Optimization of Dry Turning Parameters for Free Cutting Brass (CuZn39Pb3) Material Using Taguchi Method

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ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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DEPARTMENT OF MECHANICAL DESIGN AND MANUFACTURING ENGINEERING

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By

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DECLARATION

I hereby declare that the work, which is being presented in thesis, entitled "**Optimization of Dry Turning Parameters for Free Cutting Brass (CuZn39Pb3) Material using Taguchi Method**" In partial fulfillment of the requirement for the award of the Degree of Masters of Science in Manufacturing Engineering is my own work carried out September 2018 to June 2019 under the supervision and guidance of **Dr. Woldetinsay Gutu,** Program of Mechanical Design and Manufacturing Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other Degree or Diploma. All relevant resources of information used in this thesis have been duly acknowledge.

Kemal Temam Ebrahim ____________________ ____________________

Candidate Signature Date

This is to certify that the above declaration made by the candidate is corrected to the best of my knowledge and belief. This thesis has been submitted for examination with our approval.

Dr. Woldetinsay Gutu ____________________ ____________________

Advisor Signature Date

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ABSTRACT

Nowadays, material development is focused on continuous improvement of a material's properties. In order to lower machining costs, fabricators frequently demand materials with improved machinability properties while with mechanical and physical properties that are essentially unchanged. Pure copper produces long tubular or tangled chips which can make it difficult to machine. The challenges are due to its high ductility and high frictional forces between chip and cutting tool. This creates high tool wear and poor chip formation. Dry turning operation is very important due to save cost of cutting fluid, contribute to clean environment and safety for operator. In this work, cutting parameters (cutting speed, depth of cut and feed) were optimized for dry turning process using Taguchi Method. Surface roughness produced on the machined part of free cutting brass by turning process on the conventional lathe machine. The minimum surface roughness at optimum turning parameters in this study was obtained. Result of variance indicates that the contribution of cutting speed, feed and depth of cut were 88.74%, 1.13% and 6.46% respectively. Among which cutting speed was the most significant factor for improving surface roughness.

Key words: *Conventional Lathe Machine, Turning parameters, Surface Roughness, Taguchi Method, S/N ratio, ANOVA*

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ACRONYMS AND ABBREVIATIONS

ANOVA Analysis of Variance

DOE Design of Experiment

DOF Degree of Freedom

FEM Finite Element Method

MRR Material Removal Rate

MSE Mean Square Error

OA Orthogonal Array

OM Optical Microscope

NR Nose Radius

S/N Signal to Noise

SST Total Sum of Squares

SSTR Treatment Sum of Squares

VHN Vickers Hardness Number

CHAPTER 1

1. INTRODUCTION

1.1 Background of the Study

Machining is a material removal process where a cutting tool made of a harder material than the workpiece in conventional machining process. Machining is not only performed for the overall forming of parts into their ultimate shapes, but also it is used to convert castings, forgings or preformed blocks of metal into desired shapes, with size and finish specified to fulfil design requirements. Almost every manufactured product has components that require machining often to great precision [1]. There are a numbers of different machining processes available for machining to dimensional accuracy and surface finish. The term machinability is used for grading work material with respect to the machining characteristics. There is no proper definition of machinability and often it is referred to [2]:

- The ability of the work material to be machined
- Easy of machining the workpiece and
- Material response to machining.

Conventional machining is one of the most important material removal methods. Lathe machine is a common type of conventional machining in which different machining types like turning, facing, counter turning and tapering, boring and chamfering will be operated on it. Machining is a part of the manufacture almost all metal products. In turning, higher values of cutting parameter offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality and tool life. Turning operation is very important material removal process in modern industry. At least one fifth of all applications in metal cutting are turning operations. It is used to reduce the diameter of the work piece, usually to a specified dimension and to produce a smooth finish on the metal [3].

Turning is used to produce parts cylindrical in shape by using a single point cutting tool on lathes. The cutting tool is fed either linearly in the direction parallel or perpendicular to the axis of rotation of the workpiece or along a specified path to produce complex rotational shapes [4]. The primary motion of cutting in turning is the rotation of the workpiece and the secondary motion of cutting is the feed motion as shown in the Figure 1.1. In general, turning refers to a class of processes carried out on a lathe. A brief outline of some the sub-class of turning processes are presented in the Figure 1.2.

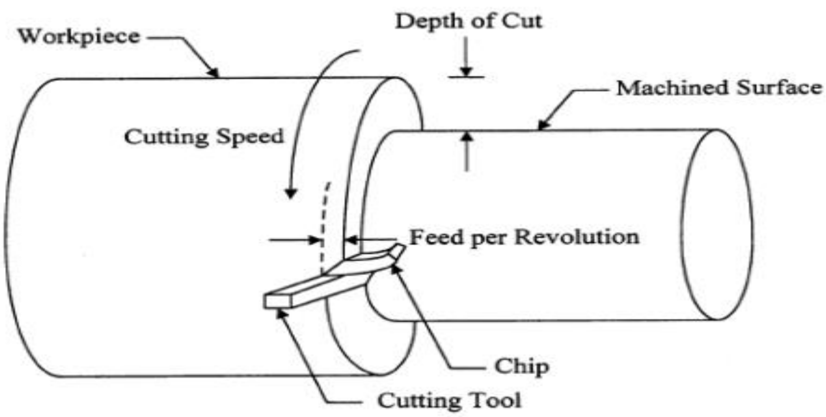


Figure 1.1 Schematic depiction of turning operation[5].

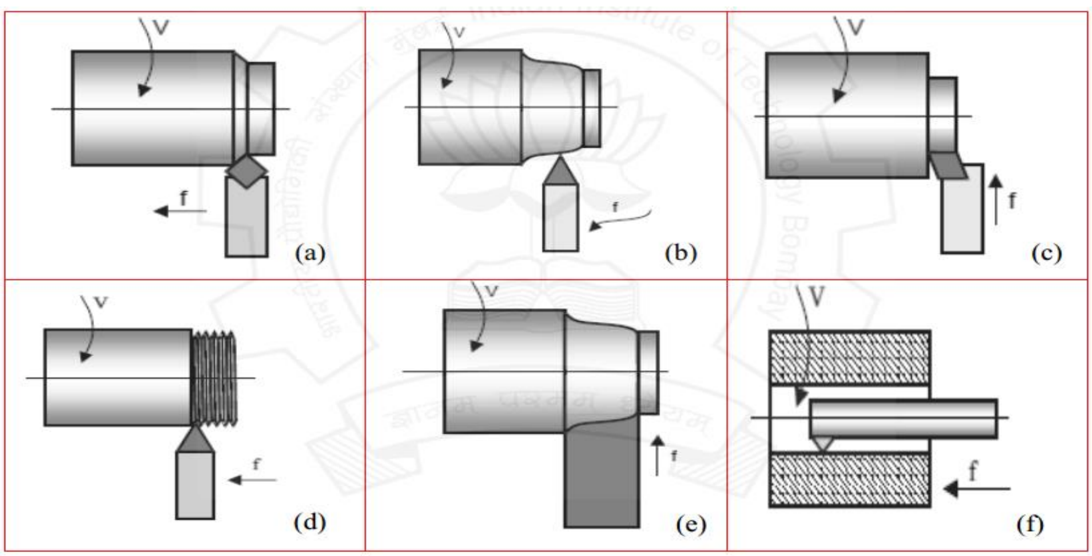


Figure 1.2 Different types of Turning Operations [straight turning(a), Contour turning and Taper turning(b), facing(c), Thread cutting(d), form turning(e) and boring(f)][6].

1.2 Machinability of Copper and Copper Alloys

Pure copper has very high conductivity values, the fact that it produces long tubular or tangled chips can make it difficult to machine. For this reason, alloys have been developed in which zinc, tin, sulphur or lead are added to the pure copper as chip-breaking alloying elements. The conductivity of these alloys is only slightly below that of pure copper [6].

Machining copper alloys is considerably easier than machining steels or aluminum alloys of the same strength as shown in Figure 1.3 and Figure.1.4. The free cutting brass with the designation CuZn39Pb3 has established itself as an excellent material for manufacturing all kinds of form turned parts. The excellent machining properties of these copper-zinc alloys is so well-known that they are often used as benchmarks for describing the machining properties of copper and copper alloys. From Figure 1.4, the specific cutting force is significantly lower for copper alloys especially brass than that of steel and aluminum alloys of the same strength.

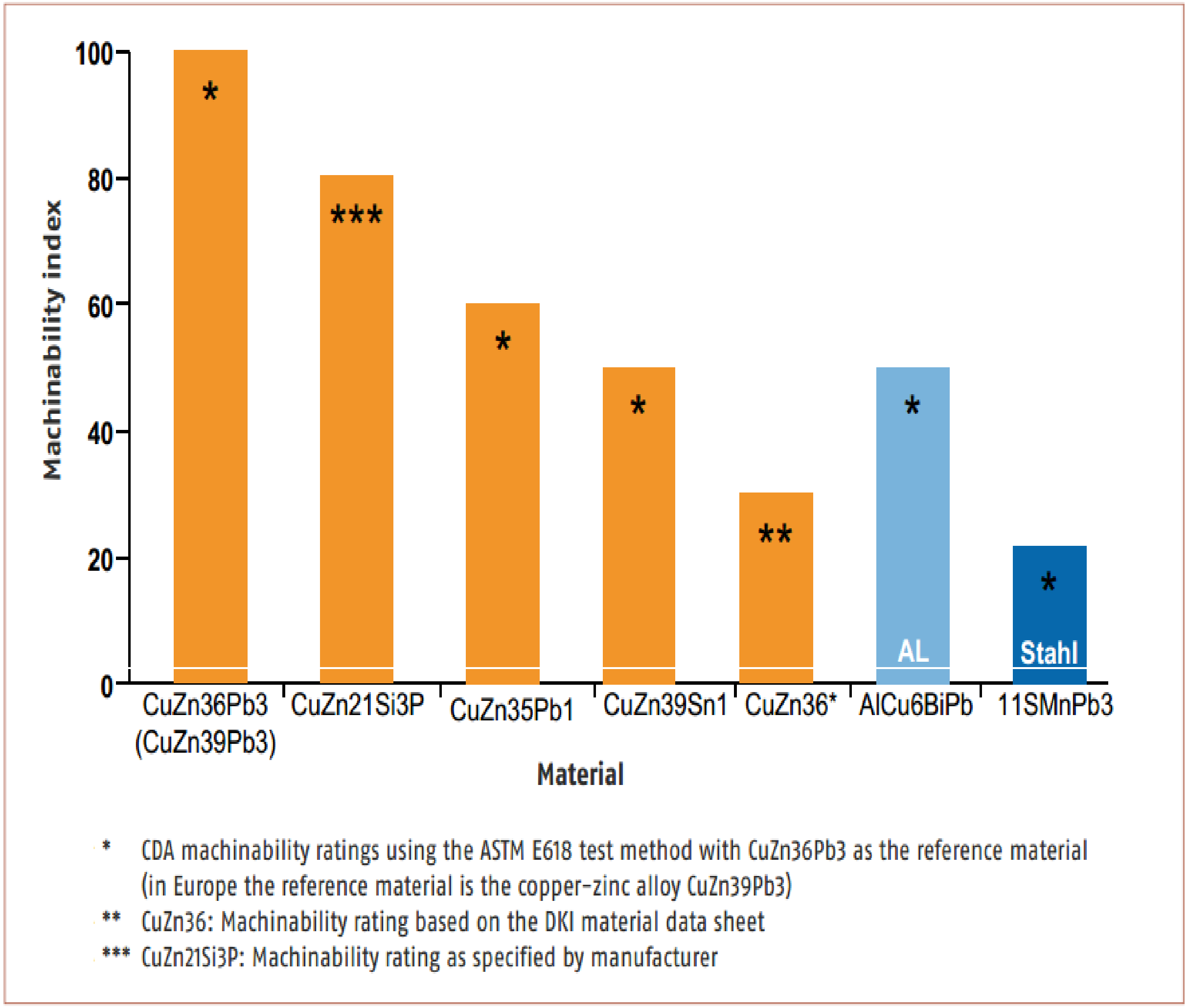
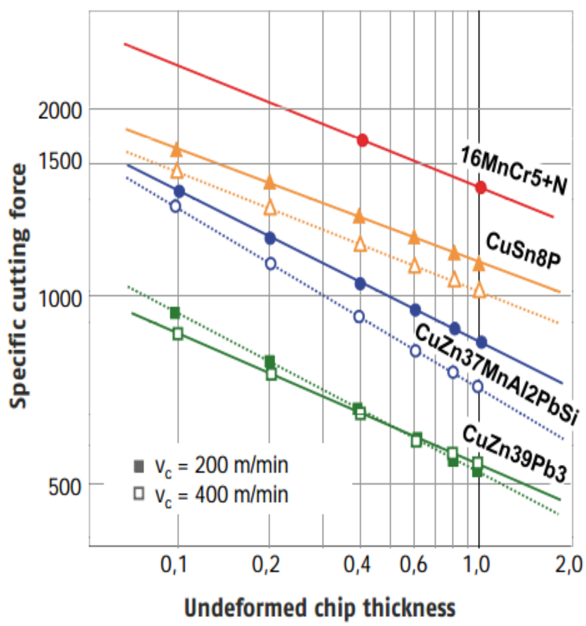


Figure 1.3 Comparison of the machinability of copper alloys with a free-cutting steel and an aluminium alloy [6].



Material	v_c m/min	$k_{c1.1}$ N/mm²	$1-m_c$
CuZn39Pb3 Free-cutting brass	200	539	0,7886
	400	521	0,7458
CuSn8P Copper-tin alloy	200	1137	0,8211
	400	1020	0,8059
CuZn37MnAl2PbSi Special brass	200	845	0,7561
	400	715	0,7036
16MnCr5+N Case-hardened steel	200	1302	0,7092

■ CuZn39Pb3 ▲ CuSn8P ● CuZn37MnAl2PbSi	N10 - N20 $\alpha_o = 7°$; $\gamma_o = 0°$; $\lambda_\sigma = 0°$ $\kappa_r = 93°$; $\varepsilon_r = 55°$; $r_\varepsilon = 0,4$ mm; $a_p = 1$ mm
● 16MnCr5+N	P10 $\alpha_o = 5°$; $\gamma_o = 6°$; $\lambda_s = 0°$ $\kappa_r = 70°$; $\varepsilon_r = 90°$; $r_\varepsilon = 0,8$ mm; $a_p = 3$ mm

Figure 1.4 Comparison of the specific cutting force of three copper alloys with a case-hardened steel [6].

1.3 Surface Roughness, Surface Finish and Surface integrity

Functional performance of any solid surface depends on the physical conditions and chemical composition of the concerned surface and subsurface layers. The quality of the surface of manufactured products by different machining process are commonly defined by Surface roughness, surface finish and surface integrity. Sometimes they are used interchangeably, but they are not exactly same. Roughness and finish imply the same thing but in different way; whereas integrity has a broad domain and encompasses the former two [7].

1.3.1 Surface Finish

Smoothness of a surface is determined by surface finish. It indirectly indicates height and depth of asperities of the solid surface. No surface is perfectly smooth; even if it is perfectly smooth, it cannot be determined as every measuring instrument has a range of its capability. High surface finish is required in the following fields; optics and electronics (lenses, mirrors), medical instruments, micro fluid (nozzle, channel, mixture) and material properties with high fatigue life, wear resistance and toughness [8].

1.3.2 Surface Roughness

Surface roughness is the quantitative approach of determining smoothness of a surface by measuring height of peaks and depth of valleys over a fixed length. There are various principles of measuring surface roughness. For example, average surface roughness (R_a), 10-point average (R_{10}) and root means square (R_z). Whatever be the case, roughness can quantitatively determine the profile of a solid surface and is one crucial parameter of surface texture. Unlike surface roughness, surface finish is one qualitative approach of indicating smoothness of a surface. In fact, roughness and finish are inversely proportional. When surface finish is good, its surface roughness is also reduced. Surface roughness was measured by an equipment called profilometer which gives the value of surface roughness with micrometers [5].

1.3.3 Surface Integrity

Surface integrity encompasses all of the elements that describe all conditions of existing solid surface which is produced by different machining process. It describes not only the topological (geometric) features of surfaces and their physical and chemical properties, but also their mechanical and metallurgical properties and characteristics. Every surface generation or modification process is associated with the alteration of various properties including roughness, plastic deformation, micro-cracking, phase transformations, micro-hardness and residual stress. Several surface defects produced and caused by different factors during turning operation can be responsible to inadequate surface integrity. These defects usually are caused by one or a combination of the following factors such as [9];

- Defects in the original material
- The method by which the surface is produced
- Improper control of the process parameters (which can result in excessive stresses, temperatures or surface deformation).

The following are general definitions of the major surface defects which are produced due to different factors in turning process of various components:

- Cracks may be external or internal; cracks that require a magnification of the image or higher to be seen by the naked eye are called microcracks.
- Craters are shallow depressions which is created on the surface of machined parts.
- Intergranular attack is the weakening of grain boundaries through liquid metal embrittlement and corrosion.

- Pits are shallow surface depressions, usually the result of chemical or physical attack.
- Residual stresses are tension or compression stresses on the surface which are caused by non-uniform deformation and a non-uniform temperature distribution during the machining process.
- Surface plastic deformation is a severe surface deformation caused by high stresses due to factors such as friction, tool and die geometry, worn tools and processing methods.

The reasons for controlling surface texture are to improve the service life of the components, to improve the fatigue resistance, to reduce initial wear of parts and to have a close dimensional tolerance of the parts.

1.4 Types and Application of Copper Alloys

Copper is used in a wide range of products due to its excellent electrical and thermal conductivity, good strength, good formability and resistance to corrosion. Pipe and pipe fittings are commonly manufactured from these metals due to their corrosion resistance. Today it is most commonly found in electrical materials such as wiring because of its ability to effectively conduct electricity. The most common types of copper alloys that are used widely in different applications are the following.

1.4.1 Brass

Brass is mainly an alloy that consists of copper with zinc added. Brasses can have varying amounts of zinc or other elements added. These varying mixtures produce a wide range of properties and variation in color. Increased amounts of zinc provide the material with improved strength and ductility. Brass can range in color from red to yellow depending on the amount of zinc added to the alloy. If the zinc content is within the range of 32%-39% it will have increased hot working abilities but, the cold working will be limited.

1.4.1.1 Tin Brass

This is an alloy that contains copper, zinc and tin. This alloy group would include admiralty brass, naval brass and free machining brass. This group has low sensitivity to dezincification, moderate strength, high atmospheric and aqueous corrosion resistance and excellent electrical conductivity. They possess good hot forgeability and good cold formability. These alloys are typically used to make fasteners, marine hardware, screw machine parts, pump shafts and corrosion resistant mechanical products.

1.4.1.2 Free Cutting Brass

C-36000 or (CuZn39Pb3) also called "free cutting brass," is alloyed with copper, zinc and lead. Free cutting brass is easy to machine, but also offers the same toughness and corrosion resistance as other forms of brass. Some uses for free cutting brass include: nuts, bolts, threaded parts, terminals, jets, taps, injectors, valve bodies, balance weights and pipe or water fittings.

1.4.1.3 Gilding metal (Red Brass)

Gilding metal is a form of brass that is made up of 95% copper and 5% zinc. A soft brass alloy, gilding metal can be hammered or easily formed into desired shapes. Its unusual deep bronze color and ease of use make it ideal for craft-related projects. It's also commonly used for artillery shells. Some other uses include: jewelry, ornamental trim, badges, door handles, marine hardware, primer caps, pen, pencil and lipstick tubes.

1.4.1.4 High Tensile Brass

High tensile brass is a particularly strong alloy which includes a small percentage of manganese Because of its strength and non-corrosive qualities, it is often used for products that undergo a good deal of stress. Some examples include: Marine Engines, Hydraulic Equipment Fittings, Locomotive Axle Boxes, Pump Casting, Heavy Rolling Mill Housing Nuts, Heavy Load Wheels, Valve Guides, Bushes Bearings, Swash Plates and Battery Clamps.

1.4.2 Bronze

Bronze is an alloy that consists primarily of copper with the addition of other ingredients. In most cases the ingredient added is typically tin, but arsenic, phosphorus, aluminum, manganese and silicon can also be used to produce different properties in the material. All of these ingredients produce an alloy much harder than copper alone. Bronze is used in the construction of sculptures, musical instruments and medals, and in industrial applications such as bushings and bearings, where its low metal on metal friction is an advantage.

1.5 Structure of The Thesis

This thesis entitled as Optimization of dry turning parameters for free cutting brass (CuZn39Pb3) material using Taguchi method has five chapters. This chapter presents introduction, definition, fundamental principles, machining process and others. Chapter 2 presents related literature works on challenges of machining of different materials, basic concepts of turning process, problem of the statement, Research gap, objectives, significance of the study, scopes and limitations of the study. Chapter 3 discussed the experimental procedures, equipment used and materials used for the study. Chapter 4 presents result and discussion of major findings of this experimental work. Chapter 5 discussed or summarize the study, conclude from overall study, recommendation and future research directions.

CHAPTER 2

2. LITERETURE REVIEW

2.1 Introduction

There are two main practical problems that engineers face in a manufacturing process. The first is to determine the values of the process parameters which yield the desired product quality (meet technical specification) and the second is to maximize manufacturing system performance using the available resources. The decisions made by manufacturing engineers are based on conventions regarding the phenomena that take place during processing. In the turning process, many of these phenomena are highly complex and interact with a large number of factors, thus preventing high process performance form being attained.

To overcome these problems, the researchers propose models that try to simulate the conditions during turning and establish cause and effect relationships between various factors and desired product characteristics. The optimization of turning process has been the object of technological research for some decades now. This chapter is to present the various methodologies and strategies that are adopted by researchers in turning optimization and different techniques used by the researchers in multi-objective optimization in turning process for different materials.

2.2 Turning Process Parameters and Output Responses

Turning process parameters affects the output responses of machined product like surface roughness, material removal rate, tool life and tool wear.

2.2.1 Turning Process Parameters and Surface Roughness

One of the most basic machining processes is turning process, which is processed on lathe machine by rotating the workpiece through spindle and machined the parts by using the cutting tool which has high strength and hardness than that of workpiece materials. It is a process in which, a single-point turning tool moves axially along the side of the workpiece, removing material to form different features including steps, tapers, chamfers and contours. The starting material is generally a workpiece that has been made by other processes such as casting, forging, extrusion, drawing or powder metallurgy. Generally turning process using lathe machine is:

- Used to creates cylindrical external or internal shapes
- Used to creates flat surfaces on part ends (faces)

- Uses a single point cutting tool
- Used to create wide variety of shapes and

Many researchers have identified the effect of turning parameters like cutting speed, feed and depth of cut on the surface roughness of the machined product during turning operation. Researchers in were investigated the effect of cutting speed, feed and depth of cut on the surface roughness of machined product of mild steel by using Taguchi method [3]. Their result showed that the surface roughness was highly affected by feed and depth of cut has low significant effect on the surface roughness. The analysis also shows that the predicted values and calculated values are very close, that clearly indicates that the developed model can be used to predict the surface roughness in the turning operation of mild steel. And the minimum average surface roughness obtained in this study was 2.22µm. The effect of turning parameters on the surface roughness and on the hardness of materials were optimized by researchers in [10]. The result shows that the cutting speed has high significant effect on the surface roughness and depth of cut has high significant effect on the hardness of the materials after turning process on conventional lathe machine.

2.2.2 Turning Process Parameters and Material Removal Rate (MRR)

The material-removal rate (MRR) in turning is the volume of material removed per unit time or it is defined as a measurement from the initial and final weight of job. For each revolution of the workpiece, a ring-shaped layer of material is removed which has a cross-sectional area that equals the product of the distance the tool travels in one revolution (feed, f) and the depth of cut (d). The volume of this ring is the product of the cross-sectional area (f)(d) and the average circumference of the ring $\pi D_{avg.}$ Surface roughness and material removal rate produced in hard turning process under dry conditions using coated carbide tool and high-speed steel tools for copper alloy was investigated [11]. Surface roughness of 1.42µm and 2.37 µm by using carbide tool and high-speed steel tools respectively.

Cutting force is an important performance parameter in which directly affects the turning process. some factors like tool breakage, tool-wear and workpiece deflection are mainly developed due to cutting force produced during the machining process. Three principal forces acting on a cutting tool during turning process are cutting force (F_c), thrust force (F_t) and radial force (F_r).The cutting force acts downward on the tool tip and thus tends to deflect the tool downward and the workpiece upward and it supplies the energy required for the cutting operation during the process.

Ratio of F_c to cross-sectional area being cut is called specific cutting force. The thrust force acts in the longitudinal direction. It also called the feed force because, it is in the feed direction of the tool and this force tends to push the tool towards the right and away from the chuck. These two forces produce the resultant force *R* and radial force acts on the cutting tool perpendicular to cutting force. The cutting force used in this study were calculated from equation (2.1) for the turning operation.

$$P_{net} = \frac{F_c{}^{*} V_c}{60000} \tag{2.1}$$

Where, F_c- cutting force, P_{net}- net machine power in KW, V_c- cutting speed in m/min

The effect of cutting parameters on cutting force (Fc) & feed force in turning Process was studied [12]. Experiments were conducted on a precision Centre lathe and the influence of cutting parameters was studied using analysis of variance (ANOVA) based on adjusted approach. Cutting Speed has no significant effect on the cutting force as well as the surface roughness of the chosen work piece. Depth of cut has a significant influence on cutting force, but an insignificant influence on surface roughness. Another researchers in [13] were studied the effect of cutting parameters on feed cutting force and estimation of feed cutting force in dry orthogonal turning. They it can be concluded that feed cutting force increases as the depth of cut and feed rate increases. The percentage error between the experimental and estimated feed force values is minimal and in the acceptable range, hence the developed method can be used by local lathe tool users for the estimation of feed cutting force and to know the effect of cutting parameters on feed cutting force in turning operation.

A researchers in [4] were proposed an orthogonal cutting force model based on slip-line field model for micro machining. Two material flow processes are being considered- chip formation process and ploughing. The paper takes into account the effects of parameters like effective rake angle, depth of deformation and minimum chip thickness. The effect of parameters spindle speed on the metal removal rate is increasing with increase in spindle speed up to 350 rpm beyond that it is decreasing according to this study.

2.2.3 Tool Life, Tool Wear and Turning Process Parameters

As cutting process proceeds the various wear mechanisms result in increasing levels of wear on the cutting tool. Three regions can usually be identified in the typical wear growth curve. The first is the break-in period in which the sharp cutting-edge wears go rapidly at the beginning of the cutting process and it occurs within the first few minutes of cutting. The break-in period is followed by wear that occurs at a fairly uniform rate which is called the steady-state wear region. Finally, wear reaches a level at which the wear rate starts to accelerate. This marks the beginning of the failure region, in which cutting temperatures are higher and the general efficiency of the machining process is reduced. If allowed to continue, the tool finally fails by temperature failure. Although the relationship shown is for flank wear, a similar relationship occurs for crater wear.

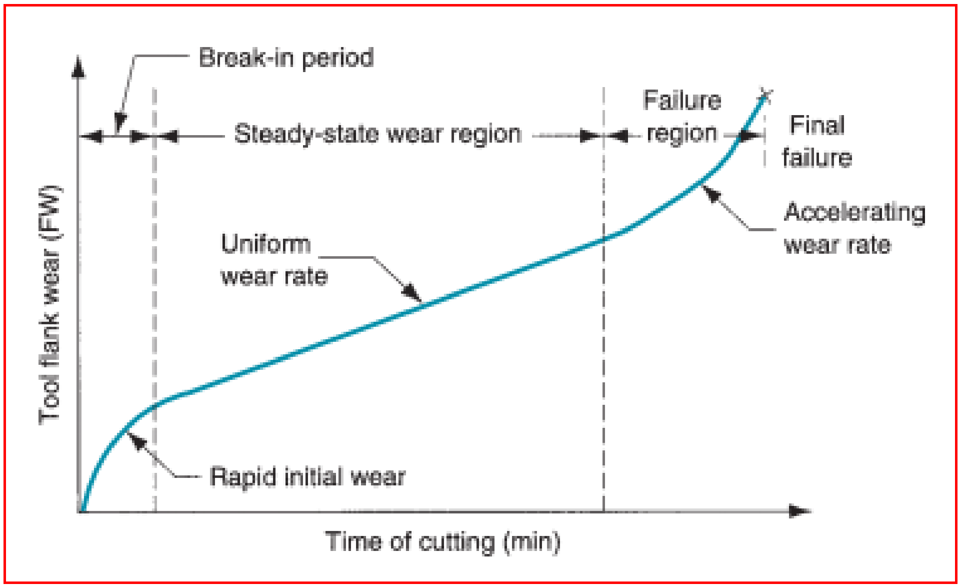


Figure 2.1 Tool wear as a function of cutting time. Flank wear (FW) is used here as the measure of tool wear, Crater wear follows a similar growth curve[14]

Tool life is defined as the length of cutting time that the tool can be used. Operating the tool until final catastrophic failure is one way of defining tool life. However, in production, it is often a disadvantage to use the tool until this failure occurs because of difficulties in re-sharpening the tool and problems with work surface quality. As an alternative, a level of tool wear can be selected as a criterion of tool life and the tool is replaced when wear reaches that level. Taylor tool life can be expressed in equation form as follows [14].

$$VT^n d^x f^y = C \qquad (2.2)$$

where,

d = depth of cut (mm)

f = feed of the tool (mm/rev)

x, y: must be determined experimentally for each cutting condition

And equation (2.2) is rearranged as;

$$T = C^{1/n} V^{-1/n} d^{-x/n} f^{-y/n} \tag{2.3}$$

Machining operations like turning, drilling, milling is accomplished using cutting tools. There are three possible modes by which a cutting tool can fail in machining process due to different conditions, which are described as follows.

1. **Fracture failure**

This mode of failure occurs when the cutting force at the tool point becomes excessive, causing it to fail suddenly by brittle fracture.

2. **Temperature failure**

This failure occurs when the cutting temperature is too high for the tool material, causing the material at the tool point to soften, which leads to plastic deformation and loss of the sharp edge.

3. **Gradual wear**

Gradual wearing of the cutting-edge causes' loss of tool shape, reduction in cutting efficiency, an acceleration of wearing as the tool becomes heavily worn and finally tool failure in a manner similar to a temperature failure.

During the machining process, wear marks will appear on the tool. The extent of tool wear will depend on the stresses to which the tool is subjected. Gradual wear marks appear on the major and minor flanks of the cutting tool where, it is contact with the workpiece and on the tool face where it is in contact with the chip being removed. Accordingly, two main types of tool wear can be distinguished: crater wear and flank wear. As a rule, the greater the amount of wear, the greater the mechanical and thermal stress experienced by the tool. To explain tool wear and the mechanisms that cause it a single point cutting tool was used.

Crater wear consists of a cavity in the rake face of the tool that forms and grows from the action of the chip sliding against the surface. High stresses and temperatures characterize the tool–chip contact interface, contributing to the wearing action. The crater can be measured either by its depth or its area. Flank wear occurs on the flank or on relief face of the tool. It results from rubbing between the newly generated work surface and the flank face adjacent to the cutting edge. Flank wear is measured by the width of the wear band, FW.

This wear band is sometimes called the flank wear land. Certain features of flank wear can be identified. First, an extreme condition of flank wear often appears on the cutting edge at the location corresponding to the original surface of the work part. This is called notch wear.

Tool wear, which is a function of tool material, tool geometry, and the physical, mechanical, and chemical properties of the workpiece is of interest because of its detrimental effects on part production and part quality [7]. Tool vibration is a frequent problem in the manufacturing industry, where metal cutting operations take place. Excessive tool vibrations during machining will increase the tool wear and cause poor surface finish. In metal cutting, tool vibration is the most influential factor affecting the surface quality of the machined surface. In order to reduce these vibrations and to obtain a better result in terms of surface finish, tool life, and other such factors, a magnetorheological damper was developed [15]. It should be noted that the tool wear, particularly when machining harder material appears under much more sever working conditions than under those traditionally used for machine components. In fact, the specific contact pressure in a workpiece of a machine component does not exceed some MPa, and temperature is usually below 100°C whereas in the active cutting tool part surface, pressure goes up to 10^3 to $2x10^3$ MPa and temperature reaches 100°C to 1000°C and even more as studied in [16].

The role of alloy microstructure and surface roughness on wear and friction behavior of leaded and unleaded tin bronzes was investigated [17]. Scanning electron microscopy (SEM), energy dispersive electron microscopy (EDX), x-ray photoelectron spectroscopy (XPS) and Auger electron spectroscopy were performed to analyze the sliding tracks and the ball scars. The wear reducing effect of lead was associated to the formation of an oxidized lead rich layer. They concluded that wear reducing effect of lead is associated to the formation of an oxidized lead rich layer of approximately 15nm thickness covering the wear track.

When no such film forms on the leaded bronze wear is more severe with respect to unleaded bronze. The formation of the lead rich layer and the wear behavior of the bronze depend on the combined effect of microstructure and surface roughness.

2.3 Recommended Cutting Parameters of free cutting brass

The range of applicable cutting parameters like cutting speed, depth of cut and feed for different cutting tool materials and for different copper alloys are given in the Table 2.1.

Table 2.1General recommendations for turning operation of copper alloys and The range of applicable cutting speeds, depth of cuts and feeds for a variety of tool materials[18]

Workpiece material	Cutting tool	General purpose starting conditions		
		Depth of cut in mm	Feed mm/rev (in/rev)	Rotational speed rev/min
Copper alloys	Uncoated carbide	1.5-5.0	0.25 (0.010)	260
	Ceramic-coated carbide	“	“	360
	Triple-coated carbide	“	“	215
	TiN-coated carbide	“	“	90-275
	Polycrystalline carbide	“	“	520
		Range for roughing and finishing		
		Depth of cut in mm	Feed mm/rev (in/rev)	Rotational speed rev/min
	Uncoated carbide	0.4-7.51	0.15-0.75 (0.006-0.03)	105-535
	Ceramic-coated carbide	“	“	215-670
	Triple-coated carbide	“	“	90-305

	TiN-coated carbide	“	“	45-455
	Polycrystalline carbide	“	“	275-915

2.4 Recommended Cutting Fluids

Many metallic and nonmetallic materials can be machined without a cutting fluid, but in most cases the application of a cutting fluid can improve the operation significantly. General recommendations for cutting fluids appropriate to various workpiece materials are given in Table 2.2. In this study dry machining was used for turning operation of copper alloy which is free cutting brass. It is used for Reducing the cost of machining operations, including the cost of maintenance, recycling, disposal of cutting fluids and improving surface quality.

Table 2.2 General recommendations for cutting fluids for machining [19]

Material	Type of fluid
Aluminum	D, MO, E, MO +FO, CSN
Beryllium	MC, E, CSN
Copper and copper alloys	D, E, CSN, MO+FO
Magnesium	D, MO, MO+FO
Nickel	MC, CSN, E
Titanium	CSN, EP, MO
Stainless steel	D, MO, C, CSN
Carbon and low-alloy steel	D, MO, E, CSN, EP

Note: CSN = chemicals and synthetics, MO = mineral oil. FO = fatty oil; D = dry; E = emulsion; EP = extreme pressure;

2.5 Factors Affecting Surface Finishing

Machinability generally is defined in terms of surface finish, tool life, force and power requirements and chip control. The machinability of materials depends on their composition, properties, and microstructure. Thus, proper selection and control of process variables are important.

Many investigations have been done so far to specify the relationship between turning conditions and their influences on the machining result. Optimization of machining processes is usually based on finding operating conditions, which minimize machining costs or maximize production rate. The three important process parameters in this research are depth of cut, cutting speed and feed. Surface roughness of a turned work-piece is dependent on these process parameters and also on tool geometry (nose radius, rake angle, side cutting edge angle and cutting edge). In addition, it also depends on the several other exogenous factors such as: work piece material and tool material type and their mechanical properties, quality and type of the machine tool used, auxiliary tooling, and lubricant used, and vibrations between the work piece, machine tool and cutting tool [1], [3], [13-18]. Therefore, related literature with these parameters have been discussed as follows in different sections.

2.5.1 Material Type

Type of material to be machined plays a vital role to get the products with high surface finish. It helps to select an appropriate cutting parameters and recommended cutting tool for turning operation and the strength of material to be machined is less than that of cutting tool. This in another ways it makes suitable machining operation as the process of final product was achieved the required dimension and accuracy. The influence of material elastic recovery on chip thickness and surface generation in Ultra Precision raster milling was studied in [22]. The experimental results showed that the proposed surface roughness prediction model makes a more precise prediction by adding the elastic recovery rate as a material factor and the presence of elastic recovery improves the surface finishing of the raster milled surface.

Material property is a particular importance in machining process. It makes a great contribution to surface roughness formation in Ultra precision machining due to the "size effect" were studied [23]. Substantial research interest has been attracted in studying the effect of material properties, such as material isotropy and anisotropy and material uniformity and non-uniformity on surface roughness. For different isotropic materials, the machined surface roughness under the same cutting conditions is different.

2.5.2 Type of Cutting-Tool Material

The selection of cutting-tool materials for a particular application is among the most important factors in machining operations. Type of tool material affects surface roughness and surface integrity of machined products during turning process. The strength of cutting tool must be higher than that of material to be machined. The selection of appropriate tool materials depends not only on the material to be machined, but also on process parameters and the characteristics of the machine tool. Generally, there are many types of cutting tools used for turning operation, some of them are high speed steel (HSS), non-coated brazed type carbide tool, coated carbide tool, ceramic tool and cubic boron nitride (CBN) tool.

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. A single point cutting tool is used to turn a variety of cylindrical shapes on lathe machine. In order to remove chips from workpiece the following condition must be fulfilled.

- The cutting tool must be harder than the metal to be cut
- The cutting tool must be shaped so that its cutting edge can penetrate the workpiece
- The tool should be strong and rigid enough to resist cutting forces and
- There must be a relative rotation of the spindle with a workpiece and longitudinal motion of the cutting tool relative to the workpiece in order to make cutting process correctly.

The cutting tool is subjected to high temperatures, high contact stresses and rubbing along the tool–chip interface and along the machined surface. Therefore, the cutting-tool material must possess the following characteristics to resist the tool wear happened during the turning process: hot hardness, thermal shock resistance, wear resistance, toughness and impact strength and chemical stability and inertness with respect to the material being machined, to avoid or minimize any adverse reactions, adhesion and tool–chip diffusion that would contribute to tool wear.

Micro cutting experiments of copper grating were carried out using the self-developed polycrystalline diamond (PCD) micro tools and the effect of width of cut, feed per tooth and spindle speed on dimensional accuracy and burr formation was investigated [24]. Machinability of Cu-Be alloys by ultraprecision grinding and facing was conducted [25]. The study shows that micro grinding of Cu-Be with a diamond wheel generates a rougher surface finish as compared to that produced by micro facing with a single-point diamond tool.

Machinability of ultrafine-grained copper using tungsten carbide on lathe machine using both tungsten carbide (WC) and polycrystalline diamond (PCD) cutting tools in order to facilitate broad applications of Equal channel angular extrusion (ECAE)-processed ultrafine-grained (UFG) coppers and polycrystalline diamond tools were studied [26]. It is found that despite its higher cost, PCD is favored to machine UFG copper based on this study since it has better wear resistance, gives lower cutting forces, yields a better workpiece surface finish, and results in no smearing on the workpiece. In machining UFG copper, notching was observed as the wear pattern and abrasion as the wear mechanism for the WC tool, while flank wear was observed as the wear pattern and diffusion as the wear mechanism for the PCD tool.

An experimental investigation of micro-machinability of copper 101 using tungsten carbide micro-endmills was reported [27]. This paper presents an experimental investigation of micro machinability during micro milling of oxygen-free high conductivity (OFHC), commercially pure copper 101 using tungsten carbide micro-endmills. The forces, surface roughness, tool wear, and burr formation are analyzed under varying cutting speeds (40, 80, and 120 m/min) and feed rates (0.75, 1.5, 3 and 6mm/rev). The experiments included full-immersion cutting with 254mm micro-endmills with an axial depth of cut of 30mm. Their result show that lowest burr formation occurs at low speeds and high feed rates. At higher feed rates, the dominant process mechanism is shearing, which causes less burr formation as compared to ploughing.

2.5.3 Cutting Parameters

The most important cutting parameters for turning operations are cutting speed, feed rate and depth of cut. Their definition is as follows with mathematical expressions. Cutting speed is one of the most important parameters in turning process and it is the speed of the workpiece surface relative to the edge of the cutting tool during a cutting process, measured in surface feet per minute or meter per minute. The rotational speed in turning is related to the desired cutting speed at the surface of the cylindrical workpiece during the process.

$$V_C = \frac{\pi DN}{1000} \tag{2.4}$$

where, $V_C -$ cutting speed in $\mathrm{m/min}$, N - spindle speed in rev/min and D-outer diameter in mm. Feed rate is the rate at which the tool advances into the work. The feed in turning is generally expressed in mm/rev (in/rev). This feed can be converted to a linear travel rate in mm/min (in/min) by the formula;

$$f_r = Nf \tag{2.5}$$

where, $f_r - \text{feed rate in mm/min}$, N- spindle speed in rev/min and $f - \text{feed in mm/rev}$

Depth of cut is the amount of material removed as the work revolves on its axis. The turning operation reduces the diameter of the work from its original diameter D_o to a final diameter D_f, as determined by the depth of cut d:

$$d = \frac{D_0 - Di}{2} \tag{2.6}$$

Where, d-depth of cut in mm, $D_0 - outer\ diameter\ in\ mm,\ Di - final\ diameter\ in\ mm$

Surface roughness is highly affected by cutting parameters like cutting speed, depth of cut and feed rate during turning process on conventional lathe machine. These parameters must be within the recommended range depending on the type of material to be machined, tool geometry and tool material. A researchers in [28] optimized CNC lathe machine turning process Parameters for prediction of surface Roughness through taguchi's parametric Design approach. Their results show that the influence of surface roughness (Ra) is depend on feed and next is followed by speed and depth of cut. And another researcher in [4] has studied Parametric Analysis and optimized the effect of cutting speed, feed rate, time and depth of cut on surface finishing of high stainless-steel material in turning process by taguchi approach.

The optimization of cutting parameters (depth of cut, feed rate, spindle speed) in wet turning of EN24 steel and Taguchi method were studied in [29]. Their result show that feed rate followed by depth of cut and spindle speed was the combination of the optimal levels of factor. Machining parameters in turning operation using Taguchi analysis are optimized by researchers in [9]. They studied the effect of speed, feed and depth of cut on material removal rate, surface roughness and tool wear in machining AISI 4320 alloy steel using tungsten carbide tipped cutter. The results indicate that the cutting speed is that the dominant issue affecting all three investigation parameters.

The effect of spindle speed, feed rate, depth of cut on surface roughness of aluminum samples in end milling was studied [30]. And the study shows that cutting feed is by far the most dominant factor of those studied. The effect of feed rate, depth of cut and lubricant temperature on the surface roughness of steel by using taguchi method was studied in [2]. And the result showed that better surface finish is obtained at cooled lubricant. The effect of cutting parameters on surface roughness of AlCu-TiC metal matric composite by using An Artificial Neural Network Approach was studied in [31]. Surface roughness parameter Ra, Rz and Rt are analyzed during this investigation.

Comparative study on optimization of surface roughness Parameters in turning EN1A steel on a CNC lathe with Coolant and without coolant was studied by a researcher in [32]. His result shows that the best surface finish was occurred with coolant used. Another person in [33] studied the influence of spindle speed, feed rate and depth of cut on the surface roughness of Al-7075 alloy during end milling and the result showed that spindle speed and feed rate are the most significant factors affecting the surface finishing during the process. Investigation surface roughness and stress modeling by finite element on orthogonal cutting of copper were studied in [34]. In this study Finite element (FE) method was applied to predict the stress during orthogonal cutting by simulating the machining process. It is mainly focused on the effect of cutting speed, depth of cut and feed rate on the surface roughness of copper. And finally, the result shows that the surface roughness is highly affected by cutting speed and less affected by depth of cut.

2.5.4 Tool Geometry

A cutting tool must possess a shape that is suited to the machining operation. One important way to classify cutting tools is according to the machining process. Thus, there are different types of tools for different operations like turning tools, cutoff tools, milling cutters, drill bits, reamers, taps and many other cutting tools that are named for the operation in which they are used, each with its own tool geometry in some cases quite different [14].

The cutting part of a turning tool comprises the rake face and the major and minor flank faces. The relative orientation of these surfaces to one another determines the tool angles. The choice of cutting angles has a major effect on the results of a machining operation and on the tool life. The greater the emphasis on achieving cost-effective material processing, the greater the importance of determining an optimal tool geometry. Therefore, the stability and life of cutting tool can be raised by selecting appropriate cutting angles and using chamfered and rounded cutting edges [6].

Single point cutting tool is used for turning process in which, the orientation of the rake face is defined by two angles back rake angle (α_b)and side rake angle (α_s) and these angles are influential in determining the direction of chip flow across the rake face. The flank surface of the tool is defined by the end relief angle (ERA) and side relief angle (SRA) which is used to determine the amount of clearance between the tool and the newly cut work surface. The cutting edge of a single point tool is divided into two sections, side cutting edge and end cutting edge. They are separated by the tool point, which has a certain radius called the nose radius. The side cutting edge angle

(SCEA) determines the entry of the tool into the work and can be used to reduce the sudden force the tool experiences as it enters a workpart. Nose radius (NR) determines to a large degree the texture of the surface generated in the operation. End cutting edge angle (ECEA) provides a clearance between the trailing edge of the tool and the newly generated work surface, thus reducing rubbing and friction against the surface [14], [18], [1] and [13]. Generally, there are seven elements of tool geometry for a single-point tool which, are collectively called the tool geometry signature; back rake angle, side rake angle, end relief angle, side relief angle, end cutting edge angle, side cutting edge angle, and nose radius. For example, a single-point tool used in turning might have the following signature: 5, 5, 7, 7, 20, 15, 2/64 in degree [36].

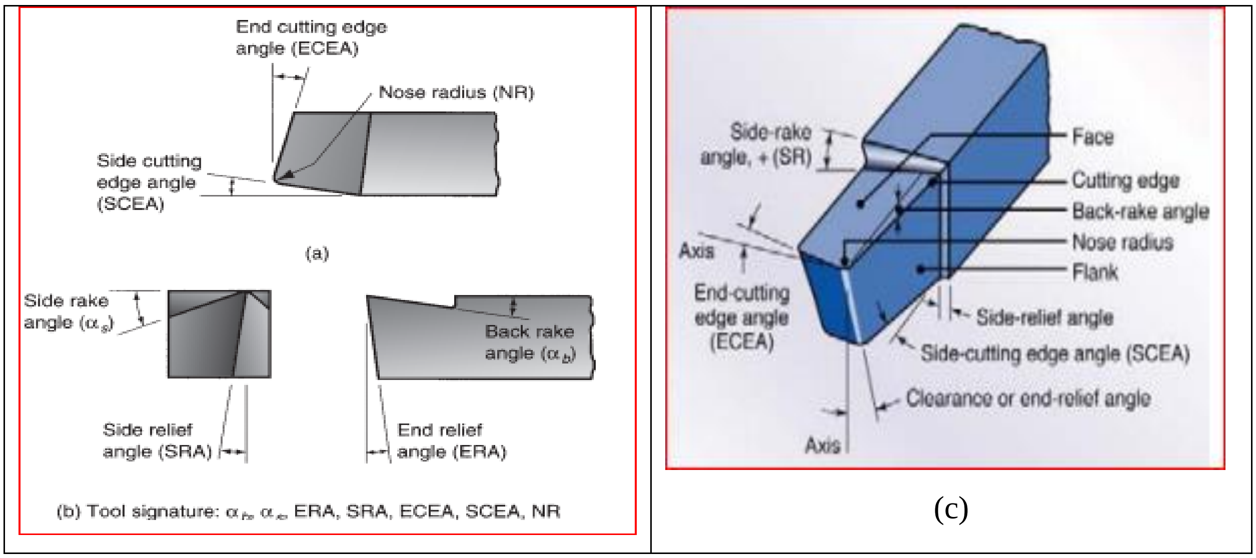


Figure 2.2 (a) Seven elements of single-point tool geometry 2D, and (b) the tool signature convention defines seven elements (c) elements of single point cutting tool geometry 3D[37].

The effect of side rake angle, back rake angle, feed, spindle speed and depth of cut on the surface roughness of mild steel and the result showed that feed is the most significant parameter influencing surface roughness and side rake angle is having very less effect on surface roughness of mild steel by using ANOVA method were studied [38]. A researchers in [39] studied the effects of tool cutting edge geometry and workpiece hardness on the surface roughness and cutting forces in the finish hard turning of AISI 52100 steel. And finally, the study showed that the cutting-edge geometry has a significant effect on the axial and radial cutting force components and also on the surface roughness.

Failure mechanism and factors affecting the micro end mill during machining of pure copper workpiece. The machining operation was performed at various cutting speeds, feed rates and depth of cuts to identify failure mechanisms using two different helix angles. Chips observed were spiral in shape based on the cutter geometry. The effect of depth of cut was reported as increase in depth of cut increases tool life [40]. An experimental investigation was conducted to determine the effects of tool cutting-edge geometry and workpiece hardness on surface residual stresses for finish hard turning of through-hardened AISI 52100 steel [40]. This study shows that tool edge geometry is highly influential with respect to surface residual stresses, which were measured using x-ray diffraction.

2.5.5 Machine Stability

It affects the surface roughness of finished product as the stability of the machine were changed. It includes the vibrations and motional accuracy of the workpiece, tool and machining equipment. In the turning operation vibration is a frequent problem, which affects the result of the machining and particularly the surface finish. Tool life is also influenced by vibration. Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the work piece. Tool vibration is a dynamic instability of the cutting process, which is a result of the interaction between the metal cutting process and the dynamics of a machine tool. The presence of such tool vibration leads to a poor surface finish, which results in cutting tool damage and the production of irritating and unacceptable noise. In order to reduce tool vibration, a magnetorheological fluid damper was developed in [15], that will respond to an applied field with a dramatic change in their rheological behaviour. In their studies a Mathematical model was developed and the amplitudes of the tool vibration and chip thickness were calculated.

A correlation between surface roughness and cutting tool vibration in turning operation by taking different levels of process parameters like speed, depth of cut, feed rate and tool overhanging were studied by researchers in [41]. Their result show that the best surface roughness condition is achieved at a low feed rate and smaller tool overhang. The relations between tool overhang and vibration signal features are investigated by another researchers in [42]. Based on their study, it can be concluded that vibration signal features in tangential direction are highly affected by overhang length. The effects of changes in the tool overhang in the external turning process on both the surface quality of the work piece and tool wear were investigated in [37]. Their result show that the surface roughness of workpiece increases as the tool overhang increases and Using the same tool overhang, the surface roughness of the work piece increases as the depth of cut increases.

2.6 Research Motivation

In any manufacturing industries surface quality of machined product plays a vital role to increase the customers demand and the competitiveness between the manufacturers. Without surface quality it is difficult to talk about high production rate, long life of product without defect, crack formation and corrosion resistance. And also surface quality plays a vital role in the applications of assembly parts in which movable parts are used. Thus, the motivation of this work is mainly due to the above said reasons.

2.7 Statement of the Problem

In the metal manufacturing industries machining is still the most commonly used methods of production formation. Better quality at lower cost in a lesser time is increasing the competitive nature among the manufacturers. The findings of optimum parameters in turning process are very important due to challenges in machining. Nowadays, especially in terms of surface quality and cost of machining, care should be taken. Turning is the most common machining processes available to meet the needs like dimensional accuracy, surface finish and ease machining of a material. Surface roughness remain the main indicator of machined component quality as it is related with surface quality.

In turning, higher values of cutting parameter offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality and tool life if there are improper process parameters were used. In the turning operation, cutting parameters (cutting speed, depth of cut and feed) are the most common factors which affects the result of machining particularly the surface finish of the product. Brass is the most common types of copper alloys which is widely used in the application of products those needs high surface quality like bolts, nuts, threaded parts, terminals, jets, taps, injectors, valve bodies, balance weights and pipe or water fittings. Its widely used in Wonji sugar factory due to its excellent electrical and thermal conductivity, good strength, good formability and resistance to corrosion. But the products like shaft, bolt and nut in this factory were failed by corrosion, wear and fatigue because of high surface roughness and needs maintenance which requires additional cost. Therefore, to minimize the failures of materials due to properties like corrosion, wear and fatigue it is important to investigate and optimize the cutting parameters those affects the surface roughness of brass in turning operation.

2.8 Research Gap

In the above literature survey critical controllable turning parameters on the conventional lathe machines like cutting speed, depth of cut, feed, tool geometry, tool material type, workpiece material and machine stability, which affects the desired output like surface quality, tool wear, tool life and performance for different material like mild steel, carbon steel, aluminum alloys etc were studied. But the optimization of dry turning parameters for free cutting brass material were not studied as well as not published. Therefore, it is vital to study the optimization of turning parameters for brass material. Based on the literature survey and major challenges identified in the literature, it is decided to investigate the following aspects of the turning process in this thesis as a research gap.

1. What are difficulties in machining operation of copper alloy (free cutting brass) on conventional lathe machine and how we minimize them?
2. What is the optimum turning parameters of machined product of free cutting brass material in the dry turning operation?
3. What are the most significant factors (cutting speed, depth of cut and feed) that affects the surface quality of machined free cutting brass by turning process?

2.9 Objective

2.9.1 General Objective

General objective of this thesis is to optimize dry turning parameters of free cutting brass material by using Taguchi Method.

2.9.2 Specific Objectives

To achieve the above general objective the following specific objectives will be required.

i. To study the difficulties in turning operation of brass on conventional lathe machine.
ii. To identify the most significant factors that affect the surface quality of free cutting brass in the turning operation.
iii. To find the optimum cutting parameters.
iv. To study the microstructure and hardness of machined product by turning.
v. To observe chip morphology during turning process.

2.10 Significance of The Study

Studying the machining parameters those affect the surface quality of advanced materials like copper and copper alloys are very important to manufacture products with high quality. As turning is the most common types of conventional machining process it is important to study the effect of cutting parameters like cutting speed, feed rate and depth of cut on the surface quality of finished products. Generally, the significances of this study are to optimize the cutting parameters, obtain better surface finish, increase the precision of the product, reduce the friction factor in movable joint and enable customer satisfaction.

2.11 Scopes and Limitations of The Study

The study is highly focused on mechanism of turning process, on the optimization of turning parameters, identifying the most significant factors (process parameters) that affect the surface quality of copper alloys (brass) materials and how we improve the surface quality of products in manufacturing process to maximize the profit, to maximize production rate, to increase tool life as well as to increase the customers demand. In this paper the effect of cutting parameters (cutting speed, depth of cut and feed) on the surface roughness of machined product of brass material and the microstructure of the machined brass were studied. But in this study the effect of cutting force and machine vibration on the surface roughness was not included because of difficulties to measure cutting force without dynamometer and difficulties to measure vibration frequencies.

CHAPTER 3

3. MATERIALS AND METHODOLOGIES

3.1 Introduction

This study was performed to investigate the machining parameters which affects the surface roughness in turning operation of copper alloy which is free cutting brass (CuZn39Pb3) by using ceramic coated carbides cutting tool through experimental analysis. The aim of this section is to present the details of the experimental procedures and material used for the study. All machines and instruments were discussed with supporting photographs and schematic diagrams.

3.2 Experimental Procedure

The overall stages of the experimental studies of optimization of parameters in turning process of free cutting brass as it is shown in Figure 3.1.

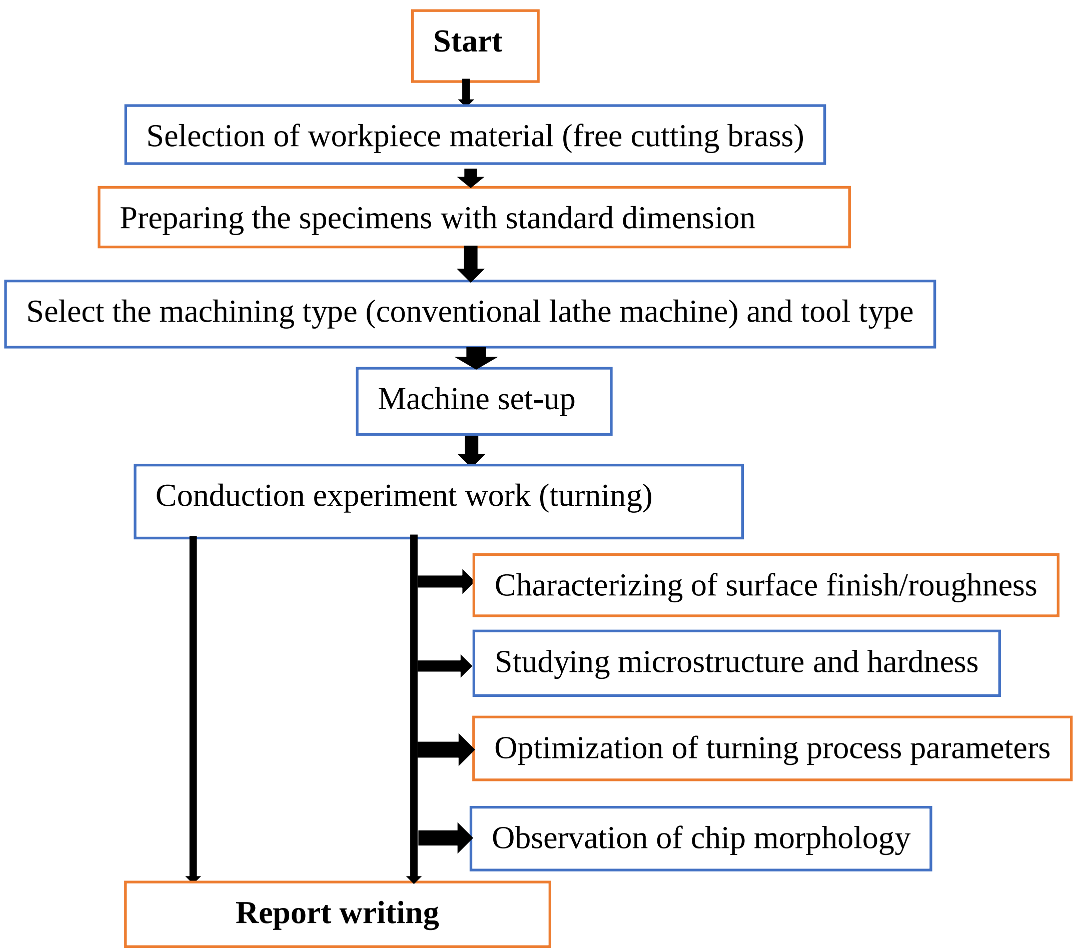


Figure 3.1 Experimental Procedure

3.3 Materials

Materials used for this study was free cutting brass (CuZn39Pb3) which is highly used in the application of gears, pinions, bolt and nuts, high speed screw machine parts etc. This copper alloy material consists of 61.5%Cu, 3.0%Pb and 35.5%Zn.

3.3.1 Properties of workpiece material

As free cutting brass is one of the most types of copper alloy which is widely used in the application of Gears, pinions, automatic high-speed screw machine parts, bolts and nuts were selected for this study. Table 3.1 presents the composition and properties of free cutting brass material.

Table 3.1 Properties and Typical Applications of free cutting brass[18]

Type and UNS number	Nominal composition (%)	Ultimate tensile strength (Mpa)	Yield strength (Mpa)	Elongation in 50 mm (%)	Hardness (HV)	Typical application
Free-cutting brass (C36000)	61.5 Cu, 3.0 Pb, 35.5 Zn	340–470	125–310	53–18	52	Gears, pinions, automatic high-speed screw machine parts

3.3.2 Cutting Tool Materials

Ceramic coated-carbide tool was used in this study because of their chemical inertness, low thermal conductivity, resistance to high temperature, resistance to flank and crater wear and ceramics are suitable coating materials for tools. The most commonly used ceramic coating is aluminum oxide (Al_2O_3). Table 3.2 shows the composition and properties of ceramic coated carbide cutting tool material

Table 3.2 The composition and properties of ceramic coated carbide cutting tool.

Composition	Hardness (HV)	Thermal conductivity (W/m.k)	Transverse rupture Strength (MPa)	Density (g/cm3)	Young's modulus (GPa)
Al_2O_3 (97.5 %), ZrO_2 (2.5%)	2100	29	2150	11.6	530

3.3.5 Equipment Used

Conventional engine lathe machine was used for experimental study for turning process of copper alloy material which is free cutting brass as it is used in different applications like gears, pinions and high-speed screw machine parts. The lathe machine with model of PSG A141 and power 7KW with spindle speed range of 15rpm to 2000rpm was used for this study. General view of a typical conventional lathe machine with its main components are shown in the Figure 3.2. Generally, the equipment used for the study are;

- Optical microscopy,
- Vickers hardness test,
- Profilometer
- Lathe machine with model PSG A141.

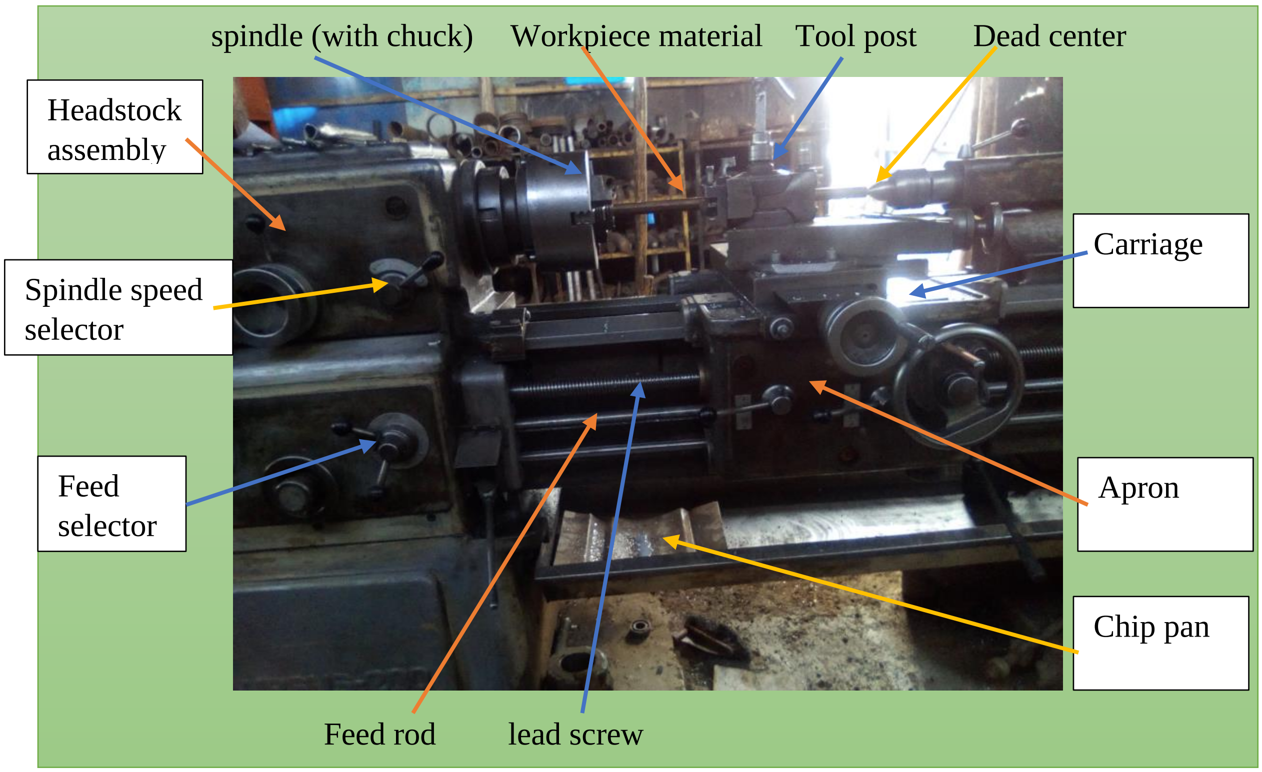


Figure 3.2 General view of a typical lathe, showing various components.

3.4 Research Methodology

By using the materials mentioned above through the following method the experimental work would be continued. Under research methodology the way of specimen preparation, design of experiment procedure, selection of orthogonal array, analysis of variance, methods for measuring surface roughness, methods for measuring hardness of the material used for the study, microstructure observation and chip morphology would be explained.

3.4.1 Specimen Preparation for Turning Operation

The workpiece materials used for this study was a common alloy of copper, free cutting brass ($CuZn39Pb3$) which, is highly used in the applications of bolts, nuts, gears, pinions, high speed screw machine parts etc. Free cutting brass ($CuZn39Pb3$) of 500mm in length and 25mm in diameter was prepared and it was gone to turning process with 1mm depth of cut to remove any irregular parts on the surface for 450mm of length. And then nine experiments with length of 50mm and 1.5, 2.5 and 3.5mm of depth of cut would be operated with different turning parameters for experimental study with different cutting parameters which is selected by using orthogonal array.

3.4.2 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 turning process namely cutting speed, feed and depth of cut each at three levels were considered in case of this thesis. The taguchi design procedure is shown in the Figure 3.3 and the selected process parameters, levels and their values at different levels are given in the Table 3.3.

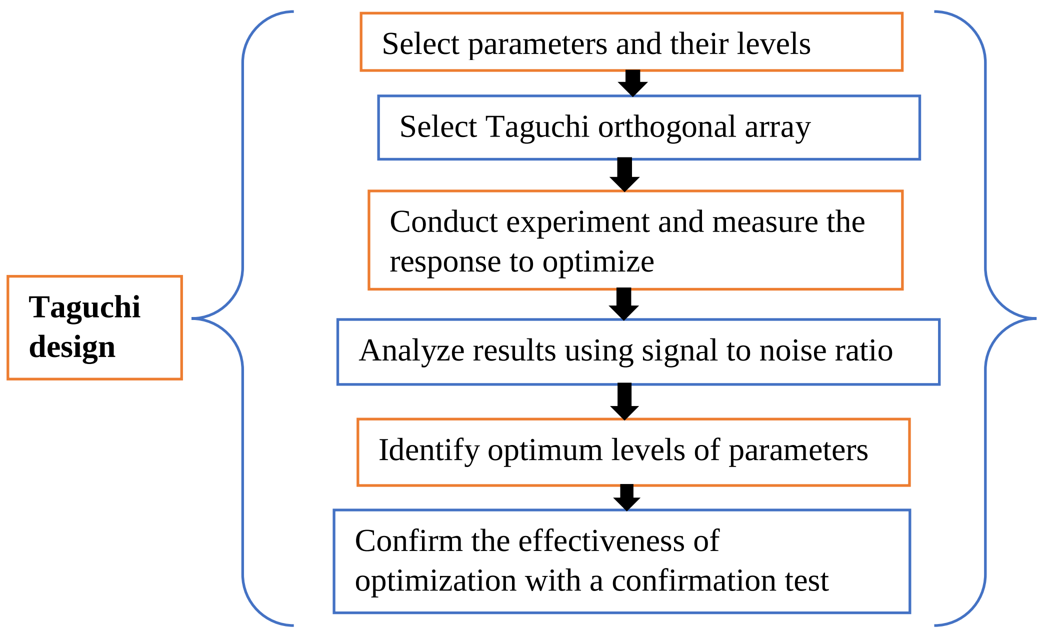


Figure 3.3 Taguchi design procedure.

Taguchi uses the S/N ratio to measure the quality characteristics deviating from the desired value and it offers three categories of signal to noise ratio as follows;

- Larger the better is suitable for determining the profit, production rate etc.
- Nominal the better is applicable for current.
- Smaller the better is appropriate for surface roughness, tool wear, unit cost etc.

Cutting parameters for free cutting brass were selected depending on the recommended cutting parameters which is given in Table 2.1 and the range was taken to get the accurate results, since the maximum difference was at maximum range.

Table 3.3 List of parameters and their levels.

Cutting parameters	Parameters designation	Level		
		1	2	3
Cutting speed (m/min)	A	30	40	50
Feed (mm/rev)	B	0.3	0.5	0.7
Depth of cut (mm)	C	1.5	2.5	3.5

3.4.3 Selection of Orthogonal Array and Column Assignment

The cutting experiments were carried out on conventional lathe machine by using ceramic coated carbide tools for machining of free cutting brass (CuZn39Pb3**)** workpiece with selected cutting parameters within three levels given in the Table 3.3 according to recommended cutting parameters for copper alloys.

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) can be calculated by the formula as given below.

$$DOF = P * (L - 1) \tag{3.1}$$

Where, DOF= degree of freedom, P = number of factors and L = number of levels

$$DOF = 3 * (3 - 1) \approx L_9 \tag{3.2}$$

Table 3.4 Experimental Layout Using an L-9 Orthogonal Array.

Ex. no	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)
01	30	0.3	1.5
02	30	0.5	2.5
03	30	0.7	3.5
04	40	0.3	2.5
05	40	0.5	3.5
06	40	0.7	1.5
07	50	0.3	3.5
08	50	0.5	1.5
09	50	0.7	2.5

However, total number of experiments 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 are shown in the Table 3.4.

This setup allows the testing of all three variables without having to run $27=3^{3.}$ Nine different samples were manufactured with different parameters and at different levels. In the Taguchi method the response variation was studied using signal-to-noise ratio and minimizing by optimizing the responses parameter. The smaller is the better S/N ratio used for these responses.

$$SN = -10log\left[\frac{1}{r}\sum_{i=1}^{1}(y_i)^2\right] \quad (3.3)$$

Here db. means decibel, y = observation, r = total number of observation and y_i = i^{th} response. The S/N ratio was calculated for surface roughness in each of the nine trial conditions to see the effect of each parameter on the response.

3.4.4 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) was to find which parameters significantly affect the quality characteristic. ANOVA 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 were 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 statistically significance in difference or not in output characteristics. ANOVA analysis involves when α values is below 0.05 is significant and above 0.05 is not significant. Percent contribution measures the percentage contribution of each model term relative to the total sum of squares. The percentage contribution is often a rough but effective guide to the relative importance of each model term. From analysis of variance Percentage contribution of each influential parameter was calculated by the following formula:

$$P(\%) = \left(\frac{SSTR}{SST}\right) * 100 \tag{3.4}$$

where, P: Percentage contribution of individual factor,

SSTR: Sum of squares or treatment sum of squares,

MSE: Mean square Error and

SST: Total sum of squares.

3.4.5 Studying Surface Roughness

The quality of the surface made using conventional and non-conventional machining is important because a smooth surface reduces the chances of surface damage caused by wear and corrosion. Likewise, quality of a part made by turning operation can affect the performance of the surface for wear and corrosion protection. The surface profiles of all samples were quantitively analyzed in order to determine the statistical standard parameter of average roughness, R_a by using tally surface. The roughness of a surface cannot be easily defined by a single parameter. It's an intrinsic property of the surface and 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 result. In this research, after turning process of free cutting brass with different cutting parameters, centerline average surface roughness was measured by surface contact profilometer.

Figure 3.4 surface contact profilometer.

3.4.6 Surface Hardness Testing

Hardness test was carried out at room temperature using ASTM E 384 standard Vickers hardness tester with at least four indentations of the specimen and then the average values were utilized to calculate hardness number. The Specimens were grinded and polished with 400, 800, and 1200 grit emery paper followed by dry and wet 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 uses 10 Kgf (98.07N) at dwell time of 15 seconds per the specimen. A diamond indenter tip is pressed on the surface of the sample to make indentation mark. The hardness of the sample was measured from the dimension of indenter mark observed on the surface. Figure 3.5 illustrates a schematic diagram of Vickers hardness testing. The value of Vickers hardness is displayed on the machine after an operator measures the distance of two diagonals ‘d1’ and ‘d2’. The applied load is the direct influential parameter of hardness as well as average dimension values of the diagonals measured. The smaller the indention mark formed on the surface confirms the harder the material when compared to bigger indentation mark under the same load and surface condition. Figure 3.6 shows Vickers hardness testing machine. Vickers hardness is evaluated using the following expressions:

HV = constant * test force / surface area of indentation

$$HV = \frac{0.102 * 2F[\sin\frac{136^o}{2}]}{d^2} \quad (3.5)$$

Where, F is the test force (kgf) and d arithmetic mean of two diagonals d_1 and d_2 (mm).

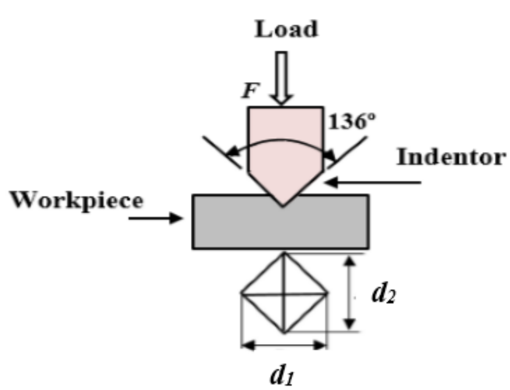


Figure 3.5 A schematic of Vickers hardness testing machine.

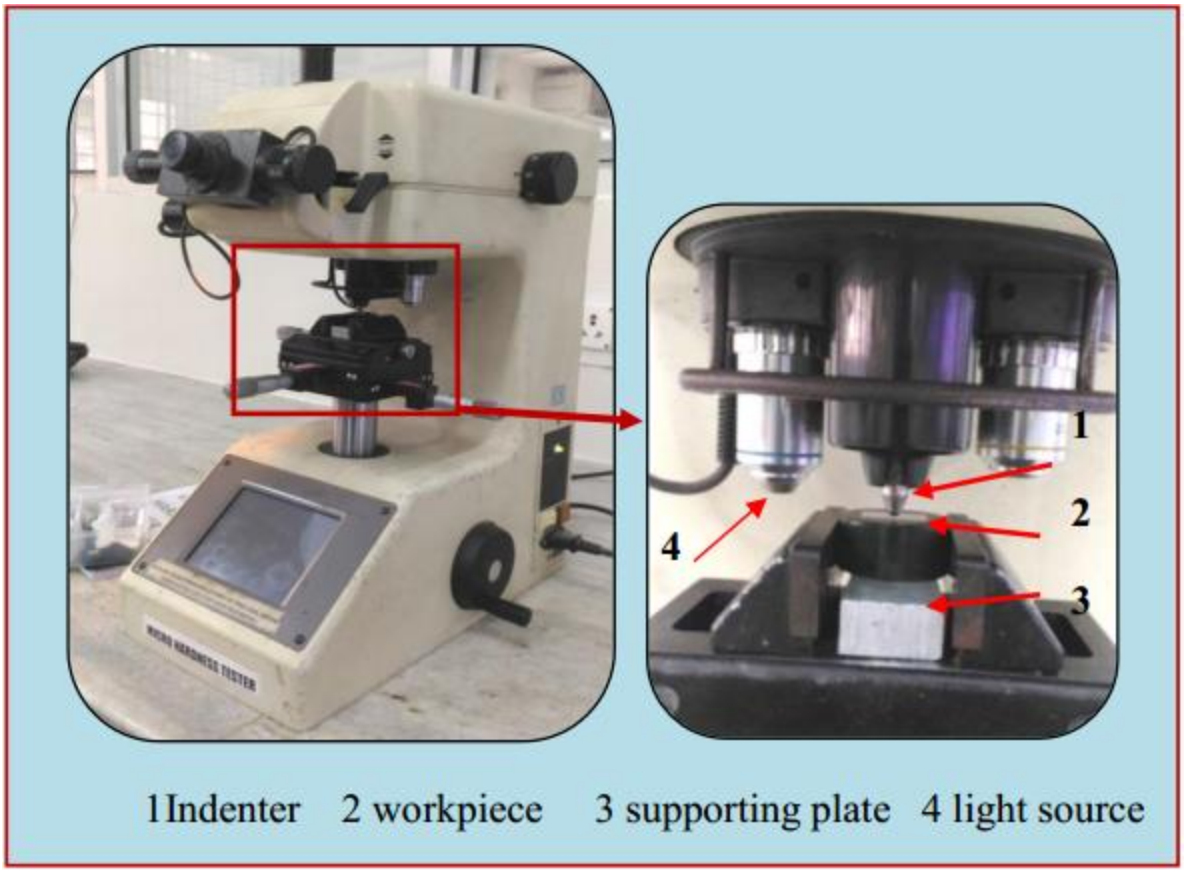


Figure 3.6 Vickers hardness-testing machine for measuring hardness.

3.4.7 Microstructure Observation

Determining grain size, shape and distribution of various phases and inclusions was important as these effects of the mechanical properties of the metal. The microstructure would expose the mechanical and thermal treatment of the metal and it may be possible to predict its behavior under a given sets of conditions. The microstructure of the specimen was observed by using Metallurgical Microscope of model: Huvitz HR-300 series, magnification: X50, X100, X200, X500, X1000, scanning area: 104x102mm, illumination system: 12V, 1000W halogen lamp (Figure 3.9). The cross-sections of the specimen were ground with 400–1200 grit silicon carbide papers, and polished using diamond suspension. The polished specimens were cleaned with acetone and etched with (Methanol (25ml) + Hydrochloric (25ml) + Nitric Acid (25ml) + Hydrofluoric acid 1 drop). The specimen preparation of sample to examine microstructure was cutting of specimen, grinding, polishing, etching and observing microstructure by optical microscopy.

Figure 3.7 shows the procedures required to study microstructure of the specimen through different methods to get the result.

Figure 3.7 microstructure observation procedure.

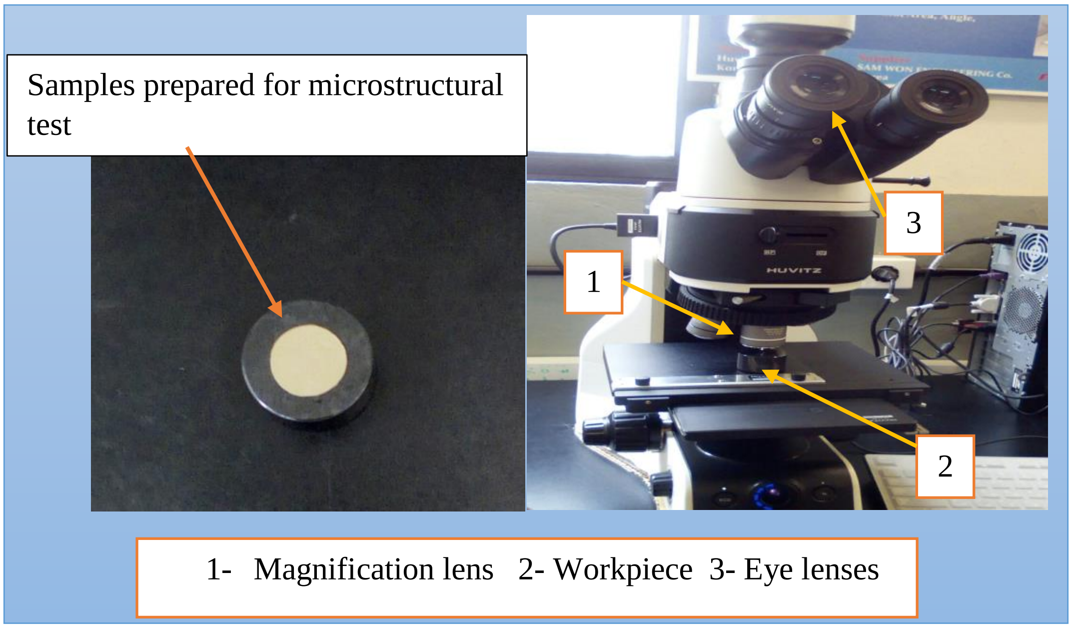


Figure 3.8 Optical microscope and specimen used.

3.4.8 Studying Chip Formation

Chip formation and effective chip removal are important in those cutting techniques in which the cutting zone is spatially limited, such as drilling, reaming, milling and all turning operations on automatic lathes. The details of chip formation process can be most readily seen using the orthogonal cutting model. In the orthogonal model, chip formation is considered to occur as a two-dimensional process in a plane perpendicular to the cutting edge [38].

During the machining process, the cutting tool penetrates the work material, which deforms first elastically and then plastically. As soon as the shear stress induced by the tool reaches or exceeds the shear strength of the work material in the shear zone, the material begins to flow. Depending on the tool geometry used, the deformed work material forms a chip that flows across the face of the cutting tool. Friction between the contact planes of the tool and the underside of the chip or the new workpiece surface creates shear stresses in the secondary shear zones. Generally, four main types of chip can be formed: continuous chips, continuous segmented chips, semi-continuous segmented chips and discontinuous chips.

Continuous chips form when the material being cut flows away continuously from the machining point. The regions of deformed material undergo lamellar sliding but without exceeding the shear strength of the material. If the work material being machined is of sufficient ductility, the chip formed will usually be continuous in form, provided that the cutting process is not impaired by the influence of external vibrations. If the workpiece material is of lower ductility, if it has an inhomogeneous microstructure or if it is subjected to external vibrations, machining will result in the formation of continuous segmented (or serrated) chips. Compared with continuous chips, the upper surface of the chip in this case exhibits a pronounced sawtooth-like structure. Continuous segmented (or serrated) chips can form at high feed rates and at high cutting speeds.

Semi-continuous segmented (or serrated) chips, on the other hand, consist of chip sections that were completely separated in the shear zone. This type of chip forms when the degree of deformation in the shear zone exceeds the material's ductility. Discontinuous chips typically form when brittle materials with an inhomogeneous microstructure are machined. These chips are not cut but rather torn from the surface of the work material, with the result that the workpiece surface is frequently damaged by these small chip fragments.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1 Introduction

Experimental study was conducted to evaluate the effect of cutting parameters namely cutting speed, depth of cut and feed on the surface quality of brass during turning process. The results for each experiment were discussed under this chapter. Design of experiment was used to identify the optimum cutting parameters and to identify the most influential parameters.

4.2 Samples After Turning Process

All nine experiment's with different cutting parameters but with the same length of 50mm after dry turning process of free cutting brass material are given in Figure 4.1. The diameter of the workpiece prepared for experimental work is 23mm and after turning process its reduced with 1.5, 2.5 and 3.5mm depth of cut. Experiment number 1, 2 and 3 were operated by similar cutting speed of 30m/min but, with different feed (0.3, 0.5 and 0.7 respectively) and depth of cut (1.5, 2.5 and 3.5 respectively). By similar manner experiment number 4, 5 and 6 were operated by similar cutting speed of 40m/min but with different feed (0.3, 0.5 and 0.7 respectively) and depth of cut (2.5, 3.5 and 1.5 respectively). And the last three experiments were also operated by similar cutting speed of 50m/min, but with different feed (0.3, 0.5 and 0.7 respectively) and depth of cut (3.5, 1.5 and 2.5 respectively).

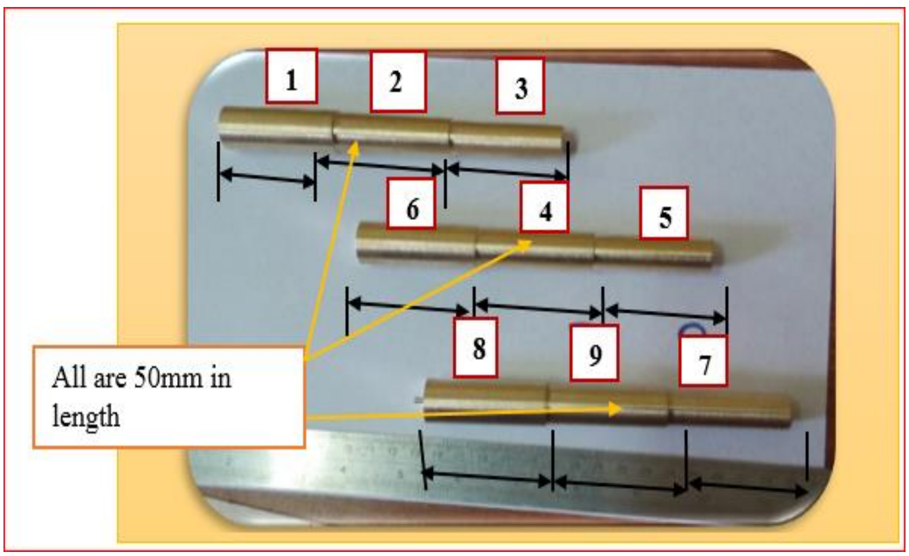


Figure 4.1 Samples after turning process.

4.3 Microstructural Analysis

Figure 4.2 (a) shows that the microstructures of the machined surface produced when machining with ceramic coated carbide tools under dry cutting conditions. It was found that when machining under dry conditions, a thin layer of disturbed or plastically deformed layer was formed immediately underneath the machined surface. Figure 4.2 (b) shows the smooth surface with less disturbed layer of the machined surface observed at magnification of X500 and some particles or voids were observed on the microstructure of machined product with magnification of X1000 at the cutting speed of 50m/min, feed 0.3mm/rev and depth of cut 3.5mm. In this study the microstructure analysed was only for the optimum cutting parameters in which the minimum surface roughness was obtained.

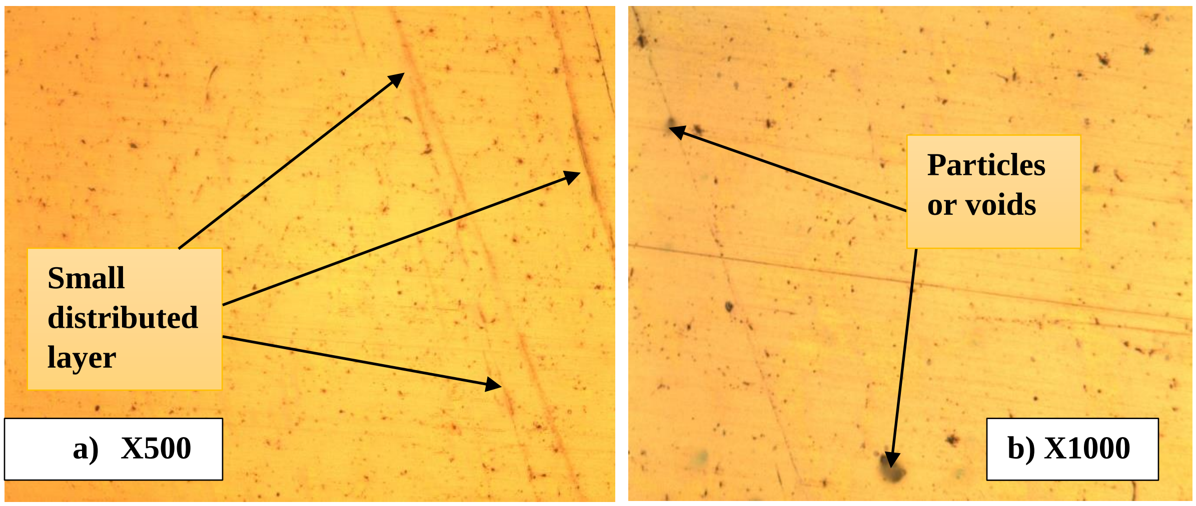


Figure 4.2 Microstructure of free cutting brass after turning process.

4.4 Hardness Analysis

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 quality of product during turning process and it must be less than that of cutting tool material. Load used during hardiness test was 98.07 N (10 kgf) on three trails on a sample. Average result was taken for HV value of a sample.

Table 4.1 Hardness value of specimen for three trails.

Hardness	Trail-1	Trail-2	Trail-3	Average
HV	62.2	63.0	62.6	62.6

From the previous studies it is evident that the harder the workpiece material, the lower is the surface roughness obtained for a given set of operating parameters. This phenomenon may be explained by a finding presented in [43]. Similarly, the average hardness of the machined product in this study was 62.5HV which, indicates that the hardness was increased by 10HV during machining since, the hardness for workpiece material was 52 HV.

4.5 Optimization of Process Parameters on The Surface Quality of Free Cutting Brass

As the objective of this study were the optimization of turning parameters for free cutting brass by using Taguchi method, through the Taguchi procedure the optimum turning parameters and the most significant factors that affect the surface quality of the machined product would be identified as follows.

4.5.1 Taguchi Design of Experiment

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus primarily on main effects. These designs can be used to estimate main effects using only a few experimental runs. Taguchi 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. In Taguchi method, response variation is studied with the help of signal-to-noise (S/N) ratio. The uncontrollable parameters are affected quality of the characteristics. The undesirable parameter values are expressed as "noise" (standard deviation) and desirable parameters values are termed as "signal (mean). Under the investigation, the product quality determined factors, which are assigned in the design of experiment elevated as response factor of the analysis. The external uncontrollable factors, outcome quality of the product is affected. Specimens are prepared based on L_9 orthogonal array and the S/N ratios are calculated using MINITAB 17 software. From the SN ratio for “smaller is better” is used to identify the optimum parameters because a smaller surface roughness is desired in this study.

4.5.2 Analysis of Mean for Surface Roughness Test

The average mean value of surface roughness for each factor i.e. Cutting speed (A), feed (B) and Depth of cut (C) calculated using the design of experiments. Table 4.2 presents the experimental results of surface roughness (Ra) values for each specimen and their mean values. In this study each surface roughness (Ra) trial value is the average of three trial reading.

Table 4.2 Experimental result for mean value of surface roughness.

Experiment No.	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Surface roughness (µm)			Avg. Ra (µm)	S/N ratios
				Trial 1	Trial 2	Trial 3		
1	30	0.3	1.5	3.5	3.47	2.83	3.27	-10.29
2	30	0.5	2.5	3.22	3.93	3.35	3.50	-10.88
3	30	0.7	3.5	3.29	2.81	2.12	2.74	-8.76
4	40	0.3	2.5	2.75	3.67	2.2	2.87	-9.16
5	40	0.5	3.5	3.15	2.7	2.85	2.90	-9.25
6	40	0.7	1.5	3.01	3.22	2.95	3.06	-9.71
7	50	0.3	3.5	1.58	1.97	1.34	1.63	-4.24
8	50	0.5	1.5	1.8	1.92	1.75	1.82	-5.20
9	50	0.7	2.5	1.9	2.19	1.93	2.01	-6.06
Average performance mean value							2.64	-8.17

The mean value of surface roughness for each factor i.e. Cutting speed (A), Feed (B) and Depth of cut (C) at each level are obtained and the result is listed in response Table 4.3.

Example calculation is shown for factor B (feed):

$$S/N_{B1} = \frac{3.27+2.87+1.63}{3} = 2.59$$

$$S/N_{B2} = \frac{3.5+2.90+1.82}{3} = 2.74$$

$$S/N_{B3} = \frac{2.74+3.06+2.01}{3} = 2.60$$

Table 4.3 Response table for mean effects plot for smaller is better.

Level	Cutting speed	Depth of cut	Feed
	Symbol		
	A	B	C
1	3.17	**2.59**	2.72
2	2.94	2.74	2.79
3	**1.82**	2.60	**2.42**
Delta	1.35	0.15	0.37
Rank	1	3	2

The control factors main effect plot for means of surface roughness value variations is as shown in the Figure 4.3. The result taken from the above data shows means as smaller is better is selected for surface roughness value output.

$$Delta = (Maximum\ mean - Minimum\ mean)$$

The factor with the greatest effect on the mean from Table 4.3 is cutting speed (Delta = 1.35, Rank = 1). The factor with the least effect on the mean is feed (Delta = 0.15, Rank = 3). Since main effect plots for means is helpful for adjusting the mean on better value. Those parameter levels with better surface finish value of specimens that means **A3B1C3** will be taken as a possible parameter combination for better values. The significant factors in the order increasing by affecting surface roughness is feed, depth of cut and cutting speed as its seen on the Table 4.3.

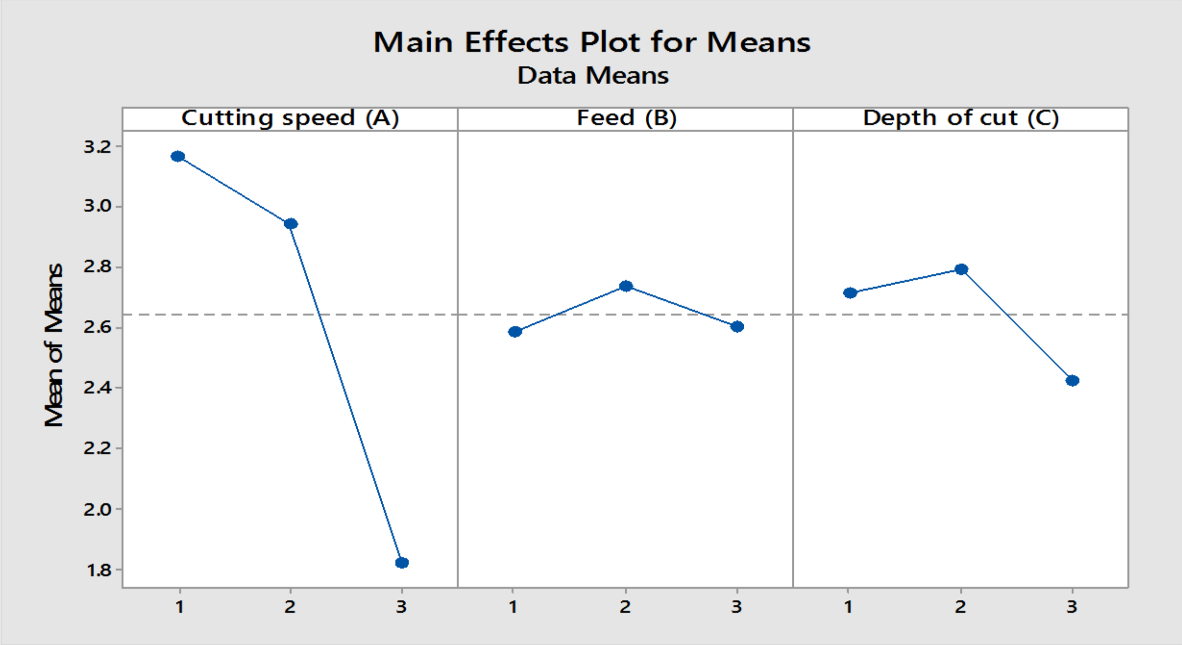


Figure 4.3 Main effect plot for means.

It can be seen from Figure 4.3 that within the scope of this investigation the minimum point in the graph for each turning parameters are the optimum conditions. The minimum point for cutting speed and depth of cut are at level three, but for feed the minimum point on this graph was at level one. This is why the identified optimum turning parameter was at high cutting speed, low feed and high depth of cut which is A3B1C3.

4.5.2.1 Predict the Performance at Optimal Levels the Mean Value

For predicting the optimum response, three factors of parameters are selected by small mean value. **A3B1C3** is the optimum levels of parameters mean value for surface roughness value. To find out predicted value of the responses (surface roughness value) the following linear regression equation is used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC3 - m) \qquad (4.1)$$

Where, m = Average performance mean value for surface roughness, $mA3$ = optimum level value for parameter A, $mB1$= optimum level value for parameter B, $mC3$= optimum level value for parameter C.

$$y_{0pt} = 2.64 + (1.82 - 2.64) + (2.59 - 2.64) + (2.42 - 2.64)$$

$y_{0pt} = 1.55$ (predict mean value for surface roughness value)

4.5.2.2 Analysis Of S/N Ratios for Surface Roughness

The Taguchi method uses S/N ratio to measure the variations of the surface roughness value in experimental design. The equations for calculating the signal to noise ratios are based on the characteristics of the response variables being reported. In this thesis, the response variables are smaller-the-better. Table 4.2 presents the calculations of S/N Ratios for surface roughness value results using design of experiments. And table 4.4 presents the response table for signal to noise ratios for smaller is better for this study. Example of calculation for response table for signal to noise ratio is as follows.

Example calculation is shown for factor C (Depth of cut):

$$S/N_{C1} = \frac{(-10.29)+(-9.71)+(-5.20)}{3} = -8.40$$

$$S/N_{C2} = \frac{(-10.88)+(-9.16)+(-6.06)}{3} = -8.70$$

$$S/N_{C3} = \frac{(-8.76)+(-9.25)+(-4.24)}{3} = -7.42$$

Table 4 Response Table for Signal to Noise Ratios Smaller Is Better.

Level	Cutting speed	Feed	Depth of cut
	Symbol		
	A	B	C
1	-9.98	**-7.90**	-8.40
2	-9.37	-8.44	-8.70
3	**-5.17**	-8.18	**-7.42**
Delta	4.81	0.55	1.29
Rank	1	3	2

$$Delta = (Maximum\frac{S}{N}ratio - Minimum\frac{S}{N}ratio)$$

By looking at the surface roughness response table (Table 4.4) and main effect plot for the signal to noise (S/N) ratios the cutting speed weight percentage have the greatest effect (Delta = 4.81, Rank = 1). The factor with the least effect on the (S/N) ratio is feed (Delta = 0.55, Rank = 3). Table 4.4 shows that optimal parameter combination on smaller is the better surface quality character is **A3B1C3** are the possible parameter combinations for increasing the surface quality of specimens. The control factors main effect plot for the surface roughness S/N ratio is shown in the Figure 4.4.

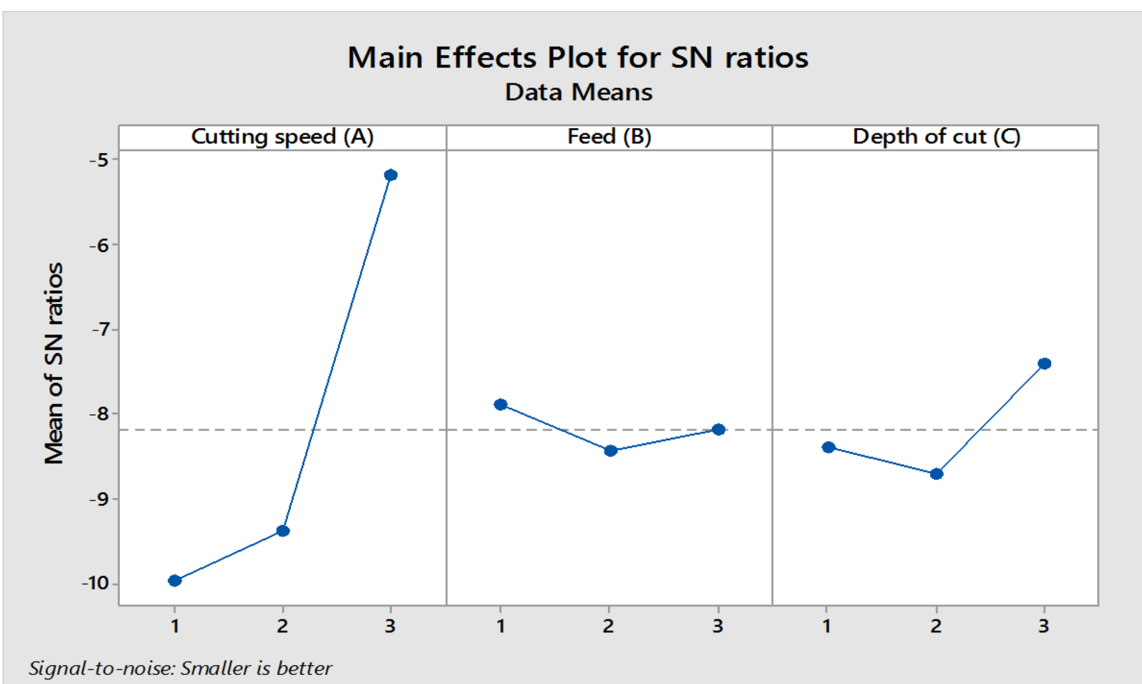


Figure 4.4 Main effects plot for S/N ratio.

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 and feed has the least effect on the surface roughness. Since, S/N ratio used for this study is smaller is better and smallest S/N ratio was selected as it shown in the Figure 4.4. That is cutting speed at level 3, feed at level 1 and depth of cut at level 3 (A3B1C3) was selected.

4.5.2.3 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. **A3B1C3** is the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response (surface roughness value) linear regression equation 3.2 was used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC3 - m)$$

$$y_{0pt} = -8.17 + (-5.17 - (-8.17)) + (-7.90 - (-8.17)) + (-7.42 - (-8.17))$$

$y_{0pt} = -4.15$ (predict S/N value for surface roughness)

4.5.3 Analysis of Variance (ANOVA) For Surface Roughness

Analysis of variance (ANOVA) is used to identify the most significant factors which affects the surface roughness of the machined part. It was calculated and reported in Table 4.5. Percent contribution for each factor were calculated by equation (3.4). Where DOF= degree of freedom, SST=Total sum of squares, SSTR = Treatment Sum of squares, MSE = Mean square error and F = F- Ratio calculated by using Minitab 17 software.

Table 4.5 Analysis of Variance for surface roughness value.

Source	DOF	SST	SSTR	MSE	F	P	Percent contribution	Significance (α=0.05)
Cutting speed	2	3.14	3.14	1.57	24.75	**0.039**	88.74%	Highly Significant
Feed	2	0.04	0.04	0.02	0.33	0.754	1.13%	Less significant
Depth of cut	2	0.23	0.23	0.11	1.81	0.356	6.46%	Significant
Residual error	2	0.13	0.13	0.06			3.67%	
Total	8	3.53					100%	

Table 4.5 presents surface roughness percentage contribution variation of factors A, B and C; where factors represents cutting speed, feed and depth of cut respectively. 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 4.5 it is observed that cutting speed factor has statistical and physical significance on the surface roughness value during turning operation of free cutting brass bar at 95% of level of confidence. From the Table 4.5 it is clearly observed that the cutting speed weight percentage (88.74%), feed (1.13%) and depth of cut (6.46%) have significant influence on the surface roughness of free cutting brass specimens. Therefore, cutting speed has significant effect parameter on the surface roughness of free cutting brass in dry turning process.

A researcher [44] identified the most significant factors that affect the surface roughness of copper beryllium alloy material lubricant temperature contribution is the largest i.e 79.299% followed by feed rate which contribution is 18.05% and then depth of cut 0.01% by using ANOVA method.

4.5.4 Determining the Optimum Condition

From the Table 4.3 and Table 4.4, its clearly observed that cutting speed weight percentage optimum level value 50m/min, feed optimum level value 0.3mm/rev and depth of cut optimum level value 3.5mm make the response S/N ratio values small. Therefore, the optimum processing parameters signal to noise (S/N) ratio was selected. Table 4.6 presents the optimum parameters setting selected for surface roughness obtained from the design of experiment and experimental results. The selected optimum parameters in this study were at higher cutting speed, at lower feed and at maximum depth of cut which, is at A3B1C3.

Table 4.6 Optimum parameters setting levels and their values.

Controllable factors	Level selected	Value of level	Rank of affecting the response
Cutting speed	3	50	1
Feed	1	0.3	3
Depth of cut	3	3.5	2

4.5.5 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 Orthogonal Array, then no confirmation test is required. By considering this, Confirmation test was not required in this case study because the optimum combination of parameters and their levels **(A3B1C3**) have a correspondent to an experiment of the orthogonal array of the trail 7 condition of the experiment. 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. The Optimum combination of parameters obtained from Table 4.6 was at 50m/min Cutting Speed, 0.3mm/rev Feed and 3.5mm Depth of cut. Table 4.7 presents the confirmation experiment and predicted results comparison for surface roughness measurements.

Table 4.7 Comparison between predicted and experimental confirmation.

Response	Optimal parameter	Predicted value		Experimental value	
Surface Roughness (µm)	A3B1C3	Mean	S/N	Mean	S/N
		1.55	-4.15	1.63	-4.24

It can be seen from Table 4.7 the result between experimental result and the predicted results are very small. The values predicted by using Taguchi approach is approximately near to the value which is experimentally obtained. This verify that, the experimental results of surface roughness are strongly correlated with the predicted results.

4.7 Observation of Chip Morphology

Discontinuous chips were observed due to heterogeneous microstructure of the free cutting brass, in dry turning operation of this study. Figure 4.5 shows the chips formed in dry turning process of free cutting brass for all nine different experiments conducted in this study. Due to the presence of lead element in the free cutting brass alloy the chips produced were discontinuous type. The maximum and minimum length of these chips were identified as the longest is 1.6mm and the smallest is approximately the size of powder which is in micrometers as shown in the Figure 4.6.

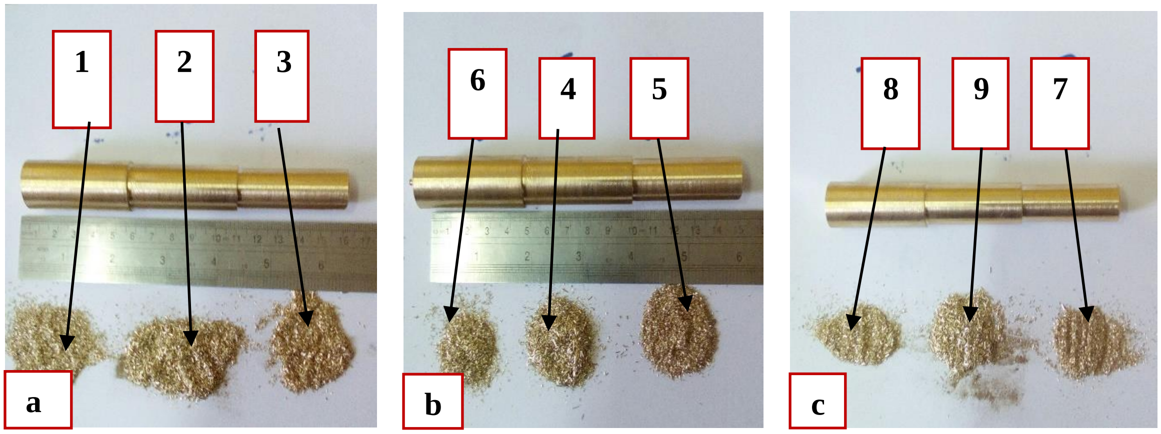


Figure 4.5 Chip morphology (a) for experiment 1,2 and 3 (b) for experiment 4,5 and 6(c) for experiment 7, 8 and 9.

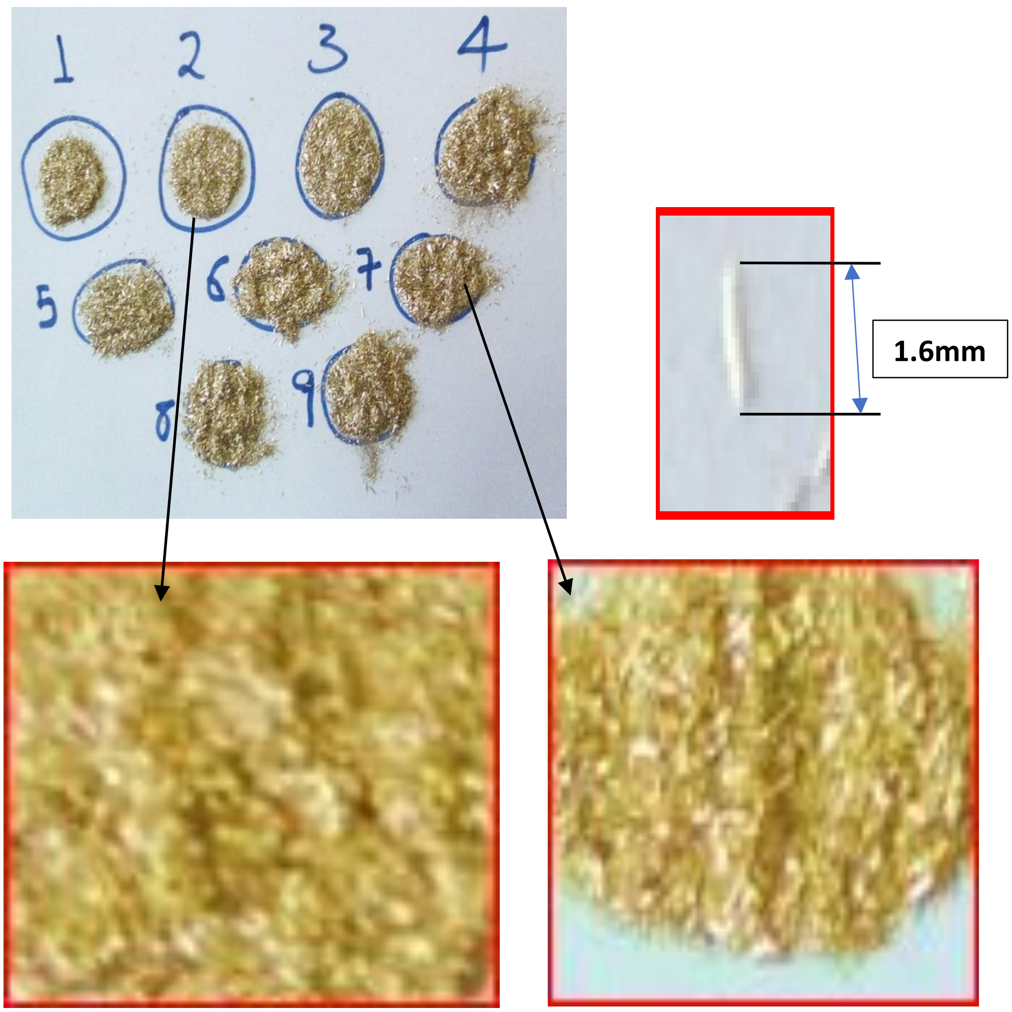


Figure 4.6 Chip morphology for each experiment and the longest chips observed.

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summery

The summery for this study are the following.

1. In the present work, the relationship between surface roughness and various process parameters namely cutting speed, feed and depth of cut has been developed.
2. Taguchi method has been adopted for the design of experiments and the results have been analyzed by minimum S/N ratio of machining parts that is turning process of free cutting brass.
3. For three factors each at three levels, L_9 orthogonal array was selected.
4. Analysis of variance used to determine the percent contribution of each parameters on the surface finish of the machined part by turning process.
5. Based on the analysis of variance (ANOVA) results, the cutting speed was most significant factor for improving surface roughness whereas feed was the least important.
6. A parameter design gives the optimum condition of the controlled parameters as well as a predictive equation. A verification procedure is then performed, which shows that the selected optimum parameters and predictive equation were accurate to within the limits of the measurement.
7. Based on the experiment work, optimum cutting parameters achieved for free cutting brass were 50m/min cutting speed, 0.3mm/rev feed and 3.5mm depth of cut.

5.2 Conclusions

In this thesis, Taguchi optimization method has been utilized to determine the optimal dry turning parameters which affects the surface quality of free cutting brass in turning process. The main parameters that affects surface roughness have been identified and analyzed under different conditions and finally optimized. The main parameters being cutting speed, feed and depth of cut. Based on the results the conclusions are drawn as follows.

1. In turning of free cutting brass for minimum surface roughness, use of higher cutting speed (50m/min), lower feed (0.3mm/rev) and higher depth of cut (3.5mm) were selected. That

is A3B1C3 are optimized to get low surface roughness which is high surface finish of machined part.

2. The contribution of most influential parameters such as cutting speed was 88.74%, feed 1.13% and depth of cut was 6.46%.
3. The major advantage of this research work recommends possibility of dry machining which save cost of machining and also contributes to green manufacturing.
4. This work has proved implementation of micromanufacturing using conventional machining process due to the fact that the surface finish obtained was in microns.

5.3 Recommendations

Based on the results and conclusions found from this study, the researcher forwards the following recommendations in machining of copper brass alloys.

1. In this study free cutting brass has been used. This can be further extended to other types of copper alloys to study the effect of cutting parameters on the surface roughness under the same condition of turning parameters.
2. The study can be extended by various parameters and their interactions and the mechanical studied can also be carried out.
3. This study was limited to single response only. However, a multi-response optimization of machining parameters for surface roughness can be used and analyzed.
4. The study can be extended by using double tool turning to improve productivity.
5. For copper brass alloys dry machining is highly recommended in machining industries.

5.4 Scope for Future Work

In this research only three cutting parameters have been studied in accordance with their effects, the further researcher can be carried out to;

1. In this study only the effect of cutting parameters on the surface roughness was considered due to, the difficulties for measuring the cutting force (unavailability of dynamometer) and difficulties for measuring the machine vibration frequencies (unavailability of accelerometer) which are important factors those affects the surface roughness of the machined part would be analyzed and optimized.
2. Study the effects of tool geometry like Nose radius and Rake angle on the surface roughness and MRR of free cutting brass in turning process.

3. Analyses the effect of cutting forces exerted and tool wear rate during the cutting operation.
4. Studies other output response like tool life, material removal rate and power consumption.
5. Study the effect of different cutting tools with similar cutting parameters.
6. Future research work may be directed towards applying response surface methodology and genetic algorithm for further fine optimization of cutting parameters, which work beyond the scope of this research as it was mainly focused towards the identification of most significantly influencing factors.

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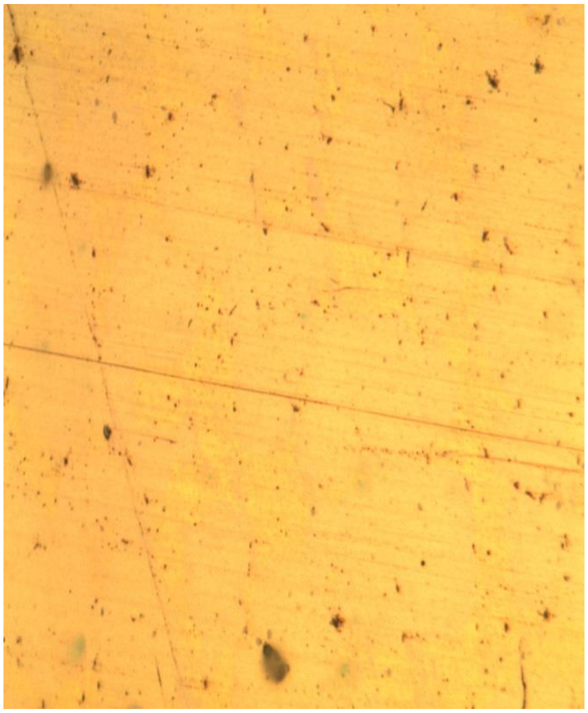
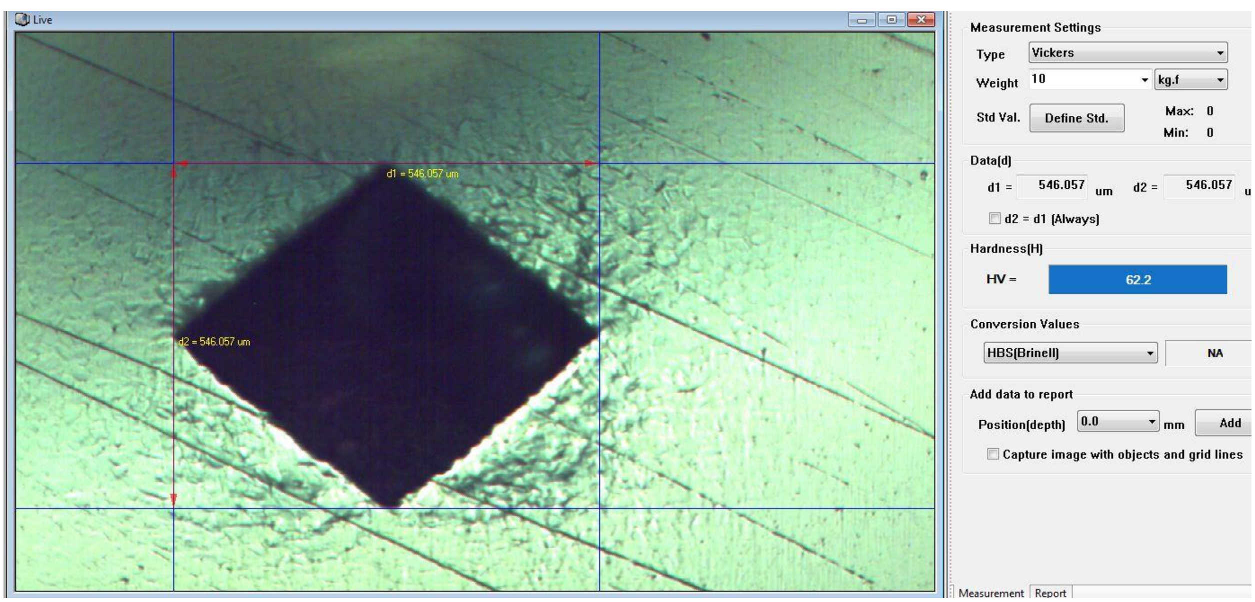
Appendix-A: Optical Microscopy Micrographs

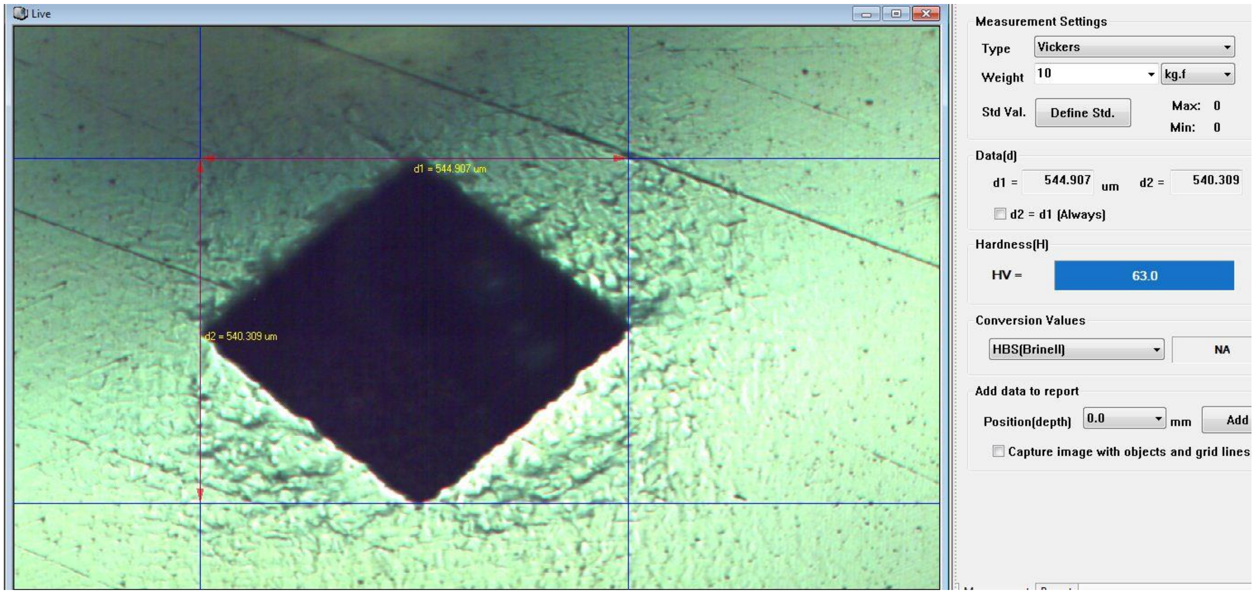


At magnification of 500X

At magnification of 1000X

Appendix-B: Vickers Hardness Test Results





Appendix-C: Taguch's Result

Response Table for Means

Level	Cutting speed (A)	Feed (B)	Depth of cut (C)
1	3.170	2.590	2.717
2	2.943	2.740	2.793
3	1.820	2.603	2.423
Delta	1.350	0.150	0.370
Rank	1	3	2

Worksheet 1

	C1	C2	C3	C4	C5	C6	C7	C8
	Cutting speed (A)	Feed (B)	Depth of cut (C)	ra	SNRA1	MEAN1	PSNRA1	PMEAN1
1	1	1	1	3.27	-10.2910	3.27	-4.13684	1.54444
2	1	2	2	3.50	-10.8814	3.50		
3	1	3	3	2.74	-8.7550	2.74		
4	2	1	2	2.87	-9.1576	2.87		
5	2	2	3	2.90	-9.2480	2.90		
6	2	3	1	3.06	-9.7144	3.06		
7	3	1	3	1.63	-4.2438	1.63		
8	3	2	1	1.82	-5.2014	1.82		
9	3	3	2	2.01	-6.0639	2.01		

```
Response Table for Signal to Noise Ratios
Smaller is better

        Cutting              Depth of
Level  speed (A)  Feed (B)   cut (C)
1        -9.976    -7.897    -8.402
2        -9.373    -8.444    -8.701
3        -5.170    -8.178    -7.416
Delta     4.806     0.546     1.285
Rank          1         3         2
```

↓	C1	C2	C3	C4	C5	C6	C7	C8
	Cutting speed (A)	Feed (B)	Depth of cut (C)	ra	SNRA1	MEAN1	PSNRA1	PMEAN1
1	1	1	1	3.27	-10.2910	3.27	-4.13684	1.54444
2	1	2	2	3.50	-10.8814	3.50		
3	1	3	3	2.74	-8.7550	2.74		
4	2	1	2	2.87	-9.1576	2.87		
5	2	2	3	2.90	-9.2480	2.90		
6	2	3	1	3.06	-9.7144	3.06		
7	3	1	3	1.63	-4.2438	1.63		
8	3	2	1	1.82	-5.2014	1.82		
9	3	3	2	2.01	-6.0639	2.01		

```
Analysis of Variance

Source                 DF   Adj SS    Adj MS   F-Value  P-Value
  Cutting speed (A)     2  3.13576  1.56788     24.75    0.039
  Feed (B)              2  0.04136  0.02068      0.33    0.754
  Depth of cut (C)      2  0.22882  0.11441      1.81    0.356
Error                   2  0.12669  0.06334
Total                   8  3.53262
```

↓	C1	C2	C3	C4	C5
	Cutting speed (A)	Feed (B)	Depth of cut (C)	ra	
1	30	0.3	1.5	3.27	
2	30	0.5	2.5	3.50	
3	30	0.7	3.5	2.74	
4	40	0.3	2.5	2.87	
5	40	0.5	3.5	2.90	
6	40	0.7	1.5	3.06	
7	50	0.3	3.5	1.63	
8	50	0.5	1.5	1.82	
9	50	0.7	2.5	2.01	
10					