remain the main indicator of machined component quality. A low surface roughness improve the tribological properties, fatigue strength, corrosion resistance and esthetic appeal of the product..

Surface roughness plays an important role in affecting friction, wear and lubrication of contacting bodies. Surface roughness is one of the parameters that greatly influence the friction under certain running conditions. Surface roughness of the contacting surfaces influence the frictional properties of those surfaces during the forming processes. It is clear now that surface roughness geometry strongly influences the manner in which the contacting surfaces are interacting. Surface roughness and material removal rate plays a vital role in deciding about the productivity in global manufacturing [8].

As far as turned components are concerned, better surface finishes (low surface roughness) is important as it can reduce or even completely eliminate the need of further machining. Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vectors of real surface of its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Surface roughness is tougher to manage and track than physical dimensions are, because relatively many causes affect the surface roughness. In today‘s manufacturing industry, dimensional accuracy and surface finish are the very important point of concern [9].

1.3. General Ideas about Surface finish

The roughness with its typical roughness height and roughness spacing represents the more closely spaced peaks and valleys. Roughness is usually produced by the basic surface forming process. The “waviness” consists of the more widely spaced irregularities and often produced by vibration in the machine. “Lay” is the term used to indicate the direction of the dominant pattern texture on the surface. The term “topography” itself represents all of the spatial structure of the peaks and valley that exist on a surface. Once again the roughness consists of the closely spaced irregularities and these may be cutting tool marks or may be produced by the grit of grinding wheel. Roughness, therefore, has a characteristic structure which can be related to those causes as shown in Figure 1.2.

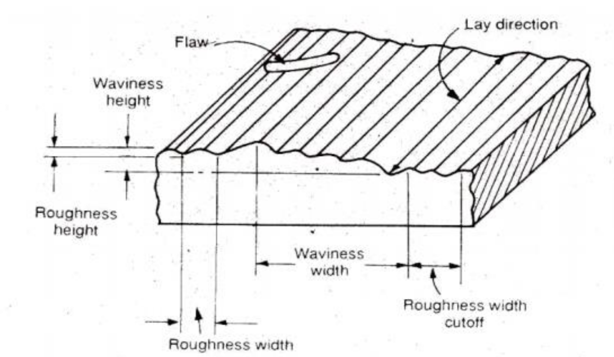


Figure 1.2 Surface characteristic and terminology [10]

The term “surface finish” is not as carefully defined as others. It generally refers to the overall description of the surface, including the texture, the flaw, the materials, and any coating applied. We generally prefer the terms “texture” and “roughness” to “finish” and will use those almost exclusively. A measure of surface height indicated by the roughness average, Ra, and a measure of the spacing of the peaks and valley of the surface roughness, indicated by periodic surface profile by the wavelength parameter D, where D –is the distance between two successive peaks as shown in Figure 1.3.

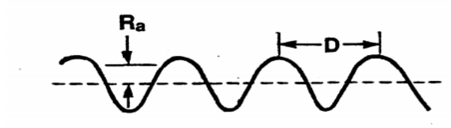


Figure1.3 Two key surface parameters [10]

A surface topographic technique, which used to measure with a technique of profiling, knowledge of the surface, is developed by carefully probing of surface with high resolution probe. With an area technique, one probes a finite area of the surface and the measured quantities represent some statistical average of the peaks and valleys in that area [10].

1.4. Surface roughness graphical symbol

Table 1.1 shows that the machined components in which its surface finish can be symbolized based on the arrangements of the lay.

Table1.1: Surface finish symbol [10]

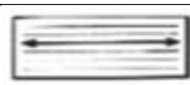
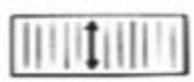
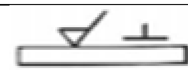
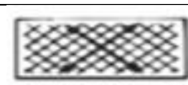
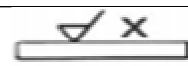
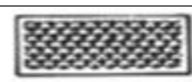
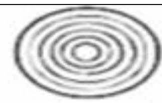
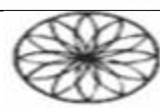
Type	Lay	Symbol
Parallel		
Perpendicular		
Crossed		
Multi directional		
Particulate		
Circular		
Radial		

Table 1.2 indicates that the surface texture of component machining by different process such as manufacturing, material removal and without removal.

Table1.2: Surface texture symbol

	Surface texture obtained by any manufacturing process.

	Surface texture obtained by material removal by machining operation.
	Surface texture obtained without removal of material.

1.5. Types of surface roughness

A surface is a boundary that separates an object from another object or substance. The Surface is divided into three sub-groups:

a) Nominal surface or **Ideal**

b) Real surface

c) Measured surface.

a) Nominal surface or **Ideal Surface:** is the intended surface. A nominal surface is a theoretical, geometrically perfect surface which does not exist in practice, but it is an average of the irregularities that are superimposed on it. The shape and extent of a nominal surface are usually shown with dimensions on a drawing. The nominal/ideal surface does not include intended surface roughness.

b) A **real surface:** is the actual boundary of an object. It deviates from the nominal surface as a result of the process that has created the surface. The deviation also depends on the properties, composition, and structure of the material.

c) A **measured surface:** is a representation of the real surface obtained with some measuring instrument. This distinction is made because no measurement will give the exact real surface.

The main factors affect real surface roughness's are as follows:

- ✓ Machining parameters; such as feed rate, cutting speed, tool angle, depth of cut, lubricant.
- ✓ Machining process conditions; such as vibrations, cheap formation, friction on the cutting zone, variations in cutting forces.
- ✓ Workpiece material properties; such as hardness, length, diameter.
- ✓ Cutting tool properties; such as material, tool tip sharpness [10].

Main parameters influence on surface roughness

Table1.3: Main parameters influence on the surface roughness

Machining parameters	Kinematics of process, lubricant, step over, depth of cut, cutting speed, feed rate.
Cutting tool	Tool materials, shape of tool, tool's cutting edge, tip radii, run

specification	out errors.
Workpiece materials	Hardness, Diameter of work piece, length of work piece.
Cutting process	Accelerations, Vibration, Chips form.

1.6. Surface roughness measurement

The surface profiles of all samples were quantitatively analyzed in order to determine the statistical standard parameter of average roughness, *R*a, by using Tally-surface (from Taylor Hobson Precision, Inc.). The type of the surface quality affects the physical properties of surface specimens. Many possible ways of measuring surface quality have been explored at one time or another. Some of these methods have sunk without any trace, but have developed in further investigations. The limitations which prevented their use, have been removed, in some cases, by the advanced technology. The roughness of a surface cannot be easily defined by a single parameter. It is an intrinsic property of the surface. Every test condition was repeated at least three times at different new locations on a rod bar surface in order to ensure the repeatability and reproducibility of the results.

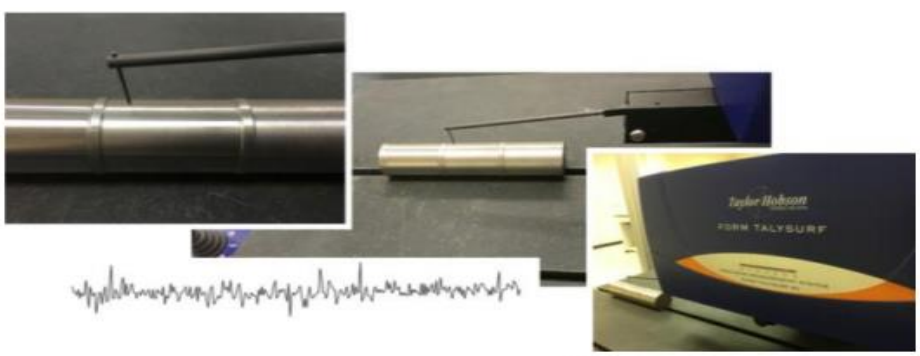


Figure1.4 Image of Tally-surface and specimen [11]

With the more precise demands of modern engineering products, the control of surface texture together with dimensional accuracy has become more important. It has been investigated that the surface texture greatly influences the functioning of the machined parts. The properties such as appearance, corrosion resistance, wear resistance, fatigue resistance, lubrication, initial tolerance, ability to hold pressure, load carrying capacity, noise reduction in case of gears are influenced by the surface texture. Whatever may be the manufacturing process used, it is not possible to produce a perfectly smooth surface.

The imperfections and irregularities are bound to occur. The manufactured surface always departs from the absolute perfection to some extent. The irregularities on the surface are in the form of a succession of hills and valleys varying in height and spacing. These irregularities are usually termed as surface roughness, surface finish, surface texture or surface quality. These irregularities are responsible to a great extent for the appearance of a surface of a component and its suitability for an intended application. There are many factors affecting surface roughness and reasons for controlling them. [11]

a) **Factors Affecting Surface Roughness:** Whenever two machined surfaces come in contact with one another, the quality of the mating parts plays an important role in the performance and wear of the mating parts. The height, shape, arrangement and direction of these surface irregularities on the workpiece depend upon a number of factors such as:

(1) Vibrations;

(2) Material of the workpiece;

(3) Type of machining;

(4) Rigidity of the system consisting of machine tool, fixture cutting tool and work;

(5) Type, form, material and sharpness of cutting tool;

(6) Cutting conditions (machining parameters) i.e., Feed, speed and depth of cut

(7) Type of coolant used and

(8) The tool geometry.

(9) Some geometric factors which affect achieved surface finish which includes:

a) Nose radius b) Rake angle c) Side cutting edge angle, and d) Cutting edge.

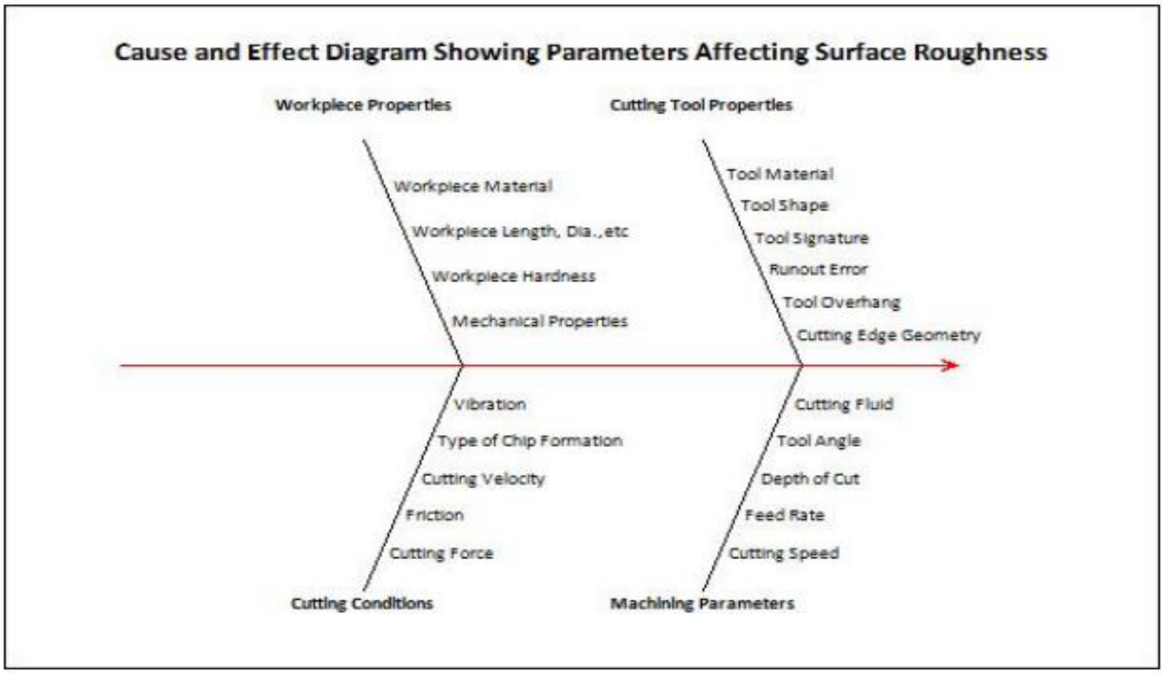


Figure1.5 Cause and effect diagram for surface roughness [19]

b) **Reasons for Controlling Surface Texture:**

(1) To improve the service life of the components;

(2) To improve the fatigue resistance;

(3) To reduce initial wear of parts;

(4) To have a close dimensional tolerance of the parts ect.

1.7. Requirements of high surface finish

High surface finish is required in the following fields:

- Optics and electronics- lenses, mirrors, etc.
- Medical- implant, surgical, instruments etc.
- Product-Die/mold, turbine blade, RP, bearing etc.
- Micro fluid- nozzle, channel, mixture etc.
- Integration- multilayer, assembly, coating etc.
- Material properties- strength, high fatigue life, wear resistance, toughness etc.

1.7. Profile Geometry

The imperfections which are found on any surface will generally take the form of peaks and valleys of varying height and width and are quite often a characteristic of the process used to produce them. It usually happens that a surface consists of many different wavelengths, some resulting from the feed of the tool and the others caused by the actual cutting action.

Profile Peak is the point of maximum height of a portion of a profile that lies above the mean line and between two intersections of the profile with the mean line.

Profile Valley is the point of maximum depth on a portion of a profile that lies below the mean line and between two intersections of the profile with the mean line.

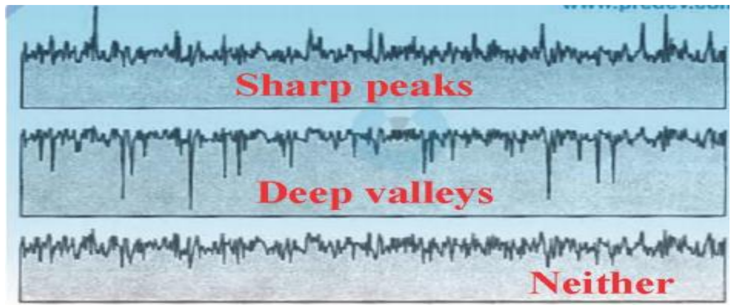


Figure1.6 Geometry of peaks and valleys [7]

Profile Irregularity is a profile peak and the adjacent profile valley. Various types of surface finish imperfections with related problems caused due to that errors are shown in the table.

Table1.4: Surface finish imperfections [12]

Type of Imperfection	Related Problem or Cause of error
Form Error	Form errors resulting from large scale problems in the manufacturing process such as errors in machine tool ways, guides, or spindles, insecure clamping, inaccurate alignment of a workpiece, or uneven wear in machining equipment. Form error is on the dividing line in size scale between geometric errors and finish errors.
Surface Texture	Surface Texture includes roughness waviness and lay, that is, the deviations that are shorter in wavelength than form error deviations.
Roughness(PrimaryTexture)	These are deemed to include transverse feed-marks and the irregularities within them. Roughness is sometimes known as “Micro-geometrical deviation” or “Micro-geometrical irregularities”. These are defined within the area, where deviations of form and waviness are eliminated.
Waviness (Secondary Texture)	It may be caused by vibrations, chatter, and heat-treatment or warping strains. Waviness is the component of surface roughness upon which roughness is superimposed.
Flaws	These are unintentional and unwanted problems with a surface. Such imperfections are scratches holes cracks, pits, checks, porosity etc.

1.8. Irregularities on the surface of the part

The irregularities on the surface of the part produced can also be grouped into two categories: (i) Roughness or primary texture, (ii) Waviness or secondary texture.

(i) Primary texture (Roughness): The surface irregularities of small wavelength are called primary texture or roughness. These are caused by direct action of the cutting elements on the material, i.e. cutting tool shape, tool feed rate or by some other disturbances such as friction, wear or corrosion.

(ii) Secondary texture (Waviness): The surface irregularities of the considerable wavelength of a periodic character are called secondary texture or waviness. These irregularities result due to inaccuracies of slides, wear of guides, misalignment of centres, non-linear feed motion, deformation of work under the action of cutting forces, vibrations of any kind etc.[13]

1.9. Statement of the Problem

Machining is still the most commonly used methods of product formation in metal manufacturing industries. Although this method is widely used in machining process, but it has a main problem which is surface roughness. Surface roughness remain the main indicator of machined component quality. Surface quality in machining process is related to surface roughness. It can be described as a process of turning operation, which leaves its own mark on machined surface leading to unacceptable product with poor dimensional accuracy, less precision of surface finish, quick wear of part, crack formation and so on. In manufactured components with high surface roughness cannot serve for the intended period of time due to surface has large peaks and valley, which reduce the quality, overall cost and drastically market share. In the turning operation, cutting parameters are a frequent problem, which affects the result of machining and, in particular, the surface finish. The surface roughness problem is dependent on these parameters (depth of cut, cutting speed and feed rate).

Due to the increasing demand of higher precision components for its functional aspect, and production price reduction, it is vital to investigate and optimize the cutting parameters that affect the surface roughness in the metal turning operation process. Therefore, taking these factors into consideration, the objective of the present research is to work on EN-9 steel grade material during turning operation to give solution and overcome these problems with a modeling technique for the prediction of surface roughness by modeling Taguchi method.

1.10. Research Motivation

During the internship of two months in Awash melkasa aluminum sulphate and hydrogen peroxide, it's found that, some of machined components in their machine shops are damaged after a few time functions and others are machined for replacement. These components are shaft and gear pump. The gear pump wears during pumping process of sandy water from Awash River. This sand erodes the surface of gear pump (vein) and quickly leads to wear, finally, out of function. So, the cost of remachining and replacing worn out parts to get the better surface finished should pay attention. Achieving this desired surface quality is a great importance of the functional behavior of a part. In the present work, it is motivated to minimize the surface roughness related to cutting parameters and improves the component from quick wear and damage, specifically in the form of rubbing, crack and cavities formed on the sub-surface of the part, which leads fail before its intended service life time.

1.11. Objectives of the study

1.11.1. General objective

The aim of this study is to find the optimal cutting parameters to produce minimum surface roughness of material in a turning operation.

1.11.2. Specific objectives

- ✓ Investigate the variation of surface roughness with varying parameters (cutting parameters) effect on the surface roughness of the machined part;
- ✓ Conduct trial experiment
- ✓ Measure the surface roughness of specimen machined on a lathe using cutting parameters;
- ✓ Make an analysis of the obtained results and
- ✓ Suggest the optimum cutting parameters.
- ✓ Suggest the most significant parmeter.
- ✓ Confirm the predicted and experimental results.

1.12. Scope of the study

This study is limited to:

Turning operations selected on lathe machine with its corresponding cutting parameters. Carbon steel and carbide inserted are selected for specimen and cutting tool materials respectively. Dry turning operation carried out and surface roughness measurement (Profilometer) used for analysis. Finally, focuses on the effect of surface roughness.

1.13. Significance of the Study

How to know, establish a machining optimization turning parameter with high quality material that will be produced in order to increase the profit is significant. These optimization technique parameters is also prevent engineer or production controller from doing something that waste in production such as time and produce a better product that satisfy the customer. This study has the following significance:

- ⇒ To optimize the cutting parameters;
- ⇒ Obtain better surface finish;
- ⇒ Increase the precision of the product;
- ⇒ Enables customer satisfaction;
- ⇒ Helps to maintain stability of dimensional accuracy;
- ⇒ Reduce the friction factor in movable joint.

1.14. Limitation of the study

The limitation for this study is lack of workshop materials that assist in doing laboratory. These become one factors which hinders the thesis not complete on time. The shortage of thesis facility such as types of working materials, machine required based on specification, cutting tool materials, and measuring instruments constraint for success. The internet to explore more data and getting standardized machining parameters limits the study.

1.15. Organization sof the thesis

The thesis consists of five chapters that discuss about an introducing the theme of the thesis, review of related literature, methods for developing turning operation and findings out of case study are available.

Chapter one: begins with an introduction in which background of the study is briefly pointed out. The objectives, definition of surface roughness, overview of surface roughness, general ideas of surface finish, factors, role of surface roughness in company level, surface measuring, measuring the scope and significance of study and relevant literature are also enlightened.

Chapter two: is concerned with the literature review that is comprises of different authors work on the analysis of demand forecasting, aggregate machining process, capacity requirement of better surface finishes, optimization techniques, significant factor affecting process parmeters, different cutting tool and workpiece materials, materials requirement for machining, different cutting tool materials and integration of machining design are also detail discussed.

Chapter three: discusses about the methodology and measuring instrument briefly. Including the cutting parameters data, machine used, material selected, types of cutting tools, measurement techniques, material chemical and mechanical composition, modeling techniques employed, and techniques that used to solve the problem and performance measures.

Chapter four: the data analysis is applied to the case study and adopts the systematic machining condition and methodology for optimization parameter. Optimimum parameters were found and statistical analysis was employeed. Results were discussed based on analysis obtained from experiment.

Chapter five: summarize the study, discuss (conclude) from overall study and on the machining parameter, recommendation and the future work is proposed.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter discusses about the turning operation, turning parameter and the previous study that involved the optimization techniques. Here, the optimization technique, Taguchi method was reviewed to get a full understanding before applied to the study. The most emerging needs of the modern metal cutting operations are to increase the material removal rate with better surface finish and high machining accuracy. In metal cutting process, its effects are generally reduced by proper selection of process parameters. The selection of optimal cutting parameters is a very important issue for every machining process in order to enhance the quality of machined products, to reduce the machining costs and to increase the production rate.

To overcome these problems, the researchers propose models that try to simulate the conditions during machining and establish cause and effect relationships between various factors and desired product characteristics. The presentation of each approach along with its advantages and disadvantages should help both the researchers and practitioners by providing compact yet adequate information so as to select the one that best suits their needs and specific requirements. In the following section, different papers focus on the turning operation and reveal different results which enhance to observed closeness in the results between experimental and predicted values in turning operation.

2.2. The turning operation

The turning operation is a basic metal machining operation that is used widely in industries dealing with metal cutting. During a turning operation, a high-precision single point cutting tool is rigidly held in a tool post and is feed past a rotating workpiece in a direction parallel to the axis of rotation of the workpiece, at a constant rate, and unwanted material is removed in the form of chips giving rise to a cylindrical or more complex profile. This operation is carried out on a Lathe Machine either manually under an operator's supervision, or by a controlling computer program. There are two types of motion in a turning operation. One is the cutting motion which is the circular motion of the work and the other is the feed motion which is the linear motion given to the tool. The basic turning operation with the motions involved as shown in Fig 2.1 shows a single point cutting tool [14]

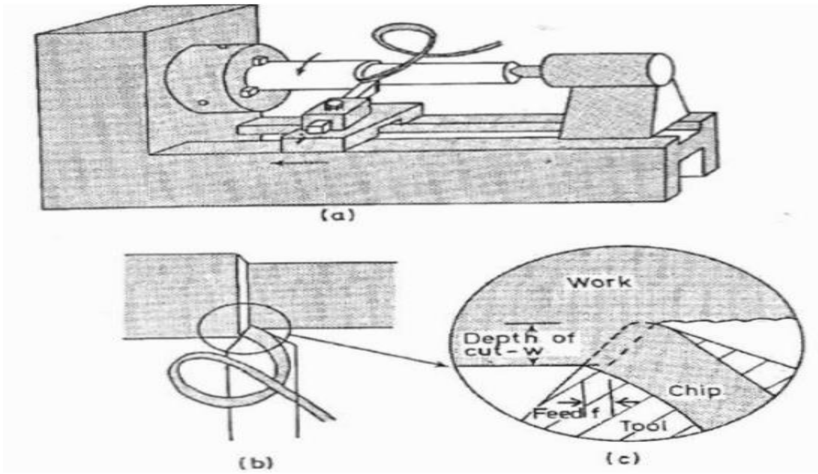


Figure 2.1 Basic Turning operation in lathe [14]

2.3. Effect of cutting parameter and surface roughness

Many factors affect the performance of the turning process and affecting the surface finish quality (Surface roughness). Some of them (speed, feed and depth of cut) are studied in this research. Surface roughness of a turned workpiece is dependent on these process parameters and also on tool geometry (nose radius, rake angle, side cutting edge angle and cutting edge etc.). In addition, it also depends on the several other exogenous factors such as: workpiece and tool material combination and their mechanical properties, quality and type of machine tool used, auxiliary tooling, and lubricant used, and vibrations between the workpiece, machine tool and cutting tool.

The surface roughness in turning operation is mostly affected by the following four cutting parameters: cutting speed, Spindle speed, feed rate and depth of cut. The surface roughness is also affected by workpiece material, cutting tool material, tool geometry, etc. Thus, to obtain a desired output the correct combination of these factors is most vital. Therefore, the basic objective of this research work is to investigate the effect of the following three cutting parameters of turning operation: cutting speed, feed rate and depth of cut on the surface roughness of carbon steel bar and thus to optimize the cutting parameters (factors) to obtain the minimum surface roughness. Attempts have been made to optimize signals in predicting tool wear and tool life in turning operations and other machining operations.

Generally, below heading entails a detailed review of literature reviews (previous study) on various cutting parameters (inputs/outputs) and the most significance of those parameters on the surface roughness were briefly discussed.

Taguchi experimental design used to optimize turning parameters and to obtain the lowest degree of surface roughness parameters Ra. The study results indicated that the feed rate and the interaction effect between feed rate and cutting speed were the most influential factors over the surface roughness. Some authors do not only focus on the study of the part, but also of the tool, which takes an important role in determining the cutting conditions, and therefore, in the surface roughness.

The influence of feed rate, cutting speed, depth of cut and geometry of the tool on the average roughness obtained in dry turning bronze parts. The results revealed that the feed rate and the tool radius were the most influential factors in Ra were measured by Pereira et al. [15].

The cutting speed has greater influence on the roughness followed by the feed and depth of cut has no significant influence on surface roughness found by using the Taguchi method. The higher insert radius, low feed rate and low depth of cut to obtain better surface finish under dry turning operation recommended by Noordin et al. [16].

Its obtained that feed rate, cutting velocity and nose radius have significant contribution on the surface roughness, whereas depth of cut and hardness of work material have less significant contribution on the surface roughness M.T. Sijo and N. Biju [17].

The feed as the most significant factor in turning mild steel with HSS cutting tool among cutting speed, feed, depth of cut, side rake angle and back rake angle. Side rake angle is found to have least effect on surface roughness. Among depth of cut, Spindle speed and feed rate in AISI 1040, surface roughness decreases with increase in depth of cut and Spindle speed but increases with feed rate. When mild steel is machined with TiN-coated carbide tools feed rate is also found to be the most influencing factor on surface roughness than cutting speed and depth of cut. Among turning parameters like cutting speed, feed rate and depth of cut in AISI 1050, feed rate is found as the most effective parameters.

The importance of achieving dimensional accuracy, good surface finish and maximum material removal rate in the machining process; and optimized the cutting parameters viz. feed, cutting speed and depth of cut for maximizing the surface finish for an aluminum alloy 6061. L-9 orthogonal array, signal- to-noise ratio, analysis of variation has been employed to study the process characteristics, and Taguchi method experiment design has been used to optimize the cutting parameters for the material using uncoated inserts. An experiment has been conducted to confirm and verify the effectiveness of Taguchi optimization method.

Surface roughness and material removal rate are found to be maximum at 11.6%and 14%; and minimum at 4.4% and 3.7% respectively. Cutting parameters viz. cutting speed, feed rate and depth of cut are found to be affecting the machining process at 45%, 36% and 19% respectively for minimum surface finish of 0.256 microns with an error percentage of 4.4%.

An experimental work carried out to optimize the cutting parameters viz. Feed rate, depth of cut and lubricant temperature in the turning operation of EN-31 steel alloy by using tungsten carbide inserts. The work aimed at explaining and demonstrating the systematic procedure of Taguchi parameter design; finding the optimal combination of cutting parameters using the signal-to-noise ratio; knowing the significance level of each cutting parameter using ANOVA analysis; and therefore finding out the effect of lubricating temperature on the response i.e. surface finish. They found that taguchi method provide simple, systematic and efficient methodology for optimization of the machining process. It has been proved experimentally that better surface finish can be observed with cooled lubricant and higher depth of cuts.

They found that speed has maximum effect & feed has minimum effect on surface roughness. The experiment was designed and carried out on the basis of standard L9 Taguchi orthogonal array. At high speeds, surface finish is least affected. At low speeds surface roughness increases with increasing feed but at higher speeds surface roughness is less dependent on feed. An experimentally investigated, and optimized the effect of cutting speed, feed and depth of cut on the surface finish, tool wear and cutting force in a continuous dry turning of hardened alloy steel, AISI 4340 having hardness: 48(48-52HRC) using the Taguchi design of experiments. It was observed that for tool wear feed has significant influence and depth of cut is the least influential of all. Optimal conditions are obtained at cutting speed (140m/min), feed (0.125mm/rev), and depth of cut (0.8mm).

The development of surface roughness prediction models for turning EN 24T steel (290 BHN) utilizing response surface methodology. A factorial design technique was used to study the effects of the main cutting parameters such as cutting speed, feed and depth of cut, on surface roughness. The tests were carried out using uncoated carbide inserts without any cutting fluid. They reveals that response surface methodology combinedwith factorial design of experiments is a better alternative to the traditional one-variable-at-a-time approach for studying effects of cutting variables on responses such as surface roughness and tool life.

An optimizing turning parameters based on Taguchi method to minimize surface roughness (Ra and Rz). Experiments have been conducted using L9 orthogonal array in a turning machine. Dry turning tests were carried out on hardened AISI 4140 (51 HRC) with coated carbide cutting tools. The results shows that the feed rate effect more compared to cutting speed and depth of cut on surface roughness at a reliability level of 95%. As a result they observed that the feed rate has the most significant effect on Ra and Rz was focused by Asilturk Ilhan et al. The process effects on significant engineering properties of work materials have to be carefully analyzed. Roughness, residual stresses, and white layers as parts of surface integrity, are functions of the machining parameters and of the cut ability of the cutting edge, i.e. of the tool wear. The aim of this work was to study the influence of feed rate, cutting speed, and tool wear on the effects induced by hard turning on case-hardened 27MnCr5 gear cone brakes and to point out the technical limitations in mass production.

Taguchi method to find the optimal cutting parameters for surface roughness in turning. The orthogonal array, the signal-to-noise ratio, and analysis of variance are employed to study the performance characteristics in turning operations of AISI 1030 steel bars using TiN coated tools. Three cutting parameters namely, insert radius, feed rate, and depth of cut, are optimized with considerations of surface roughness. The experimental results demonstrate that the insert radius and feed rate are the main parameters among the three controllable factors (insert radius, feed rate and depth of cut) that influence the surface roughness in turning AISI 1030 carbon steel was applied by Nalbant M. et al [18]. With investigations on surface roughness during hard machining of EN 24 steel with the help of coated carbide insert. The process parameters are optimized by using Grey based Taguchi approach and it was found that the feed is the most dominant parameter for surface roughness. An investigated the turning parameters namely cutting speed, feed rate and depth of cut resulting in an optimal value of feed force, tangential force and surface roughness for machining EN-19 steel with an coated carbide tool insert dealt by Dipti Kanta Das, et al [19].

2.4. Turning operation and surface roughness

Turning operation using a single point cutting tool has been one of the oldest and popular methods of metal cutting. It has even replaced grinding in several applications with reduced lead time without affecting the surface quality. One of the important aspects which are widely studied in turning operations is cutting parameters and surface roughness of the work-piece.

Process parameter optimization is of great significance while looking into the process capability of any machining operation. Dry machining (no cutting fluid; Avoids problems of cutting fluid contamination, disposal, and filtration) of steel caused most tool wear and surface roughness and wet machining didn't show considerable improvement.

Surface roughness is also a vital measure as it may influence frictional resistance, fatigue strength or creep life of machined components. As far as turned components are concerned, better surface finish (low surface roughness) is important as it can reduce or even completely eliminate the need of further machining. Many researchers have found that surface roughness has bearing on heat transmission, ability to hold lubricant, surface friction, wearing etc. Despite the fact that surface roughness plays a very important role in the utility and life of a machined component due to its dependence on several process parameters and numerous uncontrollable factors, machining process has no complete control over surface finish obtained was stated by N.R. Dhar et al [20]

So, the venture of controlling process parameters so as to produce best surface finish is an on-going process varying from various materials to tool combinations and the machining conditions. The present work is aimed at studying the influence of the three major process parameters in a turning operation, namely, cutting speed, feed and depth of cut on a surface roughness for a predefined combination of material and tool under the given set of machining conditions. The surface finish of any given part is measured in terms of average heights and depths of peaks and valleys on the surface of the work piece.

This heading entails a detailed review of literature on the effect of various cutting parameters on surface roughness during turning process of hard to machine materials.

The roughness level on surface finishing has a crucial role in the efficiency and quality of subsequent surface coatings, From many processes used to prepare the surfaces, the machining is the most used and allow low levels of surface roughness, Benardos and Vosniakos, which can reach values down-to 50nm for optical applications, Guenther. The economic factors have a strong impact in today's machining processes demanding a higher productivity, flexibility of the production systems, reduction of costs and obtaining manufactured parts with better surface and dimensional quality.

Surface roughness model was developed in terms of main cutting parameters such as cutting speed, feed rate and depth of cut, using response surface methodology. Machining tests were carried out in turning AISI 1050 hardened steels by cubic boron nitride (CBN) cutting tools under different conditions. The model predicting equations for surface roughness of *R*a, *R*z and *R*max were developed using an experimental data when machining steels. The results indicate that the feed rate was found out to be dominant factor on the surface roughness, but it decreased with decreasing cutting speed, feed rate, and depth of cut for these tools. In addition, average surface finish of *R*a value produced by CBN cutting tool was about 0.823µm when machining hardened steels. However, the *R*a value decreased about 0.55 µm in terms of trial conditions. In order to produce any machine part at a certain quality by any metal removal technique, cutting parameters should be arranged properly. Dependent upon work piece material and geometry to be desired,surface roughness has important influence on determining the machining cost related to nose radius, rake angle, clearance angle, cutting speed, feed rate, unformed chip thickness, cutting tool material etc presented by Sahin and Motorcu [21].

Optimization of surface roughness in CNC turning using Taguchi method and ANOVA, studied the effect of cutting parameters (speed, feed and depth of cut) in CNC turning of AA7075 to achieve low surface roughness using tungsten carbide insert. The experiments were designed as per Taguchi's L9 orthogonal array technique. (ANOVA) was performed to find the significance of the cutting parameters on the surface roughness. Experimental study of turning operation and optimization of MRR and surface roughnessusing Taguchi method. In this research work turning operation is performed on AISI 1020 mild steel. The experiments were performed by taking Cutting Speed, Feed Rate & Depth of cut as process parameters and got the optimized value of surface Rroughness. An L9 orthogonal array, the S/N ratio are employed to the study the performance characteristics in the turning using carbide insert with a nose radius of 0.8mm was investigated by Shivam Goyal et al [22]. The effects of tool overhang on selection of machining parameters and surface finish. It was found that too long and very small tool overhangs results in poor surface finish. Further, optimum range of tool overhang with minimum tool vibrations was established studied Vinod Mishra et. al. [23]. A group of researchers including that cutting parameters (Feed rate, Cutting Speed, Depth of Cut, and material properties of tool) directly influence the surface finish of machined components. Gaitonde et al. studied the effects of cutting conditions on machinability characteristics of dry turning copper-tungsten parts. The input parameters selected were cutting speed and feed rate, and their influence was measured on the roughness parameters Ra have found **by** Ozel and Karpat [24].

M.Nalbant and his friends have insert radius along with feed rate as the main affecting factors among insert radius, feed rate, and depth of cut in AISI 1030 with TiN coated tools. When S45C steel bars are machined using tungsten carbide cutting tools for minimum surface roughness, feed rate is found to be the most contributing factor was found by M. Nalbant et al. [25]. The rough turning experiments to optimize cutting parameters. He utilized ANOVA to single out the impacts and contribution of cutting speed, feed rate and depth of cut on the responses viz. surface roughness was conducted by Camposeco-Negrete [26]. The feed rate and also the tool nose radius square measure the variables that manufacture the fore most vital effects on surface roughness, followed by the cutting speed conclude by Thomas M. et al. [27]

During dry turning of EN8 investigated the effect of cutting parameters of cutting speed, feed rate and depth of cut using ordinary lathe machine deducing that the spindle speed (the most significant factor) contributed 63.90%, depth of cut (second most significant factor) contributed only 11.32% and feed rate contribution was least with 8.33% for Ra. The contribution for feed and RPM was 60.91% and 29.83%, whereas the depth of cut contributed only 7.82% for material removal rate, in dry turning of EN8 on lathe concluded that speed and depth of cut had negligible effect on the surface roughness and feed rate for surface roughness shows increasing trend. In dry cutting operations, the friction and adhesion between chip and tool is high resulting in high temperatures and wear rates, so complete dry cutting is not recommended and cutting fluid is also needed to remove the chips from chip tool interface thus preventing it to stick to tool stated by H. Singh et al. [28]. Influence of cutting parameters (feed rate, cutting speed and tool nose radius) and the fiber orientation on the surface roughness in turning. The results showed that the roughness of the machined surfaces was highly influenced by the feed rate and tool nose radius, whereas the influence of cutting speed was negligible examined by Eriksen [29].

An experimental work on EN-9 steel with different cutting parameters like cutting speed, feed rate and depth of cut which influenced by response parameters like surface roughness and metal removal rate in turning. For experiment L9 orthogonal array using Taguchi"s design of experiments are used and optimized by S/N ratio and analyzed by Analysis of variance

(ANOVA's). they have find that cutting speed is dominating parameter for surface roughness presented by B.Kumaragurubaran, and P.Gopal [30] .

Influence of cutting parameters on cutting force and surface finishin turninoperation describes the significance of influence of speed, feed and depth of cut oncutting force and surface roughness while working with tool made of ceramic with an Al2O3+TiC and the work material of AISI 1050 steel (hardness of 484 HV). Experiments were conducted using Johnford TC35 Industrial type of CNC lathe. Taguchi method (L27 design with 3 levels and 3 factors) was used for the experiments. Analysis of variance with adjusted approach has been adopted. The results have indicated that it is feed rate which has significant influence on surface roughness were as shown in Fig 2.2.

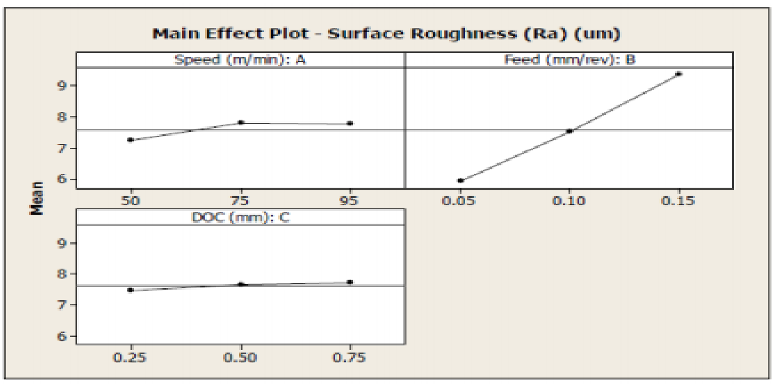


Figure 2.2 Main effect on surface roughness

Determination of optimum cutting parameters during machining of AISI 304 austenitic stainless steel. In this study determination of the optimum cutting speed has been aimed when turning an AISI 304 austenitic stainless steel using cemented carbide cutting tools. The influence of cutting speed on tool wear and surface roughness was investigated were carried out by as shown in Fig 2.3 Ihsan Korkut [31].

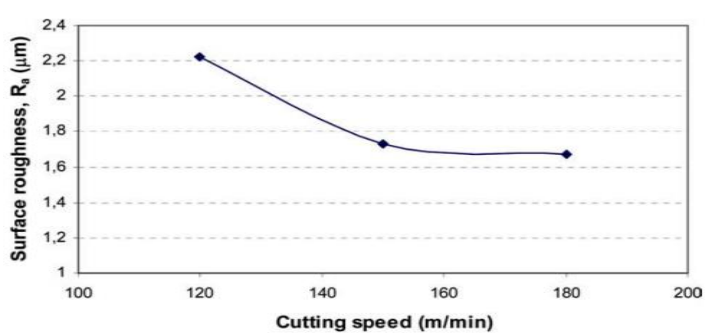


Figure 2.3 Effect of cutting speed on surface roughness

Optimization of process parameters of AISI 202 stainless steel in turning operation. They studied the effect of process parameter i.e speed, depth of cut, feed, and nose radius on surface roughness. Experiments were conducted using Full Factorial design technique and to analyse the process parameter significance, ANOVA was used. Feed and Nose radius were the dominant factor followed by speed and depth of cut were investigated by M. Kaladhar, et.al [32].

Turning of hardened steels of AISI 4340 using a single point cutting tool has replaced the cylindrical grinding now as it offers attractive benefits in terms of lower equipment costs, shorter set up time, fewer process setups, higher material removal rate, better surface quality and elimination of cutting fluids compared to cylindrical grinding. A full factorial design of experiment is selected for experimental planning and the analysis of variance (ANOVA) has been employed to analyze the significant machining parameters on surface roughness during turning. In the result they observed from the ANOVA that feed (60.85%) is the most significant parameter followed by cutting speed (24.6%) and the two level interactions were significant between cutting speed, feed (6.23%) and depth of cut-feed (2.62%) on surface roughness. From the experimentation it was found that, depth of cut has no impact the surface roughness in the studied range, significantly. The most optimal results for surface roughness were observed when cutting speed was set at 150 m/min and feed of 0.05 mm/rev. The work on turning of hardened AISI 4340 steel with CVD multilayer coated carbide insert will be useful for the advanced engineering industries those are working in the field of precision machining was investigated.

In the task of Turning it is focused to find optimum cutting parameters such as Spindle speed, Feed and Depth of cut in order to have improved performance on Machining time and Surface Roughness. This work focuses on CNC turning of EN 8 steel using Cemented Carbide tool for varying Spindle speed, Feed and Depth of cut. The experiment is designed for Second order linear model using Response Surface Method (CCD). Mathematical formulation is carried out by correlating the values of responses Machining time and Surface Roughness with the contribution of Spindle speed, Feed and Depth to develop the Empirical models for the responses were described by N. Ganesh, et al. [33].

2.5. Description of the Taguchi method

Taguchi method: Taguchi‘s parametric design is the operational tool for robust design. The Taguchi’s quality loss function approach was performed to calculate the deviation between the experimental values and the optimal values. This function is further regenerated into a Signal-to-Noise (S/N) ratio and the parameters are evaluated based on the S/N ratio. It proposes and organizes qualitative ideal design to a comparatively low cost. The Taguchi method of offline (Engineering) quality control encompasses all stages of product/process development. Taguchi developed a method based on orthogonal array experiments, which reduced "variance" for the experiment with "optimum settings" of control parameters. Hence, the optimal results can be achieved by implementing the combination of Design of Experiments (DOE) with optimization of control parameters. Signal-to-noise (S/N) ratio and orthogonal array are two major tools used in robust design. Signal to noise ratio, which is log functions of desired output measures quality with emphasis on variation, and orthogonal arrays, provide a set of well balanced experiments to accommodate many design factors at the same time. However the key component for attaining great value at low cost is Design of Experiments. Generally, the steps applied for Taguchi optimization are as following:

↔ Select parameters and their levels;

↔ Select Taguchi orthogonal array;

↔ Conduct experiments and measure the response to optimize;

↔ Analyze results by using Signal-to-Noise ratio;

↔ Identify optimum levels of parameters;

↔ Confirm the effectiveness of optimization with a confirmation test.

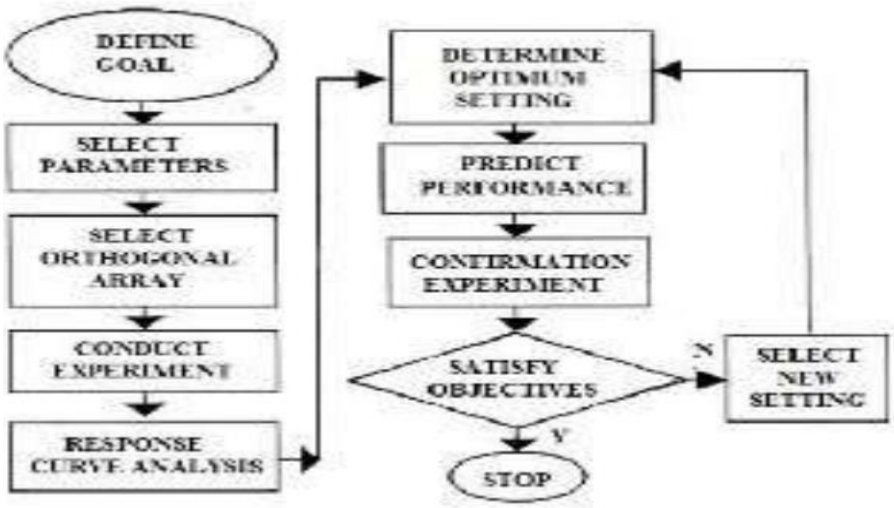


Figure 2.4 Flow chart of Taguchi Method [12]

Several studies proposed optimization of cutting parameters for surface roughness and other cutting performance. The Taguchi method, is based on the statistical design of experimental tests that can economically satisfy the process for optimizing the manufacture of a part. One of the advantages of this method is that several factors are considered at once, including the noise factors. This method is a powerful tool, but needs to be combined with other statistical tools, such as analysis of variance (ANOVA), principal component analysis (PCA), or relational analysis, Lin to extend the results of the Taguchi. Some authors have studied the machining process by associating the Taguchi method to optimize the most common controllable parameters like cutting speed, feed rate and depth of cutting. The goal on all these works is to reduce surface roughness by applying the Taguchi-based method and determine the machining parameters which have the most important contribution for the surface finishing. However, there are some parameters that weren’t accounted, such as temperature, tool nose radius, vibrations and tool wear by Ross [34].

Taguchi Optimization technique pair with relational analysis has been adopted for evaluating parametric complex to carry out acceptable surface roughness lower is better of the material EN-8 steel during turning on a 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. Cutting speed and depth of cut is found to be insignificant during ANOVA study was analyzed Ankit Dogra, Hartaj Singh, Vishal Singh, Sunil Kumar [35].

an experiment consist of eighteen combination on an engine lathe using tungsten carbide with the grade of P- 10 for the machining of S45C steel bars. The cutting parameters that have been selected are cutting speed, feed rate and depth of cut with the response variable, tool life and surface roughness. Result show that cutting speed and feed rate are the significant cutting parameters for affecting tool life, while the change of the depth of cut in the range has an insignificant effect on tool life. For surface roughness, all the cutting parameters have the significant effect. The confirmation experiments then were conducted to verify the optimal cutting parameters. The improvement of tool life and surface roughness from the initial cutting parameters to the optimal cutting parameters is about 250% carried out by W.H Yang and Y.S Tang [36].

In Taguchi Method TiN Coated AISI 1030 Greater insert radius (1.2mm), low feed rate (0.15 mm/rev) and low depth of cut (0.5 mm) leads to better surface roughness. The surface roughness improves to about 335% form initial cutting parameters to the optimal cutting parameters used by M. Nalbant et al. [37]. By Taguchi Method for Carbide EN-8 to reveal that the feed has the variable effect on surface roughness. It is interesting to note that spindle speed, feed rate and depth of cut for Material Removal Rate have increasing trend used by Hardeep Singh et al. [38].

2.6. Taguchi Techniques for Design of Experiments (DOE)

To carry out the experiments, Design of Experiments (DOE) techniques have been used to predict the surface quality in advance and to select the optimal dry turning conditions. The adequacy of the models has been tested through the analysis of variance (ANOVA).Taguchi DOE is a class of factor-monitoring methods to resolve the importance of each factor contributing to the process. It identifies the most dominant parameters and the values that generate the preferred output without formulating a model. DOE was originally used for manufacturing quality applications. It has now expanded to many other areas where performance characteristics are of interest.

2.7. Analysis of variance (ANOVA)

The purpose of the analysis of variance is to investigate which cutting parameters significantly affect the surface quality characteristics. ANOVA was performed using the S/N ratios as the response. Since there are a great number of variables governing the process, some mathematical simulations are required to represent the process. However, these models are to be developed using only the significant parameters influencing the process rather than including all the parameters. In order to achieve this, statistical analysis of the experimental results will have to be processed using the analysis of variance. ANOVA is a computational method that allows the estimation of the comparative assistances of each of the control aspects to the overall calculated response. ANOVA can be beneficial for defining effect of any given input constraint from a series of experimental outcomes by design of experiments for machining process and it can be used to translate experimental data. ANOVA was conducted on the collected data to investigate the main effect of cutting speed (v), feed rate (f) and depth of cut (t). ANOVA with Coated Carbide AISI 1045 revealed that feed is the most significant factor influencing the surface roughness used by M.Y. Noordin et al. [39].

Design of experiments to study the effect of turning parameters such as cooling condition, cutting speed, feed rate and depth of cut on arithmetic average roughness (Ra) and average maximum height of the profile (Rz) by turning of AISI 1050 steel. The mathematical model for surface roughness is created using response surface methodology and concluded that feed is the most effective parameter on the surface roughness Murat Sarıkaya et. al. [40].

the prediction model for surface roughness in turning operation. The regression model was developed by a single cutting parameter and vibrations along three axes were chosen for in-process surface roughness prediction system. By using multiple regression and Analysis of Variance (ANOVA) a strong linear relationship among the parameters (feed rate and vibration measured in three axes) and the response (surface roughness) was found. The authors demonstrated that spindle speed and depth of cut might not necessarily have to be fixed for an effective surface roughness prediction model developed by Kirby et al.[41].

2.8. Summary of literature review

A lot of work has been done in finding out optimum values of cutting parameters which provide best surface finish while turning of hard materials, but still there are various materials on which the same work has not been performed. From the above literature review it clearly shows that most of the researchers have taken input parameters speed, feed and depth of cut, while some have taken turning environment, tool tip temperature,machining time, tool length, tool vibration, nose radius, lubricant etc. to find out its impact on the performance parameters like surface roughness, MRR, tool wear and tool life.

Surface Roughness:- from various researchers’ conclusion the most significant or sound factors for good surface finish are feed and depth of cut followed by speed. Also nose radius has significant effect in obtaining better finish.

Table 2.1 :Some Summary of Literature Review

S/N	Author name	Operation and machine used	Materials used	Optimization techniques used	Input Parameter	Response variable	Results/Significant Parameters
1	B.Kumaragurubaran et.al	Turning , CNC lathe	EN9 steel	Taguchi Design of Experiment	Feed Rate and Depth of Cut	Surface Finish	Feed rate
2	Abhang L.B. and Hameedullah M.	CNC Lathe	EN31	S/N, ANOVA	Feed Rate and Depth of Cut	Surface roughness	Depth of cut
3	Prof. P.D. Kamble et al	CNC Lathe	EN8	Taguchi DOE	CuttingCondition, Speed, Feed, Depth of Nose Radius.	Surface Roughness, MRR	Spindle Speed
4	Paul B. K. M. et al.	Turning	AISI 4340	Taguchi DOE	Feed Rate and Depth of Cut	Surface roughness	Feed rate
5	Choudhary I.A. et al	Turning	EN24T	Response surface methodology, Surface roughness	Feed Rate and Depth of Cut	Surface roughness	Depth of cut
6	Asilturk Ilhan et.al	Turning	AISI 4140	Taguchi Method	Feed rate and Depth of Cut	Surface roughness	Feed rate
7	M. Nalbant et.al	Turning	AISI 1030	Taguchi, S/N,ANOVA	insert radius, feed rate, and depth of cut	Surface roughness	Feed rate, insert radius
8	H. Singh	Ordinary lathe	EN8	Taguchi method	Spindle speed, feed rate and depth of cut.	Surface roughness	Spindle speed
9	D. Singh	Ordinary lathe	EN8	Taguchi method	Spindle speed, feed rate and depth of cut.	Surface roughness	Feed rate
10	Kirby et.al	Turning	S45C	ANOVA	Cutting speed, feed rate and depth of cut.	Surface roughness	Feed rate
11	Dr. C. J. Rao	CNC Lathe	AISI 1050	ANOVA	Cutting speed, feed rate and depth of cut.	Cutting force and surface roughness	Feed rate
12	M.KALADHAR	Turning	AISI 202	ANOVA	Spindle speed, nose radius and feed rate	Surface roughness	Feed rate and nose radius
13	N.Ganesh et.al	CNC Lathe	EN8	Taguchi method	Spindle speed, feed rate and depth of cut	Machining time and surface roughness	Feed rate
14	Hardeep	CNC Lathe	EN8	Taguchi	Spindle speed, feed rate and	Surface roughness	

	Singh et al			method	depth of cut		Feed rate
15	Suresh et al	Turning	AISI 1030	Response surface methodology	Cutting speed, feed rate and depth of cut	Tool wear, machining time and surface roughness	Cutting speed
16	Ashvin J et al.	Turning	AISI 410	Response surface methodology	Nose radius feed rate and depth of cut	Surface roughness	Feed rate
17	Choudhury and EL-Baradie	Taguchi method	EN2T	Response surface methodology	,cutting speed feed rate and depth of cut	Surface roughness	Feed rate
18	Hardeep Singh et al.(2013)	Turning, Centre lathe	EN9	Force Components, Mean plot	Spindle Speed, Feed Rate, Depth	Temperature Workpiece	Feed

2.9. Research Gap

In this review paper, a survey on critical controllable turning parameters for the lathe machines like cutting speed, feed ,depth of cut, tool geometry, tool and workpiece material (different carbon steel EN or AISI grades, which are listed in literature reviews above), which affect the desired output like, surface finish , tool wear,tool life and performance are studied. Improper selection of machining parameters causes cutting tool to wear and break quickly as well as economic losses such as a damaged workpiece and rejected product quality. In this experiment, its intended to pay attention on the effect produced by primary cutting parameters (cutting speed, feed rate and depth of cut) on AISI 1055 of 070M55 (EN9) 0.55% medium Carbon Steel (S55C) in dry turning operation. On this material type and grade, enough a similar review was not found to be published before under this cutting condition.

Description: EN-9 has 0.5%-0.6% carbon steel giving higher tensile strength than EN8. EN-9 is a very popular grade of through hardening medium carbon steel, which is readily machinable in any condition. It can be further surface-hardened typically to 50-55HRC by induction processes, producing components with enhanced wear resistance. It is also available in a freemachining version and heat treated forms possesses good homogenous metallurgical structures, giving consistent machining properties. Though it sits on the border between medium to high carbon content, it does not suffer from the same brittleness that higher carbon materials contain. The expense to create this steel type is also low to moderate which makes it a perfect choice for those on a budget. It possess good machining as well as wear resistance.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Design of the experimentation

In the next section, the material selection, cutting tools and machine-tool used are first described. Then, the design of experiments when using Taguchi design of experiment is introduced, research design and finally, the measurement of surface roughness is developed.

3.2. Material selected for study

3.2.1. Material selected

In this study, the workpieces of AISI 1055 or EN-9 Steel in the form of round bar with 40mm in diameter, 300mm in length and hardness of (48HRC) was chosen for turning operation. EN-9, also known as 070m55, with a carbon content of 0.47-0.55. This is a medium carbon steel which can develop high tensile strength. In the normalized condition, EN-9 can be used for gears, sprockets and cams. This type of steel is chosen due to its high machinability and widely employed in industry due to its readily dry-machined (without using cutting fluid) and the possibility of working at high speeds with high performance at the same time. This material has good wear and corrosion resistance. This bar was machined under dry condition. Dry machining is more popular in manufacturing as a means of reducing overhead costs and protecting the environment. It has great significance for the factors of both economics and the environment. [42]

Range of steel from steel key for chemical composition of medium carbon steel

Percent	C	Si	Mn	P	S
Min %-Max%	0.47-0.55	0.15-0.40	0.50-0.8	0.05	0.05

(Source: Metec steel key document)

Material chemical composition of EN-9

Table 3.1: Material chemical composition [41]

percents	C	Si	Mn	P	S
Min %	0.50	0.10	0.50		
Max%	0.60	0.40	0.90	0.050	0.050

Material mechanical Properties

Table 3.2: Material mechanical properties [41]

	UTS (N/mm²)	Yield (N/mm²)	Hardness HB
Normalised test piece(min)	0.50	0.10	0.50
Normalised test piece(max)	0.60	0.40	0.90

The machinability of a material is difficult to quantify, but can be said to posses the following characteristics;

- Results in a better surface finish
- Promotes long tool life
- Requires low force and power to turn
- Provides easy collection of chips

Round bar for turning

Figure 3.1 Shape of turning material

Surface roughness test specimens: Surface roughness test was carried out on the prepared specimen that cut into nine equal pieces that turned based on the orthogonal array as shown in the Figure 3.2.

Figure 3.2 Specimen for testing

3.2.2. Single point Cutting tools

Cutting tool separates chips from the workpiece to obtain the desired shape and size. There are a great variety of metal cutting tools, each of which is designed to perform a particular job or a group of metal cutting operations in an efficient manner. A single point turning tool is used to turn a variety of cylindrical shapes on the lathe machine.

In order to remove chips from work apiece the following conditions must be present:

1. The cutting tool must be harder than the metal to be cut;
2. The cutting tool must be shaped so that its cutting edge can penetrate the work piece;
3. The tool should be strong and rigid enough to resist cutting forces and
4. There must be a relative rotation of the spindle with a workpiece and longitudinal (crosswise) motion of the cutting tool relative to the workpiece in order to make cutting action possible.

All cutting tool wear as a result of the stresses and temperature encountered in the cutting process to remove separated chips from the workpiece. The rate- of- wear must be controlled by the applications of correct cutting speed and feed rates. The tool signatures are shown in the Figure 3.3.

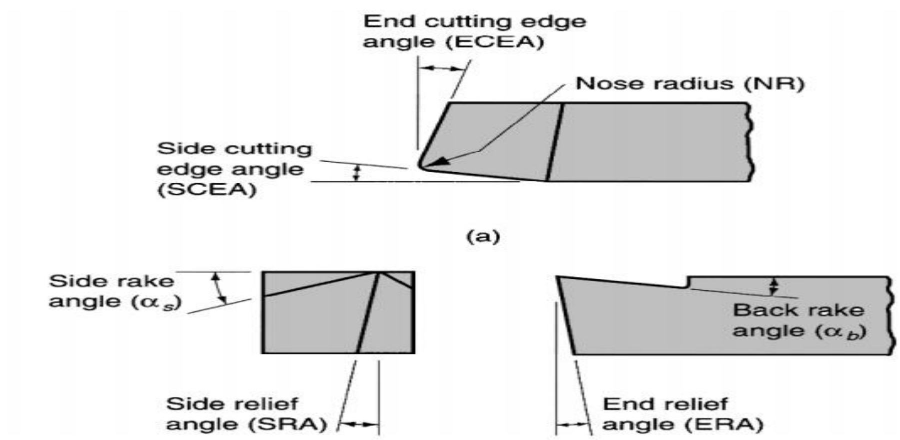


Figure 3.3 Tool signature [42]

A single-point tool is a cutting tool having one cutting part (or chips producing element and one shank as it commonly used in a lathe). The most features are the cutting edges and adjacent surfaces. They are defined as follows;

1. The face is the surface or surface over which the chips flows.
2. The flank is tool surface or surface over which the surface the surface produced on the workpiece passes.
3. The cutting edge is the edge of the surface which is intended to perform cutting and
4. The corner is a relatively small portion of cutting edge at the junction of the major and minor cutting edges; it might be curved or straight.

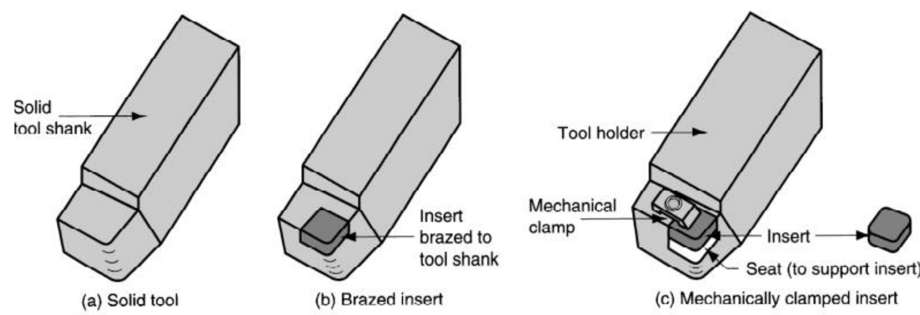


Figure 3.4 Three ways of holding and presenting cutting tool edge for a single- point tool [42]

3.2.3. Turning machine used

Turning machines typically referred to as lathes, can be found in a variety of sizes and designs. While most lathes are horizontal turning machines, vertical machines are sometimes used, typically for large diameter work pieces. Turning machines can also be classified by the type of control that is offered. A manual lathe requires the operator to control the motion of the cutting tool during the turning operation. Turning machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) lathe.

Fig 3.5 Lathe machine and experimental setup [48]

CNC lathes rotate the work piece and move the cutting tool based on commands that are preprogrammed and offer very high precision. In the present study, turning operation is conducted on a lathe machine model of PSG A141 which is manually controlled while operating, with three jaws and a range of spindle speed from 11rpm to 2000rpm, and 7.5KW motor drive.

3.2.4. Properties of workpiece materials

Chemical composition, hardness, micro structures and metallurgical consistency are known from experience to affect surface finish. For example, in case of steel, carbon content is of great importance. Steels having 0.1% or less carbon content produces built-up edge (BUE) during chip formation and thereby spoil surface finish. The addition of so called free machining elements like sulphur, selenium or lead helps this tendency. Very low hardness or ductility is not conductive to a good finish because of the tendency of tool to dig into a material having such properties. On the other hand, high hardness and strength and low ductility (and high strain hardenability) result in good surface finish. [43]

Medium-carbon steel: Generally contains between 0.31% and 0.6% carbon, and 0.06% to 1.65% manganese. Stronger than low-carbon steel, but harder to weld, form, or cut. Often hardened and tempered via heat treatment. Having these in considerations, an appropriate selection was carried out for this research. So, the work material for this research is medium carbon steel bar as shown in fig 3.1. [43]

3.2.5. Cutting tool materials

The study mainly focused on the cutting tools which affect the materials to be cut. The proper selection of cutting tools was justified by extensive use of such tools in machining products due to various rake and wide range of chip- breaking grooves. One advance in cutting tool materials involves the application of a very thin coating (~10μm), which is the toughest. The coating may consist of one or more thin layers of wear-resistant material, such as titanium carbide (Tic), titanium nitride (Tin), aluminum oxide (Al_2O_3), tungsten, and/or other, more advanced materials. The coating allows increasing significantly the cutting speed for the same tool life. Cutting tools must simultaneously withstand big mechanical loads and high temperatures. Temperature in the chip-tool interface reaches more than 700°C in some cases. Additionally, the friction between tool and removed chip, on one hand, and tool against the new machined surface, on the other, is very severe. Bearing this in mind, the main factors for a good tool design and post-manufacturing are:

- Cutting-tool substrate material must be very stable chemically and physically at high temperatures.
- Material hardness must be kept in the high temperatures suffered at the chip/tool interface.
- Tool material has to present a low wear ratio, both for the abrasion and adhesion mechanisms.
- Tool material must present enough toughness to avoid fracture, especially when operation to perform implies interrupted or intermittent cutting.

In the following sections, each of the main tool material is going to be described:

High speed steel (HSS): This crew of high-alloyed steels used to be advanced at the early years of the 20th century. Basically those are high-content carbon steels with a excessive proportion of alloy elements certain as tungsten, molybdenum, chromium, vanadium or cobalt. The cobalt component gives the material a hot hardness value much greater than carbon steels. The high toughness and excellent wear resistance make HSS suitable for all kind of cutting tools with complex shapes for relatively low to medium cutting speeds. The alloys of HSS cutting tool as shown in the table3.3 .

Table 3.3:Cutting tool materials – HSS alloying [44]

Element	Properties
Tungsten	Increases hot hardness, Hard carbides formed, improving abrasion resistance.
Molybdenum	Increases hot hardness, Hard carbides formed, improving abrasion resistance.
Chromium	Depth hardens ability during heat treat Hard carbides formed, improving abrasion resistance and some corrosion resistance.
Vanadium	Combines with carbon for wear resistance Retards grain growth for better toughness.
Cobalt	Increases hot hardness, toughness.
Carbon	Hardening element, Forms carbides.

The T series includes tungsten, the M series molybdenum, whereas vanadium produces the hardest of the carbides giving rise to the super-high-speed steels. The maximum working temperature of HSS is about 500°C. Currently, HSS produced by powder metallurgy (HSS-PM) offers a higher content of alloy elements and a combination of unique properties: higher toughness, higher wear resistance, higher hardness and higher hot hardness.

Sintered Carbide (Hard metal): Sintered carbide tools, also known as hard metal tools or cemented carbide tools are made by a mixture of tungsten carbide micro grains with cobalt at high temperature and pressure. Tantalum, titanium or vanadium carbides can be also mixed in small proportions. Carbide grade with low cobalt content can be used to higher speed and feed rate because of increased resistance to deformation. Most carbide tools in use today are either straight or multi-carbide of W-Ti or W-Ti-Ta, depending on the work materials to be machined. Cobalt is binder. These tool materials are much harder, more chemical stable, have better hot hardness, high stiffness and lower friction, and operate at higher cutting speed than HSS. Cemented carbide tools are available in inserted form in many different shapes.

Tungsten carbide is very stable regarding chemical and thermal aspects of machining, and is very hard as well. In most cases, cemented carbide degradation starts from the cobalt binder and the tungsten carbide–cobalt cohesion. A tool material derived from hard metal is the cermets (ceramic–metal) type, sintered tungsten carbide also including Tic (carbide with hardness 3200HV).

Ceramics: are very hard and refractory materials, withstanding more than 1500 °C without chemical decomposition. These features recommend them to be used for the machining of metals at high cutting speeds and in dry machining conditions. Unfortunately they are fragile, and ceramics without any reinforcement are only indicated for turning of continuous shapes. In milling the continuous impact at each tooth entrance in the machined part implies a high risk of chipping and tool failure. Ceramic materials are molded from ceramic powders at pressures more than 25MPa, to be later on sintered at approximately 1700°C.Ceramic tools are based primarily on alumina (Al_2O_3), silicon nitride (Si_3N_4)and Si Al O N (a combination of Si, Al, O and N). The material of the tool is chosen based upon a number of factors, including the material of the work piece, cost, and tool life. Tool life is an important characteristic that is considered when selecting a tool, as it greatly affects the manufacturing costs. A short tool life will not only require additional tools to be purchased, but will also require time to change the tool each time it becomes too worn.[44]

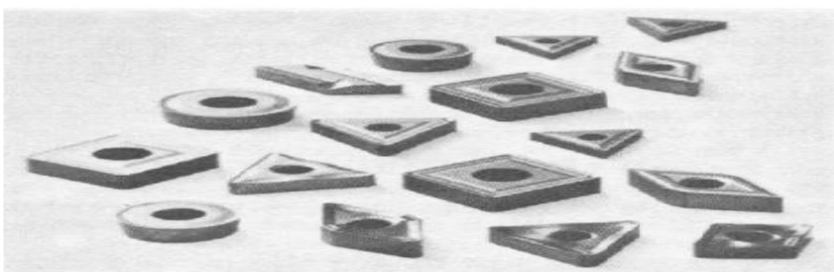


Figure 3.5 Different shapes of turning tool [44]

For the present study, the cutting tool used for this research was Cemented carbide (inserted) with a right hand, due to harder, have better hot hardness, High stiffness and lower friction which serves for a single-point cutting tool as shown in the figure 3.6.

Figure 3.6 Single point cutting tool

3.2.6. Tool Geometry

It is obvious that a larger nose radius leads to better surface finish. Additionally, it has been observed that an increase in the rake angle improves surface finish significantly. The tool geometry that will cause chips to be lifted upwards and out from the finished surface and constantly thrown clear of the cutter. Tool geometry has different influences on the surface roughness estimate. Tool nose radius has a significant effect on the surface roughness. Small tool nose radius is the preferred conditions for the prevalence of plastic side flow. Tool nose radius dependent plastic side flow become significant factors affecting the surface finish. On the other side, better surface roughness achieved with an increase of plastic side flow induced by tool nose radius can be counteracted or even surpassed by the decreasing of cutting edge radius dependent elastic recovery and minimal undeformed chip thickness. Figure3.7 shows the basic geometry for turning operation.

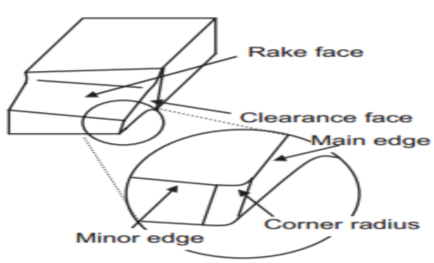


Figure 3.7 Basic geometry for turning [42]

Tool geometries are competitors influencing the surface formation, which indicates a conservation law exists in turned surface roughness. An accurate configuration of process parameters or reasonable selection of tool geometries will enable the surface roughness to be conserved. It reveals that surface roughness decreases with increasing tool nose radius. Good surface finish can be obtained for a higher tool nose radius.

Finally, the nose radius is ground into a tool to provide for a smooth machined surface of the workpiece. The purpose of the nose radius is to eliminate the threadlike groove that would be produced by the sharply pointed tool. Without a nose radius, a threadlike groove would be formed in the workpiece in the winding helical shape as a result of relative motion between the tool and work piece. The parts of tool geometry are discussed as followed;

- **Shank:** Main body of tool, it is part of the tool which is gripped in the tool holder.
- **Face:** Top surface of tool between shank and point of tool. Chips flow along this surface.
- **Flank:** Portion tool which faces the work. It is surface adjacent to & below the cutting edge when tool lies in a horizontal position.
- **Point:** Wedge shaped portion where face & flank of the tool meet.
- **Base:** Bearing surface of tool on which it is held in a tool holder.
- **Nose radius:** Cutting tip, which carries a sharp cutting point. Nose provided with radius to enable greater strength, increase tool life & surface life.
- Typical Value: 0.4mm – 2.5mm. [45]
- So, the tool radius used for this purpose is 2.3mm.

3.2.7. Cutting performance measure

The tool life is defined as the elapsed period of cutting time when the average flank wear land (V_B) which is a type of wear is placed on the flank (relief) face Wear land formation is not always uniform along the major and minor cutting edges of the tool. It is more common in the case of hard materials where no chemical affinity between tool and material exist, abrasion being the main wear mechanism of the tool is equal to 0.3mm or the maximum flank wear land $(V_B)_{max}$ is equal to 0.6mm. This tool life criterion is recommended by the International Standard Organization (ISO). [46]

The machined surface roughness was measured by profile meter (profilometer).The average surface roughness R_a, which is the most widely used surface finish parameter in industry, was selected for this study, being the arithmetic average of the absolute value of the heights of roughness irregularities from the mean value.

3.2.8. Recommended cutting parameters

Table 3.4 : Recommended cutting parameters (cutting conditions) for turning [31]

Work Material			Recommended Cutting Condition and Grades			
			Depth of cut (mm)	**Feed rate (mm/rev)**	**coolant**	**Recommended Spindle Speed and Grades**
Mild Steel	≤ 160 HB	Light cutting	≤ 0.1	≤ 0.3	Dry	**NX3035 290(235-335)**
		Medium cutting	1-6	0.4 (0.2-0.6)	Dry	**UE6110 350(260-440)**
		Semi-heavy cutting	4-9	0.6 (0.5-0.8)	Dry	**UE6110 350(260-440)**
Carbon Steel	160-280 HB	Light cutting	≤ 0.1	≤ 0.3	Dry	**UE6110 280(210-355)**
		Medium cutting	1-6	0.4 (0.2-0.6)	Dry	**UE6110 260(190-325)**
		Semi-heavy cutting	4-9	0.6 (0.5-0.8)	Dry	**UE6110 250(180-310)**
	280-	Light cutting	≤0.1	≤0.3	Water Soluble oil	**UE6110 180(120-230)**

Alloy Steel	350	Medium cutting	1-4	0.3 (0.2-0.4)	Water Soluble oil	**UE6110 170(120-210)**

3.3. Methods used for this study

3.3.1. Experimental procedure

The workpiece of carbon steel was chosen for this experiment on the lathe machine of model of PSG A141 with power of 7.5KW with spindle speed range of 11rpm to 2000rpm. This workpiece, with a dimension of 40x300mm (300mm length and 40mm in diameter) was prepared. A 30mm length of workpiece was gripped (clamped) in the chuck and rough turning turning was carried up to length of 270mm. Cleaning the samples of a surface contaminations, such as dust, grease, or any other soluble organic particles, so that there will be no adverse effect on the results. The work material was centered and cleaned by removing a 2mm depth of cut from the outside surface to remove rust (outer corroded layer), prior to the actual machining process. One end of the workpiece is held in a chuck and the other end is supported by a tail stock. The cutting tool overhang is limited to (25mm, 30mm, 35mm) at an average length so as to reduce vibration of tool post. The levels were selected in order to cover the normal range of lathe cutting operations for carbon steel. In order to minimize the effect of tool wear, which could affect the surface roughness quality, the tool was changed after 4 cuts. The newly tool installed was run for a few machining times to eliminate rapid tool wear. After turning operation finished, the specimen was cut into nine equal distances, by 30mm with different cutting parameters and at different levels so as to make easy for measurement by profilometer.

For a probe movement of 30mm**,** surface roughness readings (every test condition) were recorded at least three times at different new locations on a turned round bar surface in order to ensure the repeatability and reproducibility of the results as well as obtain accurate value and the average value was used for analysis. Finally, surface roughness Ra, was measured to select the optimum values of cutting parameters by using signal-to-ratio.

Figure 3.8, explains the experimental scheme for optimizing the surface roughness in turning operation. Initially, perform the basic turning operation on work piece with different cutting parameters, then measure surface roughness with the help of surface measurement device i.e. Profilometer.

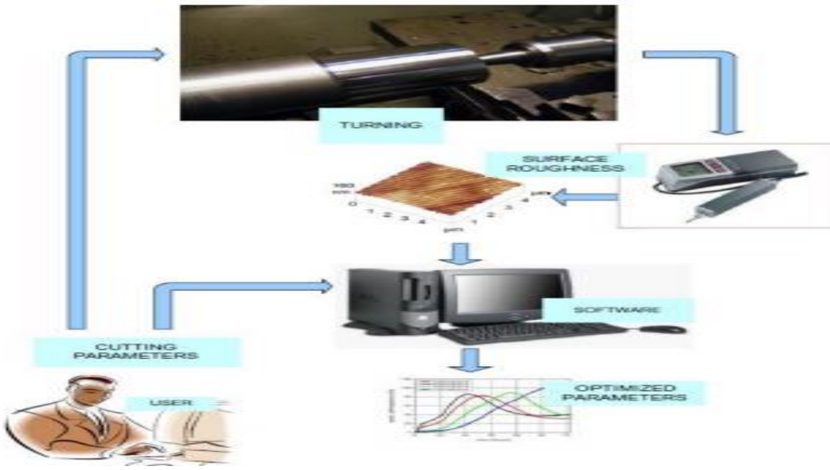


Figure 3.8 Experimental scheme [8]

3.3.2. Cutting condition

Dry cutting environment was used for an experimentation process. Dry cutting process is one that uses no coolant during machining. By the use of dry cutting, cost of cutting fluid was alleviated. Cutting fluids have corrosive effects and non environment friendly. Dry cutting reduces machining cost and is environment friendly. Also, inserts perform better at higher cutting temperatures achieved during dry cutting.

3.3.3. Research design

1. lathe Setup and parameter to be tested. Assigning and setting up cutting parameters were as follows;

a. Cutting speed, m/min: 31, 33 and 35.

b. Feed rate, mm/min: 0.2, 0.4 and 0.6

c. Depth of cut, mm: 0.5, 1.5 and 2.5.

2. Preparation of specimens; S55C.

3. Machining was performed by varying cutting speed, feed rate and depth of cut, keeping other variables constant.

4. Measuring (testing) surface roughness of the specimen resulting from the process, and recording the test results.

5. Result analysis and discussion.

3.3.4. Hardness Test Specimens

Hardness test was carried out at room temperature using ASTM 384 standard Vickers hardness tester with at least three indentations of specimen and then the average values were utilized to calculate hardness number. The Specimen was polished with 400, 800, and 1200 grit emery paper followed by dry polishing in polishing machine to get fine surface before testing their hardness. The hardness test is conducted through Vickers hardness tester having a microscope of magnification 125X and 250X. Load used on Vickers hardness tester 98.07 Kgf (10N) at dwell time of 15 seconds for each specimen. The diagonal length was more closely measured, taking measurements between 0.3-0.5mm. After the diagonal length measurement, the values of the Vickers hardness were calculated by the following equation:

$$VH = \frac{0.102 * 2F[\sin\frac{136^{o}}{2}]}{d^2} \qquad (3.2)$$

where VH is the Vickers hardness of specimens; F is the applied load (kgf) and d is the arithmetic mean of the two diagonals, $d_1$and d_2 (mm).

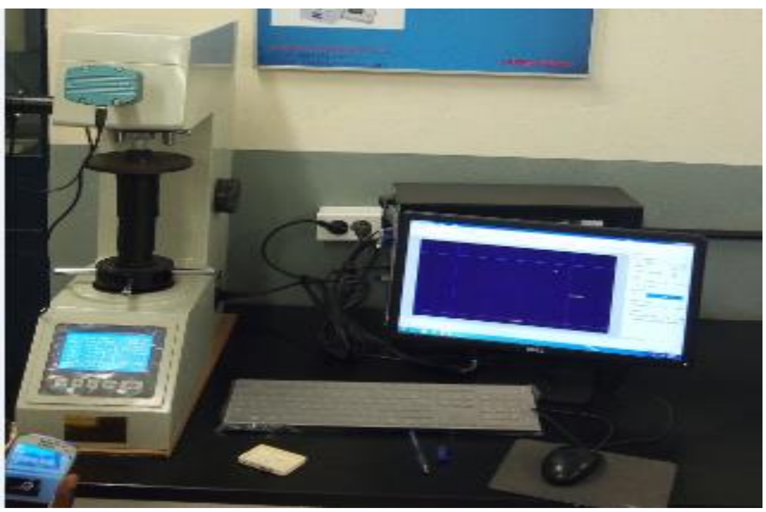


Figure 3.9 Vickers hardness testing setup [24]

3.3.5. Some of the factors to be considered when specifying speed, depth of cut and feed

1. The type and amount of materials being cut;
2. Surface finish required;
3. Rigidity of the workpiece and the cutting tool, and setup;
4. Characteristic (properties) of materials.

5. Hardness and shape of part;
6. power available on the machine tool;
7. Shape of required workpiece and
8. Required stock removal;

The experimental study was to find a better surface finish or minimum surface roughness by optimizing cutting parameters (depth of cut, feed rate and cutting speed), which were playing vital attributes to the desired surface finish quality of the product.

Cutting speed (V_C) - it is relative velocity between workpiece and cutting edge of tool responsible for cutting action. Important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is determined by:

$$V=\frac{\pi D n}{1000} \quad [19] \qquad 3.3$$

From the above equation, the spindle speed of machine is calculated as;

$$n = \frac{1000V}{\pi D} \qquad 3.4$$

Where D is- the external diameter of the workpiece in (mm) and n is the number of revolutions per minute (rpm); V- is taken from table 3.4 or reference [31].

Depth of cut (t) - It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. it is a normal distance between machined and un machined surfaces measured along a normal to machined surface.

Feed rate (f) - it is the longitudinal (cross or traverse) motion of the cutting tool per one revolution of the workpiece, measured in mm/revolution. [47]

3.3.6. Selection of the cutting parameters and their levels

The cutting experiments were carried out on a lathe using Cemented carbide (inserted) for machining of 070M55 (EN9) 0.55% Medium Carbon Steel due to good machinability. The initial cutting parameters were as follows: cutting speed (35m/min, 33m/min, and 31m/min), feed rate (0.2mm/rev, 0.4mm/rev, and0.6mm/rev) and depth of cut (0.5mm, 1.5mm, and 2.5mm).

Table3.5: Machining condition and their Levels

Machining conditions	Units	Level 1	Level 2	Level 3
Cutting speed	(m/min)	31	33	35
Feed rate	(mm/rev)	0.2	0.4	0.6
Depth of cut (DOC)	(mm)	0.5	1.5	2.5

3.3.7. Design of Experiment

In the design of experiment (DOE) Taguchi method is commonly used because it is a problem–solving tool which can improve the performance of the product, process design and system. Design of experiment is a technique of defining and investigating all possible conditions involving multiple factors, parameters and variables in an experiment. To observe the most influential process parameters in the surface roughness namely cutting speed, feed rate and depth of cut at three levels were considered in case of this study with this method.

3.3.8. Selection of OA and Column Assignment

The selection of a particular orthogonal array was based on the number of levels of various factors. Here, to conduct the experiments 3 factors each at 3 levels were selected. Now the Degree of Freedom (DOF) of turning operation can be calculated by the formula as given below.

$$DOF = P*(L-1) \qquad 3.5$$

where,

P = number of factors

L = number of levels

DOF)= 3(3 – 1) ≈ L_9.

However, total number of experiment of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus L_9 orthogonal array was selected to make the further experiments were shown in Table 3.7.

Table 3.6 : Column assignments of L9 OA

Trail No	**Cutting speed (A)**	**Feed rate (B)**	**Depth of cut (C)**
1	31	0.2	0.5
2	31	0.4	1.5
3	31	0.6	2.5
4	33	0.2	1.5
5	33	0.4	2.5

6	33	0.6	0.5
7	35	0.2	2.5
8	35	0.4	0.5
9	35	0.6	1.5

Data Analysis and Optimal setting: The optimal setting of factors is obtained by constructing main effect. The data obtained is analyzed by raw data of the S/N data (Signal to Noise Ratio) and ANOVA. For S/N data analysis, the conversion of raw data to S/N data is based on the smaller the better type of quality characteristic as Surface roughness for intended for use is smaller the better type of characteristic. Nine different composite were manufactured with different parameters and at different levels. In the Taguchi method the response variation was studied using signal-to-noise ratio and minimization of the variations due to controllable parameter. The smaller the better S/N ratio used for these responses:

3.3.9. Confirmatory Experiment

Taguchi suggested that if the optimal setting is not among the trials of the experiments, then confirmatory experiment should be done to verify the results. A confirmatory experiment is done considering the predicted optimal setting of the factors to verify the results.

Surface roughness of a material after turning is measured using surface roughness tester. Surface roughness is an important criteria to find the quality of a surface. It is an important response parameter. Surface finish can be measured using simple surface roughness tester

The stylus probe instruments currently in use for surface finish measurement incase this study is Profilometer. Profilometer is an indicating and recording instrument used to measure roughness in microns. It consists of two principal units: a tracer and an amplifier. Tracer is a finely pointed stylus. It is mounted in the pickup unit which consists of an induction coil located in the field of a permanent magnet. [48].

Figure 3.10 Profilometer

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Introduction

After completing the machining operation, the response parameter that is surface roughness was measured. Statistical analysis was performed on the optimum result obtained for attaining main effects. The main effect of a factor may be described as the average change in the response generated by a change in the level of factor studied. The response values resulting from experimental work carried out by orthogonal array are analyzed using Taguchi technique. This step determines the effect of various process parameters to achieve desired surface roughness.

4.2. Taguchi Design of Experiments

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array experiments gives much reduced variance for the experiment with optimum settings of control parameters. Orthogonal array designs focus primarily on main effects. These design can be used to estimate main effects using an experimental runs. Orthogonal Arrays (OA) provide a set of well balanced (minimum) experiments and Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results from orthogonal array.

Table 4.1: presents the process parameters selected for optimization and their levels

Machining conditions	Units	Level 1	Level 2	Level 3
Cutting speed	(m/min)	31	33	35
Feed rate	(mm/rev)	0.2	0.4	0.6
Depth of cut	(mm)	0.5	1.5	2.5

4.3. Signal -to-noise (S/N) Ratios

In Taguchi method, response variation is studied with the help of signal-to-noise (S/N) ratio. In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D) for the output characteristic deviating from the desired value. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. Taguchi's technique offers three category of signal to noise ratio.

They are;

- Larger-the- better;
- Medium –the -better and
- Smaller-the-better

- Larger is suitable for determining the profit, production rate, etc.
- Medium or nominal the better is applicable to current.
- Smaller the better is appropriate for tool wear, surface roughness, tire wear, unit cost, etc. This experimental study uses smaller-the better. The aim is to improve the surface roughness by measuring experimental result of the roughness. The signal-to-noise (S/N) ratio used in the surface roughness test was the smaller the better, since it is required to minimized the level of roughness. This category of the S/N ratio is defined as:

$$\eta_i = S/N = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y^2{}_{ij}\right) \quad [36] \qquad 4.1$$

where η_i is S/N ratio in the i-th trial, y_{ij} is the j-th observed value of the response (quality characteristic) in i-th trial, n is the number of individual observations in i-th trial, due to noise factors or repetition of trial. The experimental results of 9 runs were given in table form. The main effect plot of influence of design parameters on surface roughness was given in the graph form.

4.4. Hardness of material

Hardness is the resistance of a material to deformation, indentation or scratching. The basic goal of hardness testing is to quantify the resistance of a material to plastic deformation. The hardness of materials has a significant effect on the surface roughness. Load used during hardiness test was 98.07 N (10kg.f) on three trails on a sample. Average result was taken for HV value of a sample.

Table 4.2: Trails on hardness of sample tests at room temperature of workpiece

Hardness	Trail - 1	Trail - 2	Trail - 3	Average
HV	49.9	48.5	46.9	48.43

4.5. Surface roughness result from experimental

The experiment was conducted on AISI 1055 or EN-9 grade steel bar under dry condition. All the surface tests were conducted at specified cutting parameters as shown in the Figure 4.1.

a) Profilometer before measurement

b) Profilometer under going measurement

Figure 4.1 Profilometer for testing roughness

For each tests, three repetitions were followed and an average value was taken. All the experimental data is tabulated in the Table 4.3.

Table 4.3: Experimental results for mean values of surface roughness

Run	A	B	C	Surface roughness Ra (µm)			Average Ra(µm)
				R_1	R_2	R_3	
1	31	0.2	0.5	2.702	2.472	2.137	2.438
2	31	0.4	1.5	2.191	2.169	2.481	2.280
3	31	0.6	2.5	1.813	1.830	1.839	1.827
4	33	0.2	1.5	1.223	1.462	1.614	1.433
5	33	0.4	2.5	1.289	1.133	1.436	1.286
6	33	0.6	0.5	1.896	1.706	1.717	1.773
7	35	0.2	2.5	0.839	0.836	0.873	0.849
8	35	0.4	0.5	1.104	1.218	1.135	1.152
9	35	0.6	1.5	1.025	1.049	1.311	1.128
	Average performance mean value (m)						**1.574**

Where, R_1, R_2 and R_3 are the repetitions of trial conditions.

Table 4.4: Results from Minitab

↓	C1	C2	C3	C4	C5	C6
	Cutting speed	Feed rate	Depth of cut	Ra	SNRA1	MEAN1
1	31	0.2	0.5	2.438	-7.74067	2.438
2	31	0.4	1.5	2.280	-7.15870	2.280
3	31	0.6	2.5	1.827	-5.23477	1.827
4	33	0.2	1.5	1.433	-3.12492	1.433
5	33	0.4	2.5	1.286	-2.18482	1.286
6	33	0.6	0.5	1.773	-4.97417	1.773
7	35	0.2	2.5	0.849	1.42185	0.849
8	35	0.4	0.5	1.152	-1.22905	1.152
9	35	0.6	1.5	1.128	-1.04618	1.128

The mean value of surface roughness for each factor i.e. Cutting speed (A), Feed rate (B), and depth of cut (C) at each level i.e. level 1, 2 and 3 are obtained and the result is listed in response table 4.5.

Table 4.5: Surface roughness response table for mean

Symbol	Parameter	Mean			Delta	Rank
		Level				
		1	2	3		
A	Cutting speed	2.182	1.497	**1.043**	1.139	1
B	Feed rate	**1.573**	1.573	1.576	0.003	3
C	Depth of cut	1.788	1.614	**1.321**	0.467	2

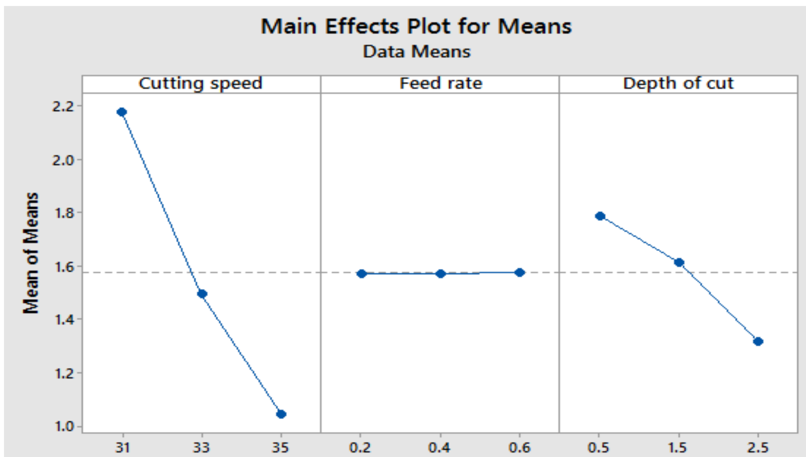


Figure 4.2 main effects plot for means

The control factors main effect plot for means of surface roughness variations is as shown in the Figure 4.2. Delta = (maximum mean – minimum mean). Table 4.5 and Figure 4.2 show that the factor with the greatest effect on the mean is cutting speed weight percentage (Delta 1.139 =, Rank = 1). The factor with the least effect on the mean is feed rate (Delta = 0.003, Rank = 3). Since main effect plots for means is helpful for adjusting the mean on better value. Those parameter levels with better surface roughness of specimens that means **$A_3B_1C_3$** will be taken as a possible parameter combination for better values.

4.6. Predict the Performance at Optimal Levels the mean value

For predicting the optimum response, three factors of parameters were selected by mean value. $A_3B_1C_3$ is the optimum levels of parameters mean value for surface roughness. To find out predicted value of the responses (surface roughness) the following equation is used:

$$Y_{opt} = m + (m_{A3} - m) + (m_{B1} - m) + (m_{C3} - m) \qquad 4.2$$

Where, m = Average performance mean value for surface roughness.

m_{A3} = optimum level value for parameter A

m_{B1}= optimum level value for parameter B

m_{C3}= optimum level value for parameter C

$Y_{opt=}$1.574 +(1.043-1.574)+(1.573-1.574)+(1.321-1.574)= 1.574-0.785

Y_{opt}=0.789 (predict mean value for surface roughness).

4.7. Analysis of S/N Ratios for surface roughness

The Taguchi method uses S/N ratio to measure the variations of the surface roughness in experimental design. The equations for calculating the signal to noise ratios are based on the characteristics of the response variables being evaluated; Smaller the better, nominal the best, larger the better. In the case of this study, the response variables are smaller the better. Therefore, smaller the better characteristic was used and S/N equation for this characteristic is given in equation 4.1. Table 4.6 presents the calculations of S/N Ratios for surface roughness results using the Minitab 17 design of experiments.

Table 4.6: Anlaysis of S/N Ratios for surface roughness

Run	A	B	C	Average Ra(µm)	S/N ratio
1	31	0.2	0.5	2.438	-7.740
2	31	0.4	1.5	2.280	-7.158
3	31	0.6	2.5	1.827	-5.234
4	33	0.2	1.5	1.433	-3.124
5	33	0.4	2.5	1.286	-2.184
6	33	0.6	0.5	1.773	-4.974
7	35	0.2	2.5	0.849	1.421
8	35	0.4	0.5	1.152	-1.229
9	35	0.6	1.5	1.128	-1.046
	Average performance mean value (m)			**1.574**	**-3.474**

After calculating the S/N ratio for each experiment, the average S/N value is calculated for each factor and level as shown in Table 4.7.

Table 4.7: Surface roughness response table for S/N ratio

Symbol	**Parameter**	**Mean**			**Delta**	**Rank**
		Level				
		1	2	3		
A	Cutting speed	-6.711	-3.429	**-0.284**	6.426	1
B	Feed rate	**-3.147**	-3.524	-3.751	0.603	3
C	Depth of cut	-4.648	-3.776	**-1.999**	2.648	2

Delta = (maximum S/N ratio – minimum S/N ratio). By Looking at the Surface roughness table and main effects plot for the signal-to-noise (S/N) ratios, the cutting speed weight percentage have the greatest effect (Delta = 6.426, Rank = 1). The factor with the least effect on S/N ratio is feed rate (Delta=0.603, Rank = 3). Table 4.7 shows that optimal parameter combination on smaller is the better quality character is $\mathbf{A_3B_1C_3}$ are the possible parameter combinations for increasing the of surface roughness specimens. The control factors main effect plot for the surface roughness S/N ratio is shown in the Figure 4.3.

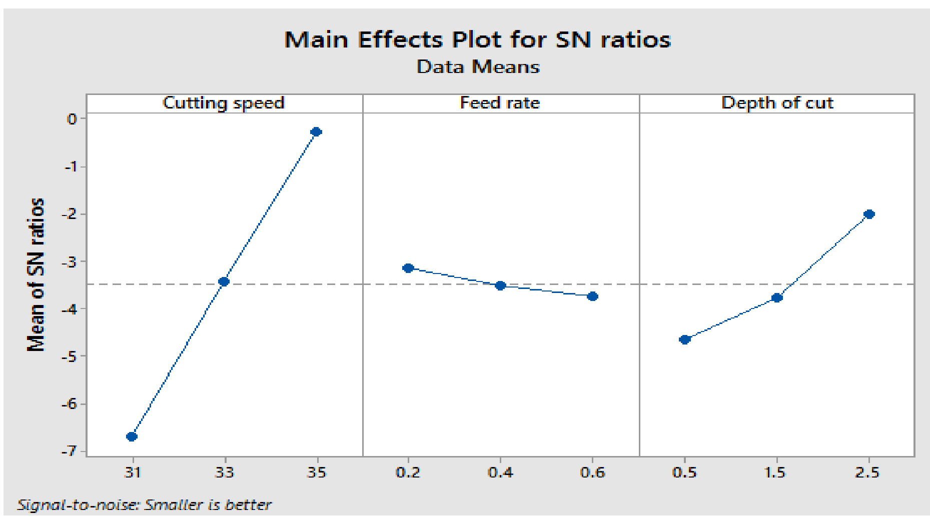


Figure 4.3 Surface roughness main effects plot for S/N ratio

The numerical value of the maximum point in each graph shows the best value of that particular parameter at that level. They also indicate the optimum conditions in the range of the experimental conditions. The most effective parameter to enhance the surface roughness is the cutting speed weight percentage when compared with other cutting factors.

4.8. Predict the Performance at Optimal Levels the S/N Result

For predicting the optimum response approximately, three factors of parameters are selected by low S/N ratio value. $A_3B_1C_3$ is the optimum levels of parameters S/N ratio value forsurface roughness. To find out predicted values of the response (surface roughness) equation 4.3;

$$Yopt = m + (mA_3 - m) + (mB_1 - m) + (mC_3 - m) \qquad 4.3$$

= -3.474+ (-0.284+3.474) + (-3.147+3.474) + (-1.999+3.474) =4.995-3.474

= **1.521dB** (predicted S/N for surface roughness)

4.9. Analysis of variance (ANOVA)

The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affect the quality characteristic. ANOVA establishes the relative significance of factors in terms of their percentage contribution to the response. It is the statistical technique used to find the influence of all control parameters. In the analysis of variance, the percentage contributions of each control factor was used to measure the corresponding effects on the performance characteristics. The significance level of 5%, i.e. for 95 % level of confidence was considered in this analysis. ANOVA results indicate whether there is difference or not in statistically significance on output characteristics. ANOVA analysis involves when α values is below 0.05 is significant and above 0.05 is not significant. From analysis of variance Percentage contribution of each influential parameter was calculated by the following formula:

$$P(\%) = \left(\frac{SSTR - DOF*MSE}{SST}\right) * 100 \qquad 4.4$$

Where,

P: Percentage contribution of individual factor;

SSTR (Adj SS): Sum of squares or treatment sum of squares;

DOF: Degree of freedom;

MSE (Adj SS): Mean square Error;

SST: Total sum of squares.

4.10. Analysis of Variance (ANOVA) for surface roughness

ANOVA results DOF = degree of freedom, SSTR = Sum of squares, MSE = Mean square error and F = F- Ratio calculated by using Minitab 17 software was shown in table 4.8.

Table 4. 8: Analysis of Variance for surface roughness

Source of	DOF	SSTR	MSE	F	P	Percent	Significance

variation						contribution	(α = 0.05)
A	2	1.971	0.985	40.67	0.024	83.78%	Significant
B	2	0.01	0.001	0.02	1.00	0.003%	Insignificant
C	2	0.334	0.167	6.90	0.127	14.19%	Insignificant
Error	2	0.048	0.024			2.03%	
Total	8	2.353				100%	

Table 4.8 presents surface roughness percentage contribution variation of factors A, B, and C; where factors represents cutting speed,feed rate and depth of cut respectiviley. It is observed that only cutting speed factor has statistical and physical significances on the surface roughness value during cutting parameters at 95% confidence level. From Table 4.8 it is observed that cutting speed factor has statistical and physical significance on the surface roughness value during turning of carbon steel bar at 95% of level confidence. From the table 4.8 it is clearly observed that the cutting speed weight percentage(83.78%), Feed rate(0.03%) and depth of cut(14.19 %) have significant influence on the surface roughness of AISI 1055 specimens. So, cutting speed has significant effect parameter on surface roughness.

4.11. Determining the Optimum Condition

From the table 4.5 and table 4.7, it is clearly observed that cutting speed weight percentage optimum level value 35m/min, feed rate optimum level value 0.2mm/rev, and depth of cut optimum level value 2.5mm make the response S/N ratio values small. Therefore, the optimum processing parameters signal to noise (S/N) ratio is selected. Table 4.9 presents the optimum parameters setting selected for surface roughness obtained from the design of experiment and experimental results.

Table 4.9: Optimum parameters setting levels and their values

Controllable factors	Level selected	Value of the level	Rank of affecting the response
Cutting speed	3	35	1
Feed rate	1	0.2	3
Depth of cut	3	2.5	2

4.12. Prediction of surface roughness

The expected surface roughness (Ra) at optimum settings of the process parameters i.e., at A3B1C3 is calculated as below.

Confidence interval (C.I.) at 95% confidence level (CL) [21]

$$\text{C.I} = \sqrt{F_\alpha(1, f_e)V_e[\frac{1}{n_{eff}} + \frac{1}{R}]}$$

Where, $F_\alpha(1, f_e)$ is the F ratio at a significant level of α % α is the risk.

f_e- is error degrees of freedom

V_e-is error mean square

n_{eff}-is the effective total number of tests and

R- is the number of confirmation test.

$n_{eff} = \frac{9}{1+8} = 1.$ $f_e = 2.$ $V_e = 0.024.$ R= 3.

C.I = $\sqrt{F_\alpha(1, f_e)V_e[\frac{1}{n_{eff}} + \frac{1}{R}]}$ = $\sqrt{F_{0.05}(1,2)0.024[\frac{1}{1} + \frac{1}{3}]}$ = $\sqrt{F_{0.05}(1,2)0.032}$ = $\sqrt{F_{0.05}(18.51)0.032} = \sqrt{(18.51)0.032} = \sqrt{0.59232} = 0.769.$

The 95% confidence interval of **confirmation experiments (CI_{CE})** and **population (CI_{POP})** are calculated by

CI_{CE}= $\sqrt{F_\alpha(1, f_e)V_e[\frac{1}{n_{eff}} + \frac{1}{R}]}$ and **CI_{POP}** = $\sqrt{F_\alpha(1, f_e)V_e[\frac{1}{n_{eff}}]}$. So, by substituting values,

CI_{CE} = 0.769 and **CI_{POP} = 0.667.**

Confidence interval (C.I.) at 95% confidence level (CL) [21], C.I. POP = ±0.970 (for Population) and C.I. CE = ±1.941 (for Confirmatory Experiment). Range of surface roughness with 95% confidence level [21], 1.388 ≤ Ra (POP) ≤ 3.329 (for Population) and 0.418 ≤ Ra (CE) ≤ 4.299 (for Confirmatory Experiment). At the 95 % confidence level, the CI is ± 1.487. Since the prediction error is within CI value the optimal combination of cutting parameter levels can be validated.

4.13. Confirmation Test

Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the predicted result against experimental result. If the optimal combination of parameters and their levels coincidently match with one of the experiments in the OA, then no confirmation test is required. By considering this, Confirmation test was not required (optional) in this case study because the optimum combination of parameters and their levels ($A_3B_1C_3$) have a correspondant to an experiment of the orthogonal array of the trail condition(trial 7) of the exepriment. The obtained optimal factor combination is one of the trial conditions (Trial 7) of the experiment. Thus the mean is calculated by averaging the response values of that trial or trial 7. From Table 4.6, the average value of the response variable (surface roughness) for Trial 7 is 0.849µm. Thus, the mean surface roughness at optimum setting is, Ra = 0.849µm.

As per the DOE analysis and the improvement steps of Taguchi approach, confirmation run is optional to check the predictability of the result. By considering this, the optimum parameter results of three specimens for the surface roughness are measured and recorded as shown in Table 4.10

Table 4.10: Confirmation experiment results for surface roughness specimens

Run	Cutting speed	Feed rate	Depth of cut	Surface roughness (µm)				
				R1	R2	R3	Mean	S/N
1	35	0.2	2.5	0.88	1.02	0.97	0.95	0.445
2	35	0.2	2.5	0.915	0.78	0.69	0.79	2.920
3	35	0.2	2.5	0.690	0.625	0.58	0.61	1.163
	Confirmation experiment mean and S/N ratio						**0.78**	**1.509**

Table 4.11 presents the confirmation experiment and predicted results comparison for surface roughness.

Table 4. 11: Comparison between predicted and experimental confirmation

Response	Optimal parameters	Predicted value		Experiment value	
Surface roughness (µm).	$A_3B_1C_3$	Mean	S/N	Mean	S/N
		0.789	1.521	0.75	1.509

The results of confirmation experiment mean and S/N obtained from the experiment were then compared with the predicted mean and S/N results as shown in table 4.10 for surface roughness. It can be seen from this table that the difference between experimental results and the predicted results are very small. The values of predicted by using Taguchi approach is approximately near to the value which is experimentally obtained. These verify that the experimental results of surface roughness is strongly correlated with the predicted results.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this work, Taguchi's methodology has been utilized to determine the optimal cutting parameters which surface affecting the quality of the workpiece. Based on the results presented the conclusions are drawn as follows:

- Taguchi's method of design of experiment an appropriate technique in minimizing surface roughness.
- A statistically designed experiment based on Taguchi optimize process was executed by means of L9 orthogonal array to investigate the surface roughness as response variable.
- The use of a L9 orthogonal array, with three control parameters at three levels required only nine specimens to conduct the experimental portion, which is less than required for a full factorial design.
- For the three parameters and three levels, L9 orthogonal array was selected.
- The combination of parameters and their levels for minimum surface roughness is $A_3B_1C_3$ (cutting speed 35m/min, feed rate 0.2mm/rev and depth of cut of 2.5).
- Analysis of variance determined the contribution of each parameter in thesurface roughness of the prepared specimen.
- The contribution of wt% Cutting speed, feed rate and depth of cut are 83.78%, 0.03%and 14.19% respectively.
- Based on analysi of variance (ANOVA) results, the cutting speed wt.% is the most significant (dominant) factor for minimizing surface roughness, while feed rate is the least important.
- The optimum cutting parameters of turning operation of EN-9 steel were 35m/min of cutting speed, 0.2mm/rev of Feed and 2.5mm Depth of cut.
- A parameter design gives the optimum condition of the controlled parameters, as well as a predictive equation. A verification procedure is then performed, which indicates that the selected parameters and predictive equation were accurate to within the limits of the measurement.

5.2. Recommendation

Based on the results and conclusion found from this study, the researcher forwards the following recommendations:

- ✓ The experiment was originally planned to be conduct with the involvement of vibration during machining operation. Due to unavailability of the measuring device (accelerometer), the experiment was conducted on a cutting parameters only. The application of vibration on the same tool work for the same domain of cutting parameters and its effect on surface roughness could be studied and analyzed.
- ✓ In this study, carbon steel has been used. This can further be extended to other materials to study the effect of surface roughness under the same cutting parameters.
- ✓ The study can be extended by various parameters and their interactions and the mechanical properties studies can also be carried out.
- ✓ This work was limited to single response only. However, a multi response optimization of machining parameters for surface roughness techniques can be used and analyzed.

5.3. Scope for future work

In this research, only three parameters have been studied in accordance with their effects. the further researches can be carried out to:

1. Study the effects of tool geometry like Nose Radius, Rake Angle on the surface roughness and MRR.
2. Analyses the effect of cutting forces exerted and tool wear rate during the cutting operation.
3. Study the other output factors like power consumption, tool life, etc. can be studied.
4. Study effect of response variables with different cutting tools.
5. Study and compare the differences in performance characteristics on same work sample after heat treatment and etc.
6. Future research work may be directed towards applying response surface methodology and genetic algorithm to further fine-tune the optimization of cutting parameters, which was beyond the scope of this research, as it was mainly focused towards the identification of most significantly influencing factors.

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APPENDIX-A

Response of ANOVA S/N and mean ratio for Surface roughness

```
Taguchi Orthogonal Array Design

L9 (3^3)

Factors:  3

Runs:     9

Columns of L9 (3^4) Array

1 2 3

Response Table for Signal to Noise Ratios
Smaller is better

       Cutting               Depth
Level    speed    Feed rate of cut
1      -6.7114    -3.1479 -4.6480
2      -3.4280    -3.5242 -3.7766
3      -0.2845    -3.7517 -1.9992
Delta   6.4269     0.6038   2.6487
Rank         1          3        2


Response Table for Means

        Cutting              Depth
Level    speed    Feed rate of cut
1         2.182      1.573   1.788
2         1.497      1.573   1.614
3         1.043      1.576   1.321
Delta     1.139      0.003   0.467
Rank         1          3       2

Analysis of Variance

Source           DF   Adj SS    Adj MS      F-Value   P-Value
  Cutting speed   2   1.97129   0.985646    40.67    0.024
  Feed rate       2   0.00002   0.000009     0.00    1.000
  Depth of cut    2   0.33421   0.167107     6.90    0.127
Error             2   0.04847   0.024233
Total             8   2.35399
```