# EFFECT OF LUBRICATION CONDITION ON SURFACE ROUGHNESS IN TURNING OPERATION

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

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NOVEMBER 2010

## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Signature

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## STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: MOHD ZULHILMI BIN RIFIN
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Specially dedicated to my beloved father, Rifin Bin Seman
Mother , Nor'Ani Binti Ismail
&
My Supervisor
Nur Azhani Abd Razak
For the support and care…

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## ABSTRACT

Minimum quantity of lubrication (MQL) in machining is an established alternative to completely dry or flood lubricating system from the viewpoint of cost, ecology and human health issues. Hence, it is necessary to select MQL and cutting conditions in order to enhance machinability for a given work material. This thesis describes experimental investigations on influence of different lubrication conditions such as minimum quantity lubrication (MQL), dry machining and wet machining on surface roughness. The surface roughness was examined with Perthometer. In this research, the main objective is to determine the effect of the lubrication conditions on the surface roughness in turning operation. Three different materials had been chosen as work material. Those were ASTM B176 Brass, AISI 1060 Aluminum Alloy and AISI 304 Stainless Steel. Two other parameters were also considered in this study; depth of cut and cutting speed. The ranges of depth of cut used were 0.2mm and 0.4mm whereby the cutting speed values were 810rpm and 1400rpm. Response Surface Method (RSM) was used to predict the surface roughness. Based on the generated results, the correlation for surface roughness with the cutting parameters satisfies a reasonable degree of approximation. It was found that, minimum quantity lubricants produced better surface finish as compared to dry and wet machining. The result can significantly reduce cost and environmental pollution by using minimum quantity lubrication.

# ABSTRAK

Minimum kuantiti pelincir (MQL) dalam pemesinan dijadikan alternatif kepada pemesinan kering atau sistem pemesinan pelinciran maksimum, dari sudut kos, isu-isu ekologi dan masalah kesihatan manusia. Maka adalah perlu untuk memilih MQL dan keadaan pemesinan yang betul untuk meningkatkan kebolehmesinan untuk bahan kerja yang di beri. Tesis ini menerangkan kajian eksperimen tentang kesan perbezaan keadaan-keadaan pelinciran seperti minimum kuantiti pelinciran (MQL), pemesinan kering, dan pemesinan basah, ke atas kekasaran permukaan. Kekasaran permukaan diperiksa dengan menggunakan Perthometer. Dalam kajian ini, objektif utamanya ialah untuk menentukan kesan keadaan-keadaan pelinciran terhadap kekasaran permukaan dengan menggunakan mesin larik. Tiga bahan yang berbeza dipilih sebagai bahan kerja dalm kajian ini. Ianya adalah ASTM B176 Brass, AISI 1060 Alloy Aluminium dan AISI 304 Stainless Steel. Dua parameter yang lain lagi yang digunakan dalam kajian ini; kedalaman pemotongan dan kelajuan pemotongan. Julat kedalaman pemotongan yang digunakan ialah 0.2mm dan 0.4mm, manakala nilai-nilai kelajuan pemotongan ialah 810rpm dan 1400rpm. Response Surface Roughness (RSM) digunakan untuk meramal kekasaran permukaan. Berdasarkan keputusan yang diperolehi, kolerasi untuk kekasaran permukaan dengan keadaan pemotongan, mencapai tahap yang di anggarkan. Telah didapati bahawa kuantiti pelinciran minimum menghasilkan permukaan yang lebih baik berbanding dengan pemesinan kering dan pemesinan basah. Hasilnya dapat aplikasikan dalam mengurangkan kos dan pencemaran alam sekitar dengan menggunakan kuantiti minimum pelincir.

# TABLE OF CONTENTS

**APPENDICES**

# LIST OF TABLES

# LIST OF FIGURES

## LIST OF SYMBOLS

| | |
|---|---|
| $D_1$ | Initial diameter |
| $D_2$ | Final diameter |
| $V$ | Cutting speed |
| $S_0$ | Feed rate |
| $\alpha$ | Rake angle |
| $\mu m$ | Micrometer |
| $Ra$ | Surface roughness |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AISI | American Iron and Steel Institute |
| ANOVA | Analysis of Variance |
| ASTM | American Standard Testing Material |
| BUE | Build Up Edge |
| CS | Cutting Speed |
| D | Diameter |
| DOC | Depth of Cut |
| DOE | Design of Experiment |
| MQL | Minimum Quantity Lubricant |
| PCMCIA | Personal Computer Memory Card International Association |
| Rpm | Revolution per minute |
| RSM | Response Surface Method |

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

Recently, increasing production quality and minimizing costs in machining process have become important aspects for green machining. Higher material removal rates and better product qualities have been obtained by using new cutting tool materials and various cutting fluids. New cutting tools have greatly been used to improve machining of several engineering materials. There are still some problems in machining process, especially, the severe friction and high temperature in cutting zone. The friction and rising of temperature during cutting processes negatively affect tool life (Wang, 2000).

Surface roughness is a commonly encountered problem in machined surfaces. It is defined as the finer irregularities of surface texture, which results from the inherent action of the production process. Consequently, surface roughness has a great influence on product quality. Furthermore a good-quality machined surface significantly improves fatigue strength, corrosion resistance, and creep life (Dhar et al., 2005).

Lubrication is simply the use of material to improve the smoothness of movement of one surface over another, and the material which is used in this way is lubricant. Lubricant are usually liquid or semi-liquid, but may be solid or gasses or any combination of solids, liquids and gasses. In addition to reducing or controlling friction, lubricants are usually expected to reduce wear and often to prevent overheating and corrosion. It also can improve tool life and surface condition.

Pollution generated during machining mainly come from waste cutting fluids. The recycling and disposal of waste cutting fluids is about 16–20% of machining cost (Sreejith, 2000). As disposal cost and environmental impacts of machining processing are high, governmental regulations have been established to force manufactures to reduce or eliminate the amount of wastes. Therefore, it seems to be a better option to eliminate using cutting fluids.

## 1.2 PROBLEM STATEMENT

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work part dimensional accuracy and surface finish, high production rate and cost saving, with a reduced environmental impact. In machining process, it is necessary to attain the desired surface quality in order to produce parts providing the required functioning. The surface quality defines some mechanical properties of the product, such as wear resistance. Being such a considerable quality, surface quality is influenced by various parameters. It will be costly and time consuming to acquire the knowledge of appropriate cutting parameters. At this point, surface roughness prediction will be helpful, which is mostly based on cutting parameters and sometimes some other parameters. Thus the choice of optimized of lubrication become very important to control the required surface quality. The concept of minimum quantity lubrication, sometimes referred to as near dry lubrication, has been suggested since a decade ago, as a means of addressing the issues of environmental intrusiveness and occupational hazards, associated with the airborne cutting fluid particles on factory shop floors. The minimization of cutting fluid also leads to economical benefits by way of saving lubricant costs and workpiece, tool machine cleaning cycle time. Health problem is caused by the long-term exposure to cutting fluids. In order to eliminate the effect of cutting fluids, dry machining has become a reliable choice in machining of some materials. However, some engineering materials still require cutting fluid in their machining operations and this is because of the needed surface quality, tool life, and machining dimensional accuracy (Sreejith, 2000; Vierira, 2001 and Diniz, 2002). Hence the implementation of machining without coolant will bring down the manufacturing cost but can cause tool wear problems and low surfaces finish. Minimum quantity of lubricant can cut of manufacturing cost and produce better surface finish than dry cutting.

## 1.3 PROJECT BACKGROUND

Currently, there is a wide-scale evaluation of the use of cutting fluids in machining. Industries are looking for ways to reduce the amount of lubricants in metal removing operations due to the ecological, economical and most importantly human health. Therefore, it is important to find a way to manufacture products using the sustainable methods and processes that minimize the use of cutting fluids in machining operations. In addition, it is essential to determine the optimal cutting conditions and parameters, while maintaining long tool life, acceptable surface finish and good part accuracy to achieve ecological and coolant less objective.

Lathe machine is the oldest machine tool that is still the most common used machine in the manufacturing industry to produce cylindrical parts. It is widely used in variety of manufacturing industries including automotive and aerospace sectors. Quality of surface plays a very important role in the performance of turning as good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life. Surface roughness also affects several functional attributes of parts, such as wearing, heat transmission, and ability of holding a lubricant, coating, or resisting fatigue. Nowadays, roughness plays a significant role in determining and evaluating the surface quality of a product as it affects the functional characteristic.

The product quality depends very much on surface roughness. Decrease of surface roughness quality also leads to decrease of product quality. In field of manufacture, especially in engineering, the surface finish quality can be a considerable importance that can affects the functioning of a component, and possibly its cost. Surface roughness has been receiving attention for many years in the machining industries. It is an important design feature in many situations, such as parts subject to fatigue loads, precision fits, fastener holes and so on. In terms of tolerances, surface roughness imposes one of the most crucial constraints for the machines and cutting parameters selection in process planning.

In this project, a number of ASTM B176, AISI 1060 Aluminum Alloy and AISI 304 Stainless Steel are turning with lathe machine. This experiment will be held in three conditions which are dry, wet and minimum lubrication. Two machine parameters are varies during this experiment. Full factorial is used to assist in design experiment. By using mixed 2 and 3 level designs, yields 12 run of experiments for each material. Minitab15 software is used for analyzing data obtained.

## 1.4 PROJECT OBJECTIVES

The objectives of this study are to:

(i) Determine the effect of the lubrication condition on surface roughness in turning operation.
(ii) Identify the effectiveness of minimum quantity lubricant as compare to dry and wet machining on surface roughness.

## 1.5 SCOPES OF THE PROJECT

(i) Three different lubrication conditions are considered; wet machining, dry machining and minimum quantity lubricant.
(ii) Machining variables considered are lubrication condition, cutting speed and depth of cut.
(iii) Feed rate is set as constant throughout the entire experiments.
(iv) Turning operation is performed using conventional lathe machine.
(v) The effect of different lubrication conditions on surface roughness of 1060 Aluminum alloy, ASTM B176 brass and AISI 304 Stainless steel is investigated.
(vi) Surface roughness of material is analyzed by using perthometer.
(vii) Minitab15 software is used to analyze the data.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

This chapter is discusses on some literature studies related to the effect of cutting fluid condition on surface roughness in turning operation.

## 2.2 CUTTING FLUID

Cutting fluids have been used for centuries and their form has changed very little, though significant efforts have been made to improve their performance over the past several decades. These attempts at improvement have coincided with a better understanding of the adverse health impacts that cutting fluids can have on people and the environment, which has in turn driven the development of environmentally adapted alternatives. It has been well recognized empirically that supplying some fluid to the vicinity of contact between the tool and the workpiece could facilitate the machining operation, so that the functions of cutting fluids have also been the main subject of early investigations.

At higher cutting speeds, since the tool undergoes wear because of increased temperature, it is important that the cutting fluid acts as a coolant. As cutting speeds lower, the lubricating properties of the fluid become more prominent, easing the flow of the chip up the tool rake face. The main functions of cutting fluids are, cooling at relatively high cutting speeds and lubrication at relatively low cutting speed. Cutting fluids is a liquid added to reduce the friction coefficient between the grain and workpiece by way of cooling and lubrication the cutting site of tools by flooding or spraying (Rao, 2007).

Most metal cutting process need cutting fluids action. Very little (1 to 3 %) of the work of metal cutting is stored as residual stresses in workpiece or chip, more than 97% appearing as heat (Siliman, 1992). Unfortunately, conventional cutting fluids cause environment and health problems. Pollution generated during machining mainly come from waste cutting fluids. The recycling and disposal of waste cutting fluids is about 16–20% of machining costs (Sreejith, 2000). As disposal cost and environmental impacts of machining processing, are high, governmental regulations have been established to force manufactures to reduce or eliminate the amount of wastes. Therefore, it seems to be a better option to eliminate using cutting fluids. Health problem is caused by the long-term exposure to cutting fluids.

In order to eliminate the effect of cutting fluids, dry machining has become a reliable choice in machining of some materials. However, some engineering materials still require cutting fluid in their machining operations (Sreejith, 2000; Vierira, 2001; and Diniz, 2002). The base of specially prepared cutting fluids is commercially available mineral oil. The cutting fluid contains coolant, lubricant and additives such as surfactant, evaporator and stabilizer (Ramamoorthy, 2006).

## 2.3 MACHINING CONDITION

Different machining processes set varying demands on the amount of lubricants needed for secure and satisfactory machining results. To implement dry machining, aspects like heat generation, clearance of chips, and kinematic conditions have to be considered when designing the process (Sreejith, 2000). Figure 2.1 shows the influence of the machining process on the cooling lubricant supply.

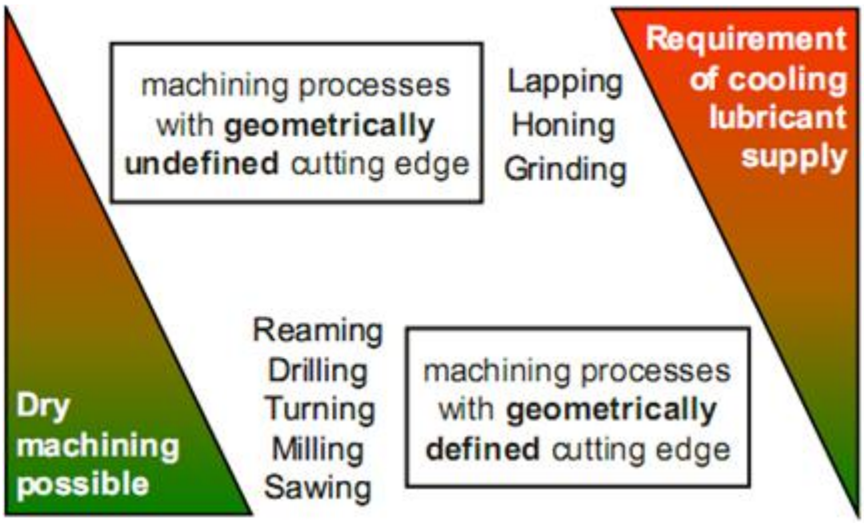


**Figure 2.1:** Influence of the machining process on the cooling lubricant supply

Source: Weinert et al. (2004)

### 2.3.1 Dry Machining

Dry machining means machining the material without any fluids at all, and only atmospheric air surrounding the cutting zone. Dry machining is elimination on the use of cutting fluids. The interest in dry machining is often related to the lower cost (Sreejith, 2007), healthy issues and environmentally friendly (Dhar, 2005; and Dhar et al. 2004). Dry machining requires less power. Cutting dry, the chips will move across the rake face of the tool and so take the point of maximum heat a way back from the tool tip. The tool will get hot, but there is a larger bulk of tool in which to dissipate the heat. In dry machining, bringing the point of maximum heat much closer to the point of cut where there is less material to conduct away the heat; the tool life decrease (Byers, 2006). The high temperature at the machining zone will ultimately cause dimensional inaccuracies for the work piece and tool wear problems (Sreejith, 2007) and also produce less surface finish. However the chips will be drier and of higher financial value, since they may be recycled directly and more efficiently with less negative impact to the environment.

An obvious way to reduce the impacts and cost of metals manufacturing is to eliminate the cutting fluid all together. In most cases, this will result in shortened tool life or reduced product quality but in other cases may result in comparable performance if modifications are made to existing processes. For example, tool geometry can be modified to have wider flutes and higher helix angles on drills to make chip evacuation easier and reduce the need for lubricants to serve that purpose. The machining process can also be adjusted to reduce tool wear by slowing the cutting speed or reducing the feed rate.

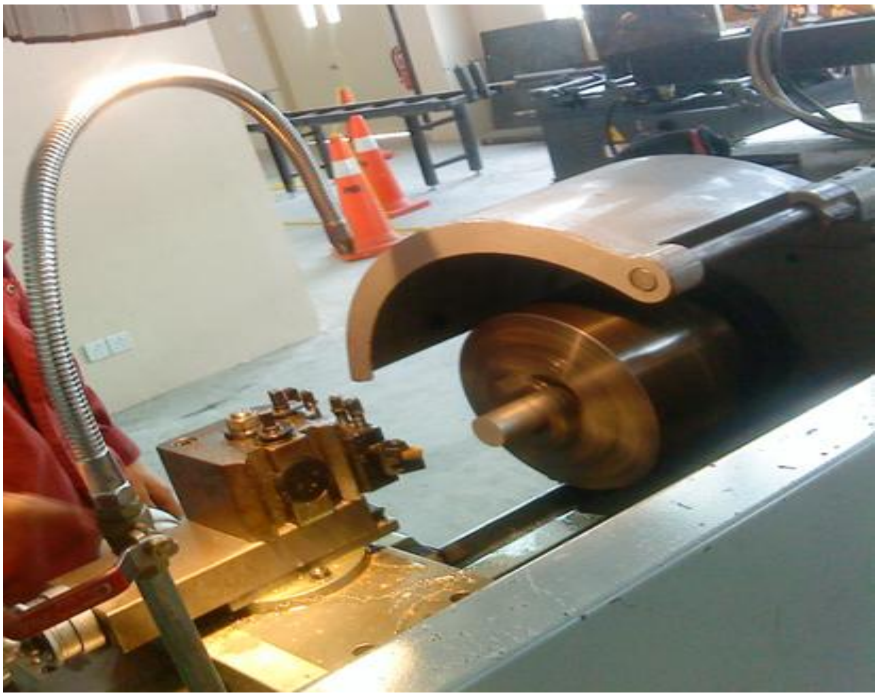

**Figure 2.2:** Dry Machining

### 2.3.2 Minimum Quantity Lubricant

Minimum quantity lubricant (MQL) is the technique of applying very small volume of liquid into a cutting zone. The lubricant is directed into the cutting zone attempt to form a film between tool, chip, and workpiece. It is important to direct the fluids into the nip between the rake face and the underside of the chip, at the point of cut (Byers, 2006). Forcing the fluids along the tools edge may be achieved by using high fluids application. This technique will provide longer tool life by maintaining tool hardness. Usually, the minimum quantity lubricant refers to use the cutting fluid only a minute amount-typically of a flow rate of 50-500 ml/h. This minimum quantity of lubricants is considered as replacements of dry machining (Sreejith, 2007) and also considered as alternative to flood lubricants (Attansio et al., 2004).

The concepts of minimum quantity of lubricants have been referred as near dry machining or micro lubrication (Dhar et al., 2004; Dhar, 2005; and Sreejith, 2007). The advantages of minimization of cutting fluid can make benfits, by saving lubricants cost, workpiece and tool (Dhar et al. 2004; Rao, 2007; and Sreejith, 2007). Minimum quantity lubrication (MQL) techniques use cutting fluid in a small amount to provide the function of a cutting fluid without the large volumes of aqueous waste (Silva et al., 2005). In the United States, many manufacturers are making a transition to MQL to reduce health and fluid costs. Conventional water-based fluids require significant infrastructure to deliver and store fluids through a system of grates, drains, storage tanks, and pipes. The lubricant volumes used in MQL are much lower, and although such fluids have limited cooling ability, the technology is being deployed successfully in the field for certain machining application.

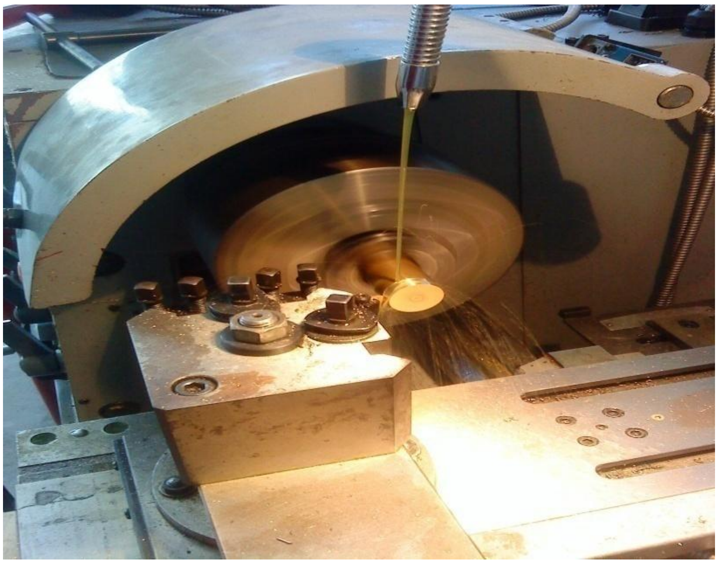

**Figure 2.3:** Minimum Quantity Lubricant

### 2.3.3 Wet Machining

Wet machining refers use a large quantities of lubricants. The wet machining can reduce the heat between the material surface and tools surface (Byers, 2006). In wet machining, both the tool and the workpiece are cooled using large quantities of lubricants. The coolant is subsequently cleansed and used again (Dhar, 2005; and Dhar et al. 2004). In wet machining, the role of cutting fluids is transports the chips away from the cutting zone, at the same time cooling the chips and keeping dust and small particulates in liquids rather than in the air (Byers, 2006). Hot chips have collecting around the machine base and the cutter or the part, thus it need the wet machining to cools the chips and also washes them away from the machine tool into the filtering system for separation from the fluids. In wet machining, less heat is generated. It will generally follow that if less heat is generated, the tools will last longer and the surface integrity of the workpiece will be protected (Byers, 2006). It is important to keep the cutting tool cool in order to avoid the exceeding the temperature. The cutting fluids also will bathe the workpiece and so helps to establish thermal stability of the system and assists in better size control of the material used.

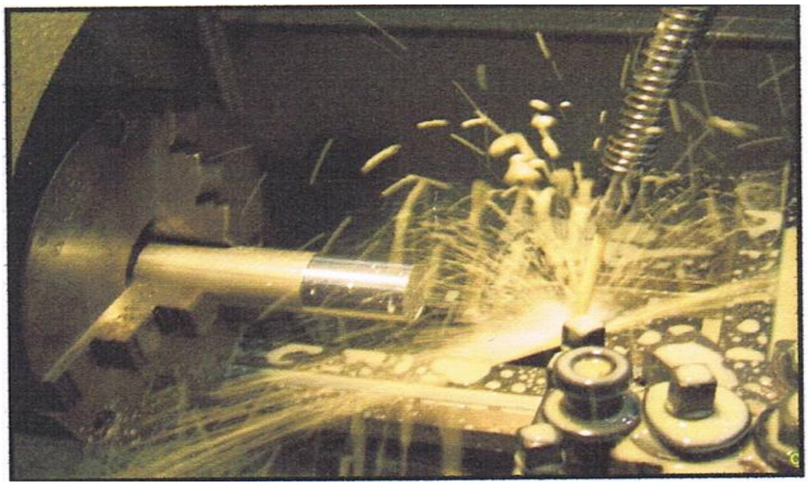

**Figure 2.4:** Wet Machining

## 2.4 LATHE MACHINE

Lathes are considered to be the oldest machine tools. Although simple and versatile, an engine lathe requires a skilled machinist because all controls are manipulated by hand. It is used principally for shaping pieces of metal, wood, or other materials by causing the workpiece to be held and rotated by the lathe while a tool is advanced into the work causing the cutting action. Lathes can be divided into three types for easy identification: engine lathe, turret lathe, and special purpose lathe (Steve et al., 2003). Turning is the process of machining external cylindrical and conical surfaces. The workpiece is rotated into a longitudinally fed, single-point cutting tool. This is done by rotating the metal held in a work-holding device while cutting tool is forced against its circumference. The cutting forces, resulting from feeding the tool from right to left, should be directed toward the headstock to force the workpiece against the work holder and thus, provide better work support.

Turning is commonly used as a secondary process to add or refine features on parts that were manufactured using a different process (Byers, 2006). The part is rotated while it is been machined. When turning, a piece of material is rotated and a cutting tool is transverse along 2 axis of motion to produce precise diameters and depths. At this machine, the cutting tools are held rigidly in a tool holder. The tool holder is mounted on a movable platform called carriage. Meanwhile, the workpiece is mounted at the spindle. The workpiece is static. Only the tool is moved in and out by means of hand cranks and back and forth either by hand crank.

There are two types of chuck in lathe machine; three and four jaws. Usually three jaws have a geared-scroll design that makes the jaw self-centering. They are used for round work piece. For four jaw, it can be moved and adjust independently for each other. Thus, they can be used for square, rectangular, or add-shaped work piece. It also can be used for heavy work piece or for work requiring multiple chucking. In order to get an efficient process and beautiful surface at the lathe machining, it is important to adjust a rotating speed, a cutting depth and cutting speed (Lin, 2006). Lathes machine must be lubricated and checked for adjustment before operation.


**Figure 2.5:** Lathe Machine

### 2.4.1 Turning process

In recent years, hard turning which uses a single point cutting tool has replaced grinding to some extent for such applications. Turning is process whereby a stationary tool is moved axially along a rotating workpiece. Such an action may produce a straight cylindrical shaft, or by offsetting the tool path or by interpolating in two axes, a tapered shaft may be produced. Straight and tapered cylinders, spheres, and threads, in fact almost any shape may be turned around the surface of the rotating workpiece with respect to the turning tool shape, geometry and tool path. There are two reasons the lathe machine work; to produce a true diameter and to cut it in needed size. Work cut to size and be the same diameter along the entire length of the workpiece involves the turning operation. This process has been developed as an alternative to the grinding process in a bid to reduce the number of setup changes, product cost, and lead time without compromising on surface quality to maintain competitiveness. Study of cutting forces is critically important in turning operations because cutting forces correlate strongly with cutting performance such as surface accuracy, tool wear, tool breakage, cutting temperature, self-excited and forced vibrations, etc (Siliman, 1992).

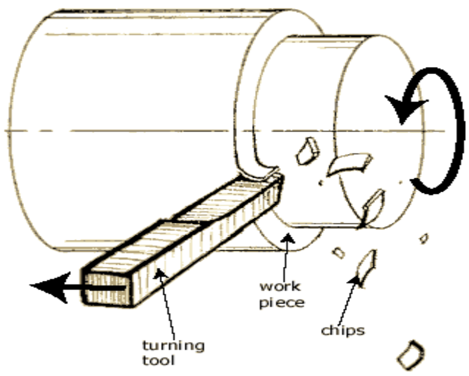


**Figure 2.6:** Cutting In Turning

Source: Steve et al. (2003)

## 2.5 MACHINING PARAMETERS

The parameters refer to the factors that would affect the result of the experiment. There are two type of parameter consider for this experiment; first parameter is parameter varies in experiment and second parameter is constant parameter.

### 2.5. Cutting Speed

Cutting speed (V) is one of the parameters in this experiment. It can be expressed with number of rotation, revolution per minutes, (rpm), of the chuck of the lathe and are changed by means of gear levers or variable speed adjustment. The cutting speed must be set as close as possible to the calculated speed but never higher. It is better to set the rpm to lower speed at the first range. If the cutting action is satisfactory, the speed must be increased slightly, however, if the cutting action is not satisfactory or the work vibrates or chatters, the speed must be reduced and increase the feed. Cutting speed selected based on type of the material and tool using. The harder the material, the slower the cutting speed (Figure 2.7) and the harder the cutting tool material, the faster the cutting speed (Figure 2.8).

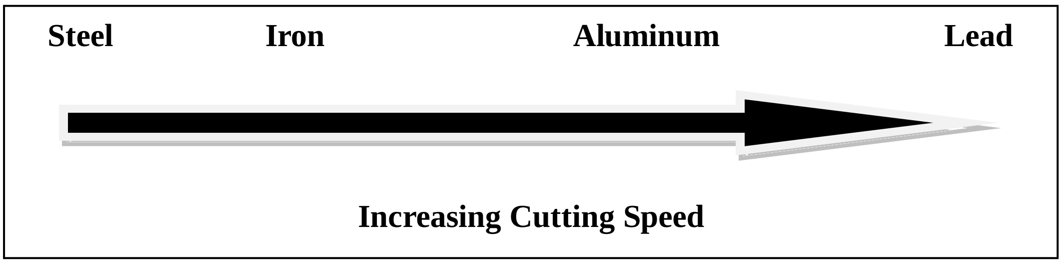


**Figure 2.7:** Relation between work material and cutting speed

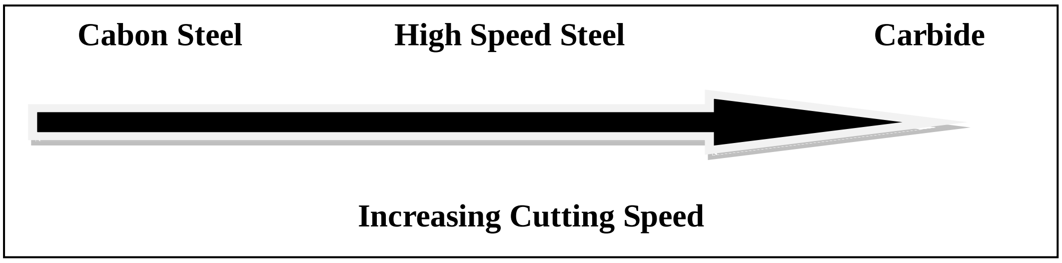


**Figure 2.8:** Relation between cutting tool material and cutting speed

When the rotating speed is high, processing speed become quick, surface roughness is finely finished. At higher cutting speeds, since the tool undergoes wear because of increased temperature, it is important that the cutting fluid acts as a lubricant. For lower cutting speed, the lubricating properties of the fluid become more prominent, easing the flow of the chip up the tool rake face (Weinert et al., 2004). The recommended cutting speed (CS) for various materials is listed in Table 2.1.

**Table 2.1:** Lathe cutting speeds in feet per minute and meter per minute (Scmid, undated).

| | **Turning** | | | |
|---|---|---|---|---|
| | **Rough cut** | | **Finish cut** | |
| | **Ft/min** | **m/min** | **Ft/min** | **m/min** |
| Machine steel | 90 | 27 | 100 | 30 |
| Tool steel | 70 | 21 | 90 | 27 |
| Cast iron | 60 | 18 | 80 | 24 |
| Bronze | 90 | 27 | 100 | 30 |
| Aluminum | 200 | 61 | 300 | 93 |

**Spindle speed calculation**

To calculate rpm to set at lathe machine, material, diameter of the workpiece and cutting speed must be known first (Steve et al., 2003). The revolution per minutes (rpm) should be set can be found by applying this formula:

i. Inch calculations

The spindle speed of lathe where the workpiece dimensions are given in inches is:

$$\text{Rpm} = \frac{CSX\,4}{D} \qquad (1.1)$$

*CS* = cutting speed of the material ft/min

*D* = diameter of the workpiece in inches

ii. Metric calculations

The simplified formula for calculating the spindle speed when the cutting speed is given in meters is:

$$\text{Rpm} = \frac{CSX\,320}{D} \qquad (1.2)$$

*CS* = cutting speed in m/min

*D* = diameter of work in millimeters

### 2.5.2 Depth of Cut

The depth of cut (DOC) in a lathe work may be defined as the chip or cut that is taken by the cutting tool. It can be defined as the thickness of material removed by one pass of the cutting tool. The cutting depth of the tool affects to the processing speed and roughness of surface. When the depth of cut is low, the surface roughness is highly sensitive to cutting speed, as depicted (Paulo, 2008) an increase in cutting speed sharply reduces the surface roughness. However, this reduction becomes smaller and smaller with the higher values of depth of cut. It is also observed that, surface roughness variation is minimal with the variations of depth of cut at higher values of cutting speed. When the cutting depth is large, the processing becomes faster, but the surface temperature becomes increase and tool life of become short. In rough turning, the depth of cut depends upon the condition of the machine, the type of cutting tool used, and the rigidity of the workpiece.

To calculate the depth of cut (DOC) in lathe operations as follows:

$$DOC = \frac{D_1 - D_2}{2} \tag{1.3}$$

$D_1$ =initial diameter

$D_2$ = final diameter

The DOC is half the difference between the initial diameter and the final diameter.

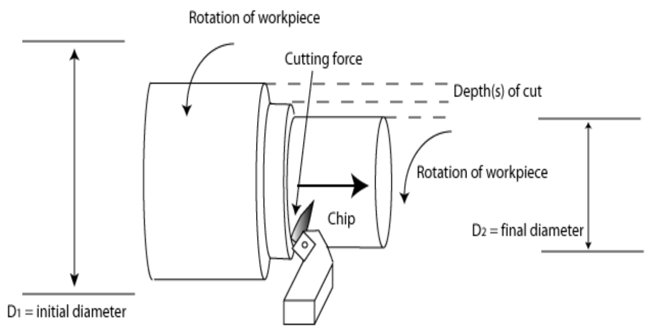


**Figure 2.9:** Depth of cut process

Source: Childs (2000)

### 2.5.3 Feed Rate

Feed rate is known as sending speed (Itogawa, 2005) and defined as velocity at which the cutter is fed, that is, advances against the workpiece. Feed is movement of the tool per revolution of the spindle. For example, if the lathe is set for a 0.007in feed, the cutting tool will travel along the length of the work 0.007 in for every complete turn that the work makes. Its unit is given in mm/rev or in/rev. When the feed is high, the processing becomes quick. When the feed is low, the processing is slow but the surface finish is beautiful. Since the purpose of a roughing cut is to remove excess material quickly and surface finish not too important, a coarse feed may be used. The finishing cut is used to bring the diameter to size and produce a good surface finish; therefore a fine feed should be used. The feed of engine lathe is dependent upon the speed of the lead screw or feed rod. Table 2.2 lists the recommended feeds for cutting various materials when using high speed steel cutting tool.

**Table 2.2:** Recommended feeds for cutting various materials

| | Rough Cut | | Finish cut | |
|---|---|---|---|---|
| | **inches** | **millimeters** | **inches** | **millimeters** |
| Machine steel | 0.10-0.020 | 0.25-0.50 | 0.003-0.010 | 0.07-0.025 |
| Tool steel | 0.10-0.020 | 0.25-0.50 | 0.003-0.010 | 0.07-0.025 |
| Cats iron | 0.015-0.025 | 0.40-0.65 | 0.005-0.012 | 0.13-0.30 |
| Bronze | 0.015-0.025 | 0.40-0.65 | 0.003-0.010 | 0.07-0.25 |
| Aluminum | 0.015-0.030 | 0.40-0.75 | 0.005-0.010 | 0.13-0.25 |

## 2.6 CUTTING TOOLS

Toolbit is used to machine a metal in lathe machine. This toolbit must be made of the correct material and ground the correct angles to machine a workpiece efficiently. The effectiveness and overall economy of machining of any work material by given tools depend largely on the machinability characteristics of the tool-work materials under the recommended condition. Toolbit are made from variety of size and shape and used for different size machines and different applications (Steve et al., 2003). Lathe tool bit shapes can be many types, such as, pointed, rounded, square off or irregular in shape but still can cut as long as the tool bit angles are properly ground for the type of material being machined. The rake angle is the angle which chip must slide up the rake face of the tool and affects the forces of sliding friction in the tool/chip interface, the primary friction zone. The rake angle can be positive, negative, or no rake angle at all. The heat and high pressure on the corner of the cutting edge during rough machining especially restricted the performance of the process. The amount of heat produced when rake angle is constant is inversely proportional with shear angle. Special toolbits are used when to cut the various shaped desired. For example, left-hand toolbits have their cutting edge on the right-hand side and are used for turning work toward the tailstock. Right-hand cutting tools have the cutting edge on the left-hand side and are used for cutting toward the headstock. A cutting tool is generally known by the operation it performs. For example, a roughing tool is used to rough-turn work; a threading tool is used for thread cutting (Byers, 2006).

### 2.6.1 Material of Cutting Tools

Cutting tool is any tool that is used to remove metal from the workpiece by means of shear deformation and they are generally made of tool steels. The selection of cutting-tool materials for a particular application is among the most important factors in machining operations. The cutting tool is subjected to high temperatures, high contact stresses, and rubbing along the tool–chip interface and along the machined surface. Various cutting-tool materials with a wide range of mechanical, physical, and chemical properties have been developed over the years.

Coated carbide insert is a cutting bit made of hard carbide material that has multiple cutting edges. Once a cutting edge is excessively worn, it can be indexed to another edge, or the insert can be replaced. There are two types of cutting tool grades of carbides: cast-iron carbides and steel-grade carbides. Cast-iron carbides are specifically made for cutting cast-iron materials and Steel-grade carbides are specially made to resist cratering and heat deformation that may be caused by the long chips of steel on higher cutting speeds. The main carbide material used in its manufacture is tungsten carbide (WC) with a cobalt binder.

Aside from tungsten carbide and cobalt, other alloying materials are added in the manufacture of carbide cutting tools. Among them is titanium carbide and tantalum carbide. Titanium carbide helps the carbide cutting tool to resist cratering while tantalum carbide can reduce heat deformations in the tool. Also commonly used in the cutting industry today is coated carbide cutting tools. Aside from the basic carbide materials, titanium carbide, titanium nitride, ceramic coating, diamond coating or titanium carbonitride are used as coating materials. The different coating materials aid the carbide cutting tool differently, although they are generally used to further toughen the cutting tool.

## 2.7 SURFACE ROUGHNESS

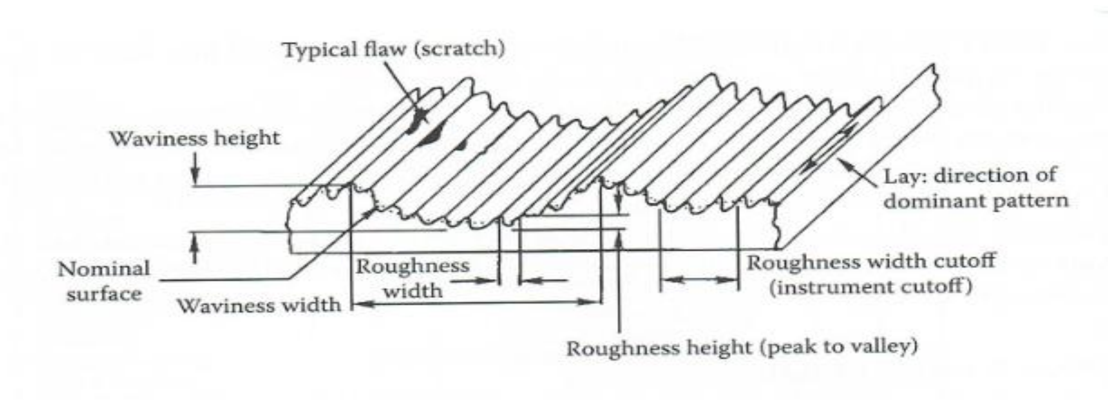


**Figure 2.10:** Surface Roughness

Source: Childs (2000)

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact. Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machinability.

Specifying surface roughness is basically a process of describing the topography of the boundary surface of a solid body if the finer surface irregularities in the surface texture. Surface roughness is important parameters of a component part. It determines how the part will respond to sliding friction, how well it will retain a lubricant, the wear rate that will be experienced and how well it retain a coating. The surface finish is depend on the rotational speed of cutter, velocities of traverse, feed rate and mechanical properties of workpieces being machined. Type and amounts of lubrication also will affect the surface roughness of material. Surface finish mainly improved by reduction of tool wear and damage of tool tips by applications of MQL. Such reduction in tool wear will improve in tool life or enhancement of productivity allowing higher cutting velocity and feed.

## 2.8 PERTHOMETER

Perthometer is equipment used for measuring the surface roughness of the workpiece. It is high-precision measurement in different positions and easy to position the material by using the V-blocks. It also has high level of scope of supply and service. The perthometer does not complicate in handling and operating. It results is high level quality and in the nanometer range.

The featured of the Perthometer is given as below:

(i) Roughness and waviness measurements according to current standards (DIN EN ISO 3274, e.g. band-pass filter).

(ii) A large high-resolution graphics display to indicate results and profiles

(iii) Easy operation based on the automatic teller principle and large operating elements.

(iv) Quick documentation via the integrated high-resolution thermal printer.

(v) Storage facility on PCMCIA memory card for measuring programs, results and profiles.

(vi) Extensive, easily applicable software functions, such as:

   a. Automatic function for setting standardized filters and traversing lengths.
   b. Monitoring of calibration and maintenance intervals
   c. Variable selection of filters and traversing lengths
   d. Tolerance monitoring with audible and visual signals

## 2.9 WORK MATERIALS

Table 2.3 shows the properties of 1060 Aluminum Alloy, ASTM B176 Brass and AISI 304 Stainless Steel. Properties consist of category, hardness, tensile strength, density and elastic modulus.

**Table 2.3:** Table properties of material

| **PROPERTIES** | **MATERIAL** | | |
|---|---|---|---|
| | **1060 Aluminum Alloy** | **ASTM B176 Brass** | **AISI 304 Stainless Steel** |
| | **Aluminum Alloy** | **Copper Alloy** | **Steel** |
| Hardness (HB) | 23 | 55 | 201 |
| Tensile Strength (Mpa) | 83 | 379 | 5-620 |
| Density (x 1000 kg/m3) | 2.7 | 8.8-8.94 | 7.7-8.03 |
| Elastic Modulus (Gpa) | 70-80 | 117 | 193 |

## 2.10 DESIGN OF EXPERIMENT (DOE)

In general usage, design of experiments, or experimental design, (DOE) is the design of any information-gathering exercises where variation is present, whether under the full control of the experimenter or not. In the design of experiments, the experimenter is often interested in the effect of some process or intervention on some objects. For this research, experimenter wants to investigate the effect of the lubrication condition on the surface roughness (process), on different types of material (object) and parameter.

In many fields of study it is hard to reproduce measured results exactly. Comparisons between treatments are much more reproducible and are usually preferable. Often one compares against a standard or traditional treatment that acts as baseline. For this research, a comparison is made to compare the surface roughness in different condition of lubrication. The experiment which is based on three parameters is better in making comparison as compared to one parameter. In this experiment, three parameters are used, lubrication condition, depth of cut, and cutting speed.

Design of Experiment involves designing a set of ten to twenty experiments, in which all relevant factors are varied systematically. When the results of these experiments are analyzed, they help to identify optimal conditions, the factors that most influence the results, and those that do not, as well as details such as the existence of interactions and synergies between factors. This experiment has thirty six numbers of experiments based on the three parameter of the experiment.

Design of Experiments (DOE) is widely used in research and development, where a large proportion of the resources go towards solving optimization problems. The key to minimizing optimization costs is to conduct as few experiments as possible. DOE requires only a small set of experiments and thus helps to reduce costs

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

Methodology is an important element where it specifically describes the method to achieve the objectives of this research. Methodology use to make sure the progress of the project will follow the flow from the beginning until the end of the project. For the present experimental studies, the 1060 Aluminum Alloy, ASTM B176 Brass, and AISI 304 Stainless Steel will be machined by using conventional lathe machine. The length and diameter of the workpiece is 150mm long and 30mm diameter respectively. This workpiece will be machined at different cutting speed and depth of cut combinations under dry, wet and minimum quantity lubrication (MQL) conditions. The ranges of the cutting velocity (Vc) and depth of cut (DOC) are selected based on the tool manufacturer's recommendation and industrial practices. Coated carbide is selected as cutting tool for this experiment. From the experiment the feed rate is set to be constant. The methods are basically refers to the design of experiment (DOE) methodology and procedure.

## 3.2 METHODOLOGY FLOW CHART

The methodology flow chart is a visual representation of the sequence of the project. This flowchart organizes the topic and strategies done to ensure a smooth flow when running the project. Figure 3.1 is an illustration of a simple flow chart showing the process flow. As illustrated, the first step is literature study based on related topic and then prepares the design of experiment (DOE). Machining work starts by cutting the material with band saw and then use conventional lathe machine to conduct turning. Next step is determining the surface roughness by using perthometer. The final step is a process comparison between results obtained with predicted results from using Response Surface Method (RSM) in Minitab15 software to decide the significance of parameters on surface roughness.

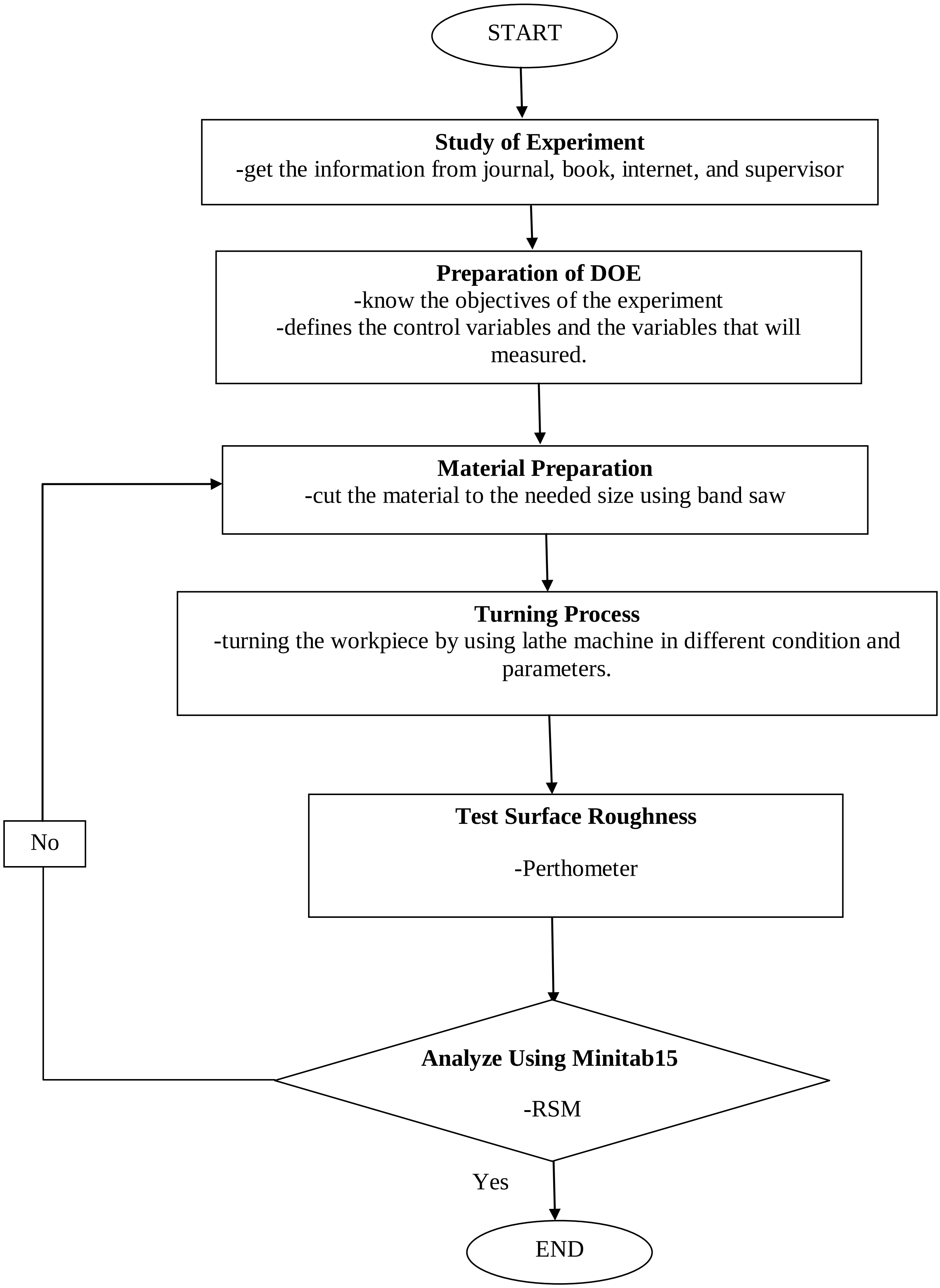


**Figure 3.1**: Methodology Flow Chart

## 3.3 TURNING

Before the turning operation is done, the specimen has to be cut into desired dimension; 75mm length for each material. Wear a safety jacket, goggle and safety boots during operating the machine. The cutting speed of the material will be calculated based on the given formula. The nearest cutting speed is taking if there have a different value with value have stated on lathe machine. The calculation is continued by finding the appropriate feed rate for the material.

The workpiece must be clamped tightly with dead center during the cutting operation. After set up the lathe machine with the cutting speed and feed then start the machine. Reference point is marked by start cut a bit on the material. Then the cutting operation starts by setting the X-axis and Y-axis are both zero as the reference point on the outer surface tip end of the workpiece.

After the cutting operation of the first workpiece is complete, start next turning with a new setting of the machine, for new cutting speed and depth of cut. Then, the surface roughness of the material is test under Perthometer. The value of surface roughness then recorded into the table. The test is repeated for another work piece.

## 3.4 DESIGN OF EXPERIMENT (DOE)

Building a design means, carefully choosing a small number of experiments that are to be performed under controlled conditions. There are four interrelated steps in building a design:

(i) Define an objective to the investigation, e.g. better understand or sort out important variables or find optimum. The main objective of this experiment is to investigate the effect of the lubrication condition on the surface roughness in turning operation.

(ii) Define the variables that will be controlled during the experiment (design variables), and their levels or ranges of variation. The variable that will control this experiment is lubrication condition. The material will be cut under three different lubrication conditions, which are in dry machining, wet machining, and minimum quantity of lubricant.

(iii) Define the variables that will be measured to describe the outcome of the experimental runs (response variables), and examine their precision. The surface roughness of the material will be measured with perthometer.

(iv) Among the available standard designs, choose the one that is compatible with the objective, number of design variables and precision of measurements, and has a reasonable cost.

Standard designs are well-known classes of experimental designs. They can be generated automatically as soon as we have decided on the objective, the number and nature of design variables, the nature of the responses and the number of experimental runs we can afford. Generating such a design will provide with a list of all experiments must be perform, to gather enough information for the purposes.

All of the machining experiments were carried out on a conventional lathe machine as on Figure 2.4. The experiment will be carried out using design of experiment (DOE) method. The DOE method used is called General (Multi Level) Factorial Design. The General (Multi Level) Factorial Design is have factors that each different number of levels. This will create an experiment that includes all possible combinations of the factor levels. The 3 lubrication condition, 2 cutting speed and 2 depth of cut (DOC) are used. The 3 lubrication condition to the factor of 1, 2 cutting speed to the factor of 1, and 2 DOC to the factor of 1, come out with total experiments of 12 sets for each material.

Set of experiments $=3^1 \times 2^1 \times 2^1 = 12$ sets for each material.

As the range of rpm on the lathe machine is limited, so the cutting speed is selected based on the available rpm that are 810 rpm and 1400 rpm. A new cutting edge is use for every cut. A series of 3 conditions will be run on each specimen using different level of parameters. The turning process had run under constant feed rate of 0.15 mm/rev and conventional coolant supply.

**Table 3.1:** 12 sets of machining parameter

| **Lubrication Condition** | **Cutting Speed (rpm)** | **Depth of Cut (DOC) (mm)** |
|---|---|---|
| dry | 810 | 0.2 |
| dry | 810 | 0.4 |
| dry | 1400 | 0.2 |
| dry | 1400 | 0.4 |
| wet | 810 | 0.2 |
| wet | 810 | 0.4 |
| wet | 1400 | 0.2 |
| wet | 1400 | 0.4 |
| MQL | 810 | 0.2 |
| MQL | 810 | 0.4 |
| MQL | 1400 | 0.2 |
| MQL | 1400 | 0.4 |

## 3.5 MATERIAL

The materials that used for the test are 1060 Aluminum Alloy, ASTM B176 Brass, and AISI 304 Stainless Steel. Each material of the specimens will cut off in required length which is 75mm and the diameter is 30mm each. All the dimensions of the material are constant. Table 3.2 below shows the prediction of quantity of workpiece needed.

**Table 3.2:** Prediction of quantity of workpiece needed

| | | **Cutting Speed (CS)** | | | | |
|---|---|---|---|---|---|---|
| | | **CS1** | | **CS2** | | |
| **MATERIAL** | **DOC Condition** | **DOC1** | **DOC2** | **DOC1** | **DOC2** | |
| **1060 ALUMINUM ALLOY** | **Dry** | 1 | 1 | 1 | 1 | 12 |
| | **MQL** | 1 | 1 | 1 | 1 | |
| | **Wet** | 1 | 1 | 1 | 1 | |
| **ASTM B176 BRASS** | **Dry** | 1 | 1 | 1 | 1 | 12 |
| | **MQL** | 1 | 1 | 1 | 1 | |
| | **Wet** | 1 | 1 | 1 | 1 | |
| **AISI 304 STAINLESS STEEL** | **Dry** | 1 | 1 | 1 | 1 | 12 |
| | **MQL** | 1 | 1 | 1 | 1 | |
| | **Wet** | 1 | 1 | 1 | 1 | |
| **TOTAL** | | 9 | 9 | 9 | 9 | 36 |

DOC = depth of cut

MQL = Minimum Quantity Lubricants

## 3.6 LUBRICATION CONDITION

The experiment will be performed under three different condition of lubrication of dry machining, minimum quantity of lubricant and wet machining.

## 3.7 CUTTING TOOL

Coated carbide has been selected as cutting. Coated carbide is selected because it can cut the material about 3 to 5 time compared with high-speed steel tool. The Table 3.3 shows the properties of cutting tool.

**Table 3.3:** Properties of cutting tool

| | |
|---|---|
| Shape of tool bit | rounded |
| Angle of tool bit | 80 degree |

## 3.8 CONSTANT PARAMETER

Machining parameter for lathe machine was selected based on the tool manufacturer's recommendation. From the experiment, feed rate ($S_o$) is fixed at 0.15 mm/rev. The tool bit is constant because we use coated carbide as cutting tool.

## 3.9 SURFACE ROUGHNESS

The Perthometer is used to measure the surface roughness for each material. The value of surface roughness of the specimens in each level of parameter in turning operation are stated down for further analyze. Surface roughness value is taken 3 times for in account of accuracy.

## 3.10 RECORDING DATA

The data will be recorded in Table 3.4 and Table 3.5 below. The data has been taken 3 times for in account of accuracy.

**Table 3.4:** Recording data for cutting speed 1 (CS 1)

<table>
<tr><td rowspan="4">MATERIAL</td><td colspan="8">CUTTING SPEED 1 (CS1)</td></tr>
<tr><td colspan="4">Depth of Cut 1 (DOC1)</td><td colspan="4">Depth of Cut 2 (DOC2)</td></tr>
<tr><td colspan="4">Dry Machining</td><td colspan="4">Dry Machining</td></tr>
<tr><td>Reading1</td><td>Reading2</td><td>Reading3</td><td>Average</td><td>Reading1</td><td>Reading2</td><td>Reading3</td><td>Average</td></tr>
<tr><td>Aluminum</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brass</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Steel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Minimum Quantity Lubricant</td><td colspan="4">Minimum Quantity Lubricant</td></tr>
<tr><td>Aluminum</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brass</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Steel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="4">Wet Machining</td><td colspan="4">Wet Machining</td></tr>
<tr><td>Aluminum</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brass</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Steel</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

**Table 3.5:** Recording data for cutting speed 2 (CS2)

| MATERIAL | CUTTING SPEED 1 (CS2) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Depth of Cut 1 (DOC1) | | | | Depth of Cut 2 (DOC2) | | | |
| | Dry Machining | | | | Dry Machining | | | |
| | Reading1 | Reading2 | Reading3 | Average | Reading1 | Reading2 | Reading3 | Average |
| Aluminum | | | | | | | | |
| Brass | | | | | | | | |
| Steel | | | | | | | | |
| | Minimum Quantity Lubricant | | | | Minimum Quantity Lubricant | | | |
| Aluminum | | | | | | | | |
| Brass | | | | | | | | |
| Steel | | | | | | | | |
| | Wet Machining | | | | Wet Machining | | | |
| Aluminum | | | | | | | | |
| Brass | | | | | | | | |
| Steel | | | | | | | | |

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 INTRODUCTION

This chapter discusses about the experimental results that have been obtained after conductivity the experiment. The results will be expressed in tables and graphs to provide the reader with a clearer view. The experimental result will then be analyzed and compared.

## 4.2 RESULTS

All experiment result had fill in the table based on lubrication condition, depth of cut and cutting speed. Data in each table had then analyzed to build a graph.

### 4.2.1 Results of Surface Roughness of the Materials

The data of surface roughness of the materials was recorded in the table. Surface roughness is determined using the perthometer. The test is run 3 times on the surface to get accurate result.

**Table 4.1:** Results for Aluminum at 810 rpm

| **Depth of Cut (mm)** | **Surface Roughness, Ra (µm)** | | | **Averages Surfaces Roughness (µm)** |
|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | |
| 0.2(Dry) | 1.225 | 1.230 | 1.237 | 1.231 |
| 0.4(Dry) | 1.256 | 1.260 | 1.250 | 1.255 |
| 0.2(MQL) | 0.946 | 0.943 | 0.938 | 0.942 |
| 0.4(MQL) | 1.013 | 1.014 | 1.057 | 1.028 |
| 0.2(Wet) | 1.343 | 1.340 | 1.340 | 1.341 |
| 0.4(Wet) | 1.378 | 1.378 | 1.364 | 1.372 |

**Table 4.2:** Results for Aluminum at 1400 rpm

| **Depth of Cut (mm)** | **Surface Roughness, Ra (µm)** | | | **Averages Surfaces Roughness (µm)** |
|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | |
| 0.2(Dry) | 1.081 | 1.065 | 1.066 | 1.071 |
| 0.4(Dry) | 1.113 | 1.093 | 1.083 | 1.096 |
| 0.2(MQL) | 0.874 | 0.874 | 0.871 | 0.873 |
| 0.4(MQL) | 0.939 | 0.939 | 0.940 | 0.939 |
| 0.2(Wet) | 1.291 | 1.290 | 1.292 | 1.291 |
| 0.4(Wet) | 1.336 | 1.340 | 1.332 | 1.336 |

**Table 4.3:** Results for Stainless Steel at 810 rpm

| **Depth of Cut (mm)** | **Surface Roughness, Ra (µm)** | | | **Averages Surfaces Roughness (µm)** |
|---|---|---|---|---|
| | **1st** | **2nd** | **3rd** | |
| 0.2(Dry) | 1.106 | 1.111 | 1.118 | 1.112 |
| 0.4(Dry) | 1.128 | 1.134 | 1.129 | 1.130 |
| 0.2(MQL) | 1.074 | 1.042 | 1.023 | 1.046 |
| 0.4(MQL) | 1.071 | 1.055 | 1.082 | 1.069 |
| 0.2(Wet) | 1.279 | 1.311 | 1.281 | 1.296 |
| 0.4(Wet) | 1.444 | 1.432 | 1.502 | 1.479 |

**Table 4.4:** Results for Stainless Steel at 1400 rpm

| Depth of Cut (mm) | Surface Roughness, Ra (µm) | | | Averages Surfaces Roughness (µm) |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | |
| 0.2(Dry) | 1.053 | 1.078 | 1.070 | 1.067 |
| 0.4(Dry) | 1.090 | 1.095 | 1.097 | 1.094 |
| 0.2(MQL) | 0.919 | 0.912 | 0.933 | 0.921 |
| 0.4(MQL) | 0.986 | 0.984 | 0.986 | 0.985 |
| 0.2(Wet) | 1.181 | 1.173 | 1.178 | 1.178 |
| 0.4(Wet) | 1.279 | 1.283 | 1.305 | 1.289 |

**Table 4.5:** Results for Brass at 810 rpm

| Depth of Cut (mm) | Surface Roughness, Ra (µm) | | | Averages Surfaces Roughness (µm) |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | |
| 0.2(Dry) | 1.598 | 1.609 | 1.598 | 1.602 |
| 0.4(Dry) | 1.773 | 1.774 | 1.770 | 1.772 |
| 0.2(MQL) | 1.311 | 1.329 | 1.326 | 1.322 |
| 0.4(MQL) | 1.390 | 1.423 | 1.392 | 1.402 |
| 0.2(Wet) | 2.015 | 2.021 | 1.995 | 2.010 |
| 0.4(Wet) | 2.202 | 2.074 | 2.389 | 2.222 |

**Table 4.6:** Results for Brass at 1400 rpm

| Depth of Cut (mm) | Surface Roughness, Ra (µm) | | | Averages Surfaces Roughness (µm) |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | |
| 0.2(Dry) | 1.459 | 1.422 | 1.423 | 1.434 |
| 0.4(Dry) | 1.554 | 1.584 | 1.580 | 1.573 |
| 0.2(MQL) | 1.185 | 1.154 | 1.178 | 1.172 |
| 0.4(MQL) | 1.199 | 1.215 | 1.215 | 1.211 |
| 0.2(Wet) | 1.835 | 1.715 | 1.848 | 1.799 |
| 0.4(Wet) | 1.907 | 1.893 | 1.907 | 1.902 |

### 4.2.2 Analysis of Surface Roughness of 1060 Aluminum Alloy

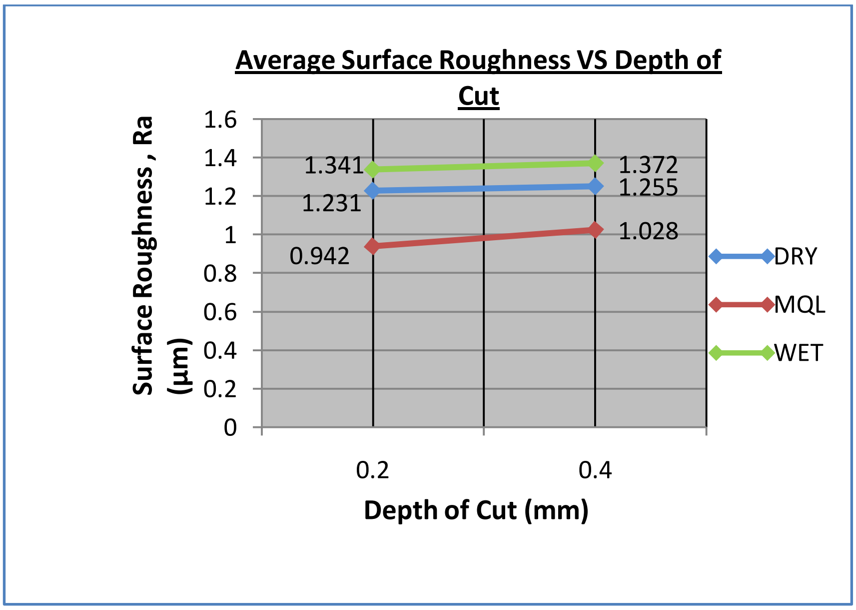


**Figure 4.1:** Graph of average surface roughness vs depth of cut for 810 rpm

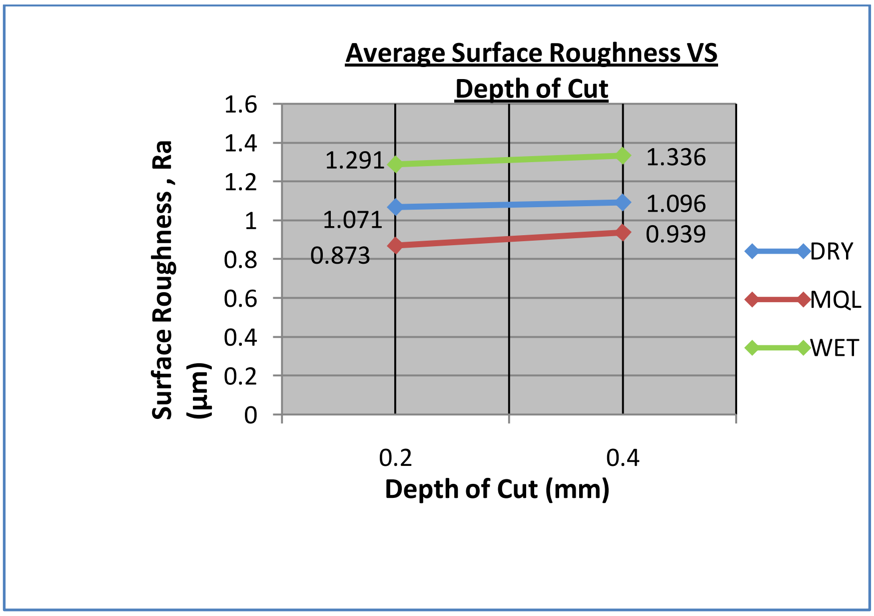


**Figure 4.2:** Graph of average surface roughness vs depth of cut for 1400 rpm

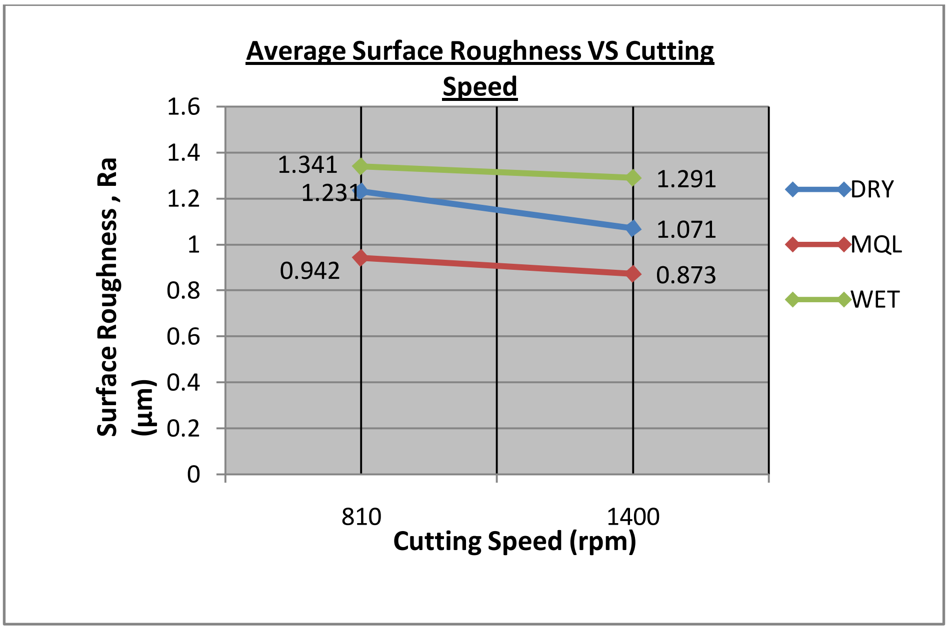


**Figure 4.3:** Graph of average surface roughness vs cutting speed for 0.2 mm DOC

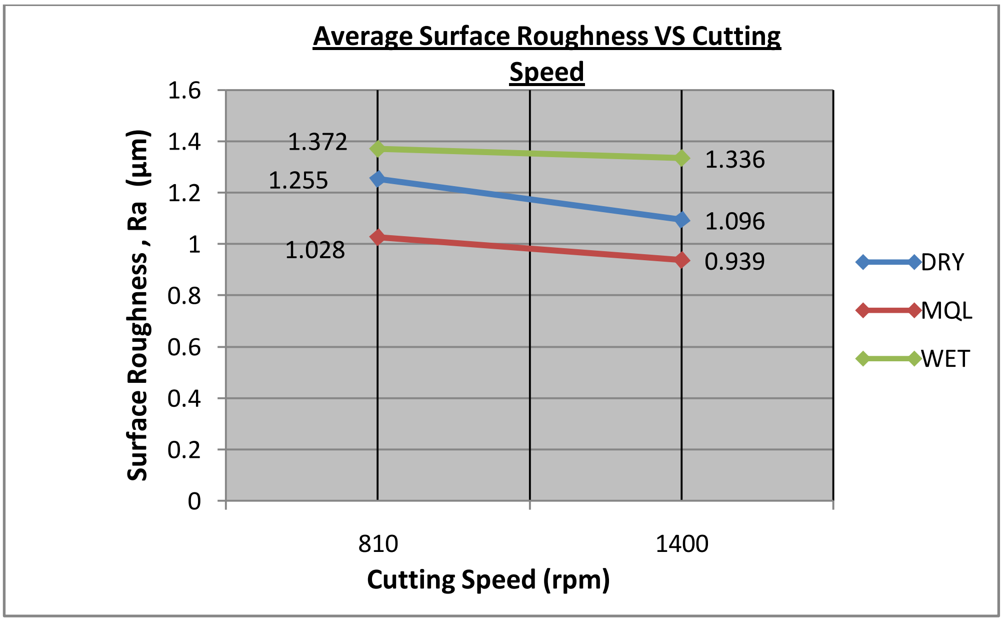


**Figure 4.4:** Graph of average surface roughness vs cutting speed for 0.4 mm DOC

From the Figure 4.1 and Figure 4.2, displays the surface roughness for spindle speed 810 rpm and 1400 rpm respectively. The depth of cut used were 0.2mm and 0.4mm. The feed rate was set at 15 mm/rev. Surface roughness is measured using a Perthometer, and 3 measurements were taken for each experiment. The data was collected and analyzed based on Table 4.1 and Table 4.2. There are 3 different colour lines which are green, red and blue represent different condition. Blue line represent for dry machining, red for minimum quantity lubricants and green for wet machining.

Figure 4.3 and Figure 4.4 display the surface roughness for depth of cut 0.2mm and 0.4mm respectively. The data was collected and analyzed from Table 4.3 and Table 4.4. It was showed the value of average surface roughness decreased when the value of cutting speed increased.

From Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4, it was observed that the value of surface roughness is less under minimum quantity lubricant followed by dry and then wet machining. The value of average surface roughness is increased for all condition when the value of depth of cut increases such Figure 4.1 and Figure 4.2. However for Figure 4.3 and Figure 4.4, the value of surface roughness is decreased when value of cutting speed is increased.

From Figure 4.1, average value of surface roughness in wet machining is increased from 1.341μm for 0.2 mm DOC to 1.372 μm for DOC 0.4 mm, whereby for dry machining the value of average surface roughness is increased from 1.231 μm to 1.255 μm, and for minimum quantity lubrication the value of surface roughness is increased from 0.942 μm to 1.028 μm. The same with Figure 4.2, the value of surface roughness is increase when depth of cut increases. It shows that surface finish is better when using in minimum quantity lubrication for small value of depth of cut.

Figure 4.3 showed that the value of surface roughness is decreased from 1.341 μm to 1.291 μm for wet machining, 1.231 μm to 1.071 μm for dry machining, and 0.942 μm to 0.873 μm for minimum quantity lubrication condition (MQL). The same pattern occurs for surface roughness in Figure 4.4, where the value of surface roughness is decreased for all condition. The value of surface roughness for wet machining decreased from 1.372 μm to 1.336 μm, for dry machining the value decreased from 1.255 μm to 1.096 μm and for minimum quantity lubrication, the value decreased from 1.028 μm to 0.939 μm. It shows that the value of surface roughness is decreased when cutting speed is increase. In spite of that, minimum quantity lubricant still produces better surface roughness as compared to wet and dry machining.

### 4.2.3 Analysis of Surface Roughness of ASTM B176 Brass

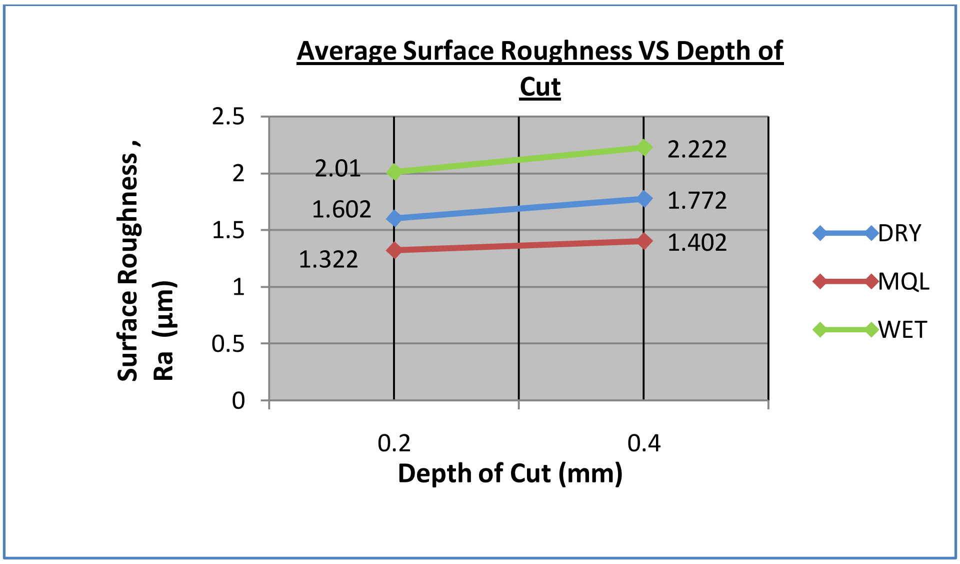


**Figure 4.5:** Graph of average surface roughness vs depth of cut for 810 rpm

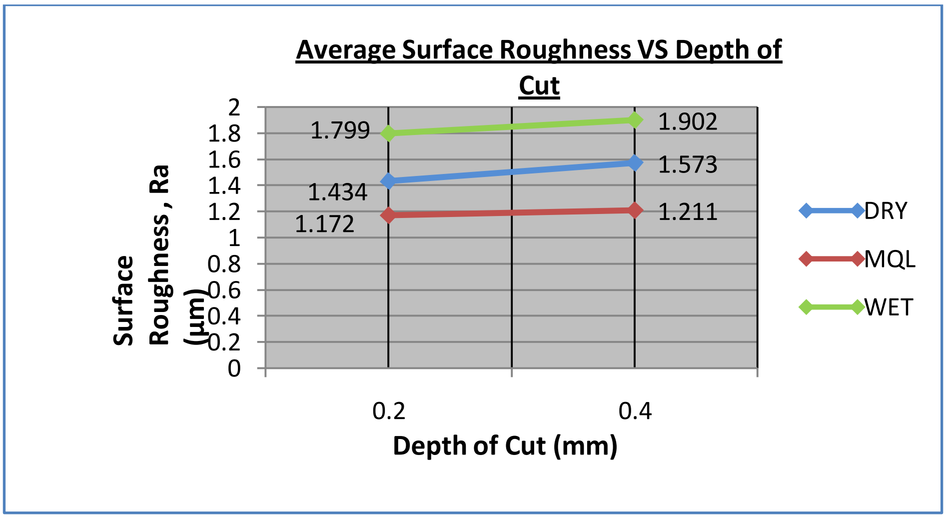


**Figure 4.6:** Graph of average surface roughness vs depth of cut for 1400 rpm

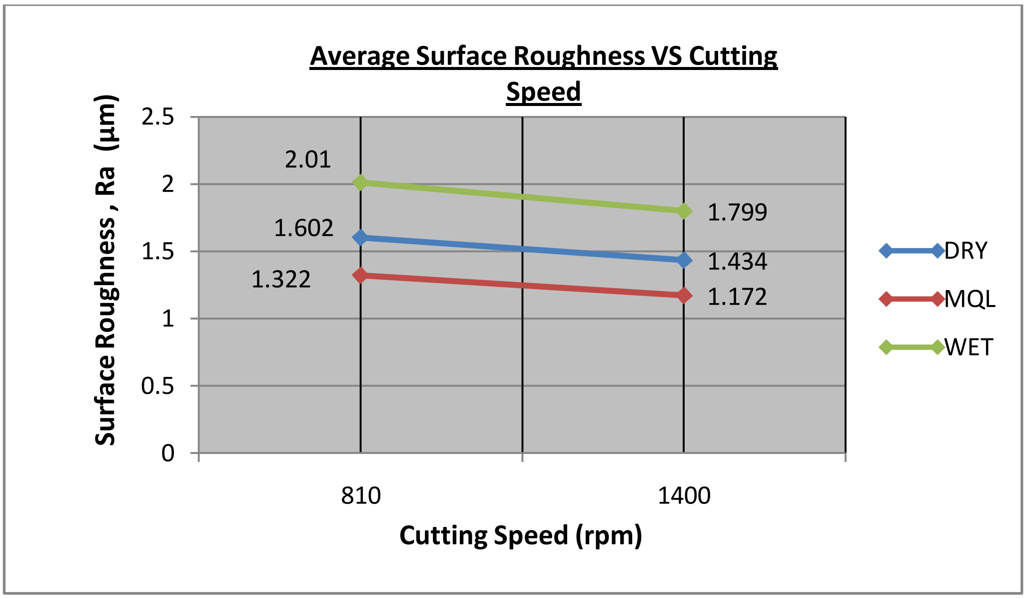


**Figure 4.7:** Graph of average surface roughness vs cutting speed for 0.2 mm DOC

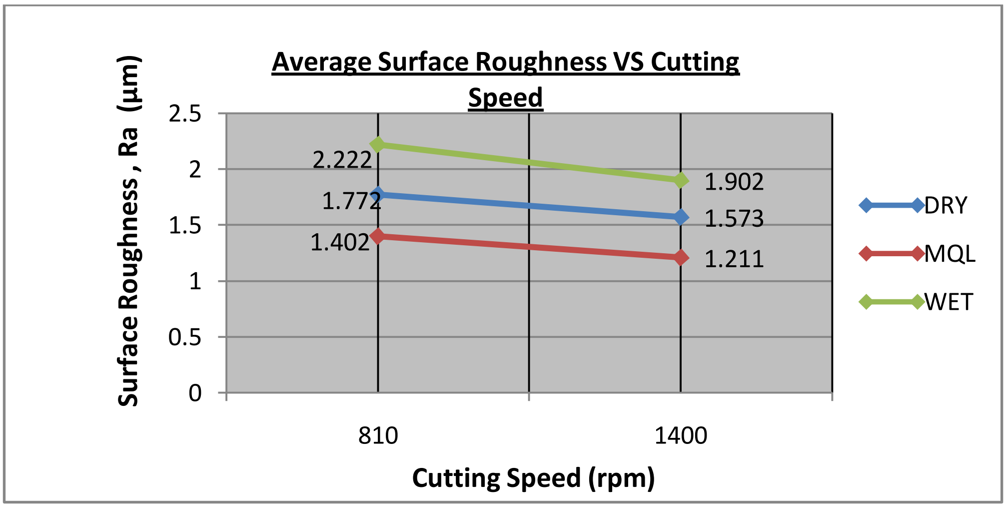


**Figure 4.8:** Graph of average surface roughness vs cutting speed for 0.4 mm DOC

Figure 4.5 and Figure 4.6 display the value of surface roughness for cutting speed of 810 rpm and 1400 rpm respectively. The material was turned under 0.2 mm and 0.4 mm depth of cut. The feed rate was set at 0.15 mm/rev which acted as a constant parameter of the experiment. As it can be seen from Figure 4.5 and Figure 4.6, surface roughness value for minimum quantity lubricant is finer compare to dry and wet machining. From Figure 4.5, for wet machining, the value of surface roughness is 2.01 µm at 0.2 mm DOC and 2.222 µm at 0.4 mm DOC, while for dry machining; the value of surface roughness is 1.602 µm at 0.2 mm DOC and 1.772 µm at 0.4 mm DOC. For minimum quantity lubrication condition, the value of surface roughness is 1.322 µm for 0.2 mm DOC and 1.402 µm for 0.4 mm DOC. The same with Figure 4.6, the value of surface roughness is increased when depth of cut increases. It shows that surface finish is better machining under minimum quantity lubrication for small depth of cut value, followed by dry machining and then wet machining.

Figure 4.7 showed graph of average surface roughness vs cutting speed for 0.2 mm DOC. It displays that the value of surface roughness is decreased from 2.01 µm to 1.799 µm for wet machining, 1.602 µm to 1.434 µm for dry machining, and 1.322 µm to 1.172 µm for minimum quantity lubrication condition (MQL). Figure 4.8 showed the value of surface roughness is decreased for all conditions when cutting speed is increased. For wet machining the surface roughness value decreased from 2.222 µm to 1.902 µm, and for dry machining the value the value decreased from 1.772 µm to 1.573 µm. For minimum quantity lubrication, the value decreased from 1.402 µm to 1.211 µm. It shows that the value is decreased when cutting speed is increased. In spite of that, minimum quantity lubricant still produces better surface finish compared wet and dry machining.

### 4.2.4 Analysis of Surface Roughness of AISI 304 Stainless Steel

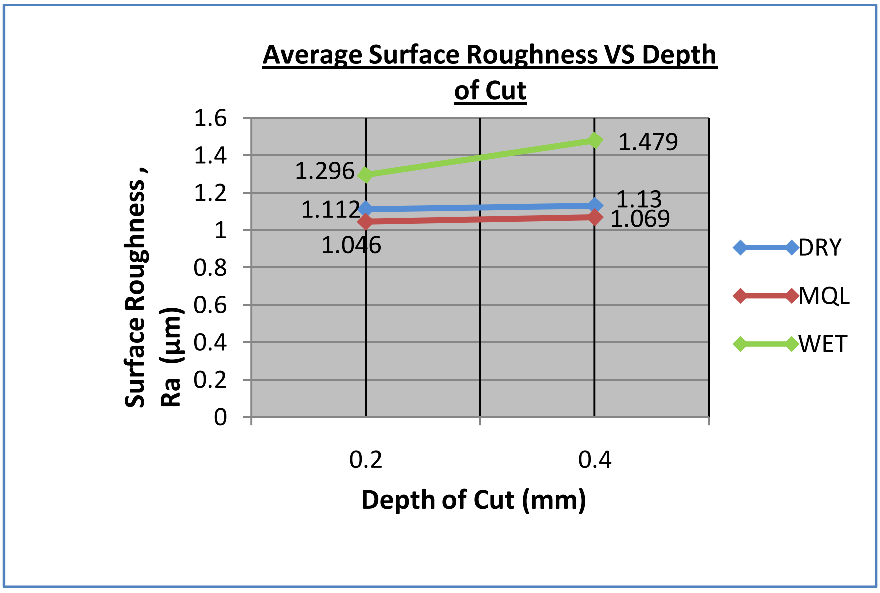


**Figure 4.9:** Graph of average surface roughness vs depth of cut for 810 rpm

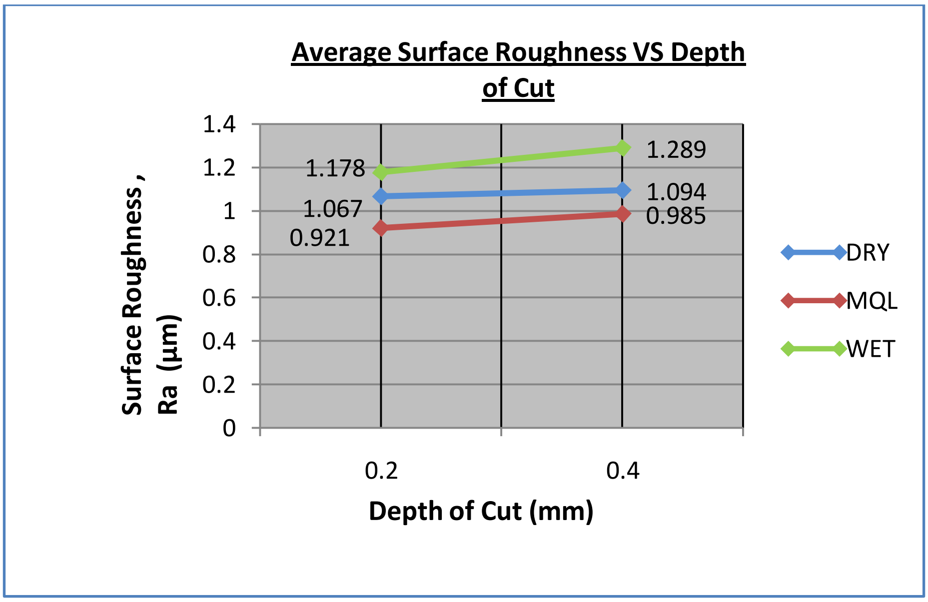


**Figure 4.10:** Graph of average surface roughness vs depth of cut for 1400 rpm

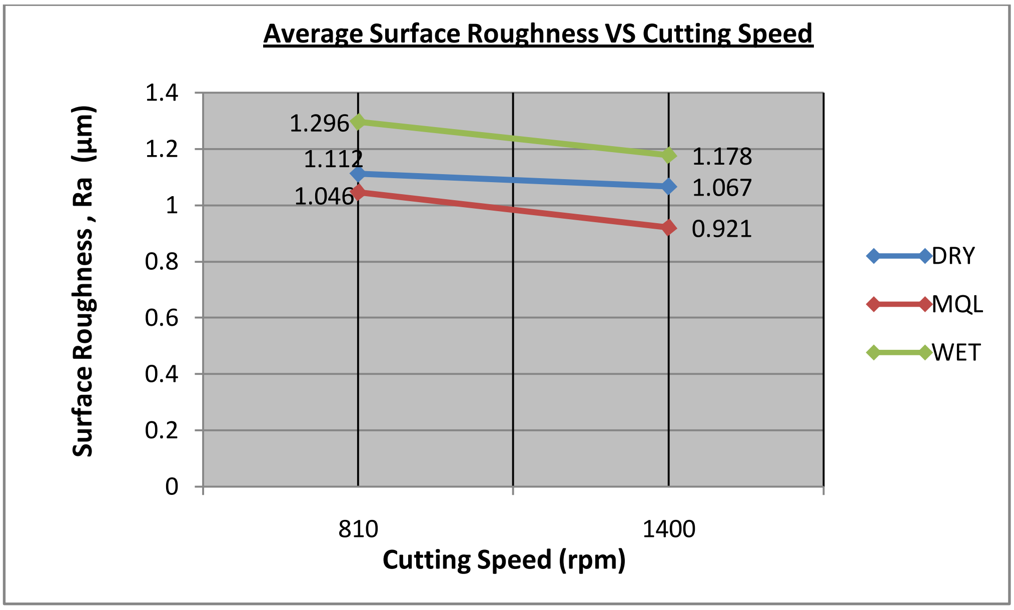


**Figure 4.11:** Graph of average surface roughness vs cutting speed for 0.2 mm DOC

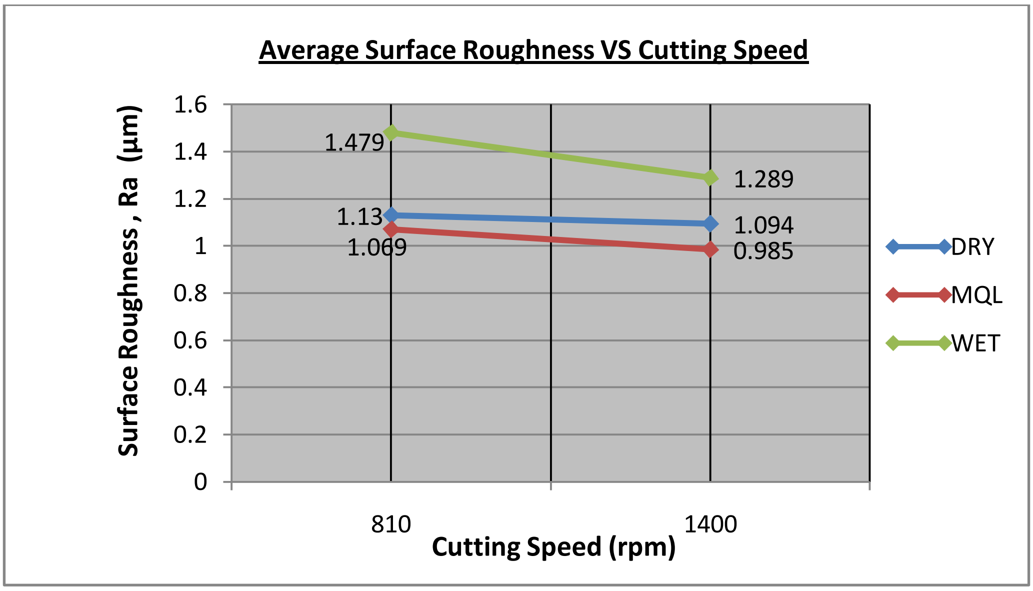


**Figure 4.12:** Graph of average surface roughness vs cutting speed for 0.4 mm DOC

The Figure 4.9 and Figure 4.10 showed the value of surface roughness for cutting speed of 810 rpm and 1400 rpm respectively. The material was turned under 0.2 mm and 0.4 mm depth of cut. The feed rate was set at 0.15mm/rev. As it can be seen from Figure 4.9 and Figure 4.10, surface roughness for minimum quantity lubricant is finer compare to dry and wet machining. From Figure 4.9, for wet machining, the average value of surface roughness at DOC 0.2 mm is 1.296 µm and at DOC 0.4 mm is 1.479 µm, while for dry machining, the value of surface roughness at DOC 0.2 mm is 1.112 µm and at DOC 0.4 mm is 1.13 µm. For minimum quantity lubrication condition, the value of surface roughness is 1.046 µm for 0.2 mm and 1.069 µm for 0.4 mm. The same with Figure 4.10, the value of surface roughness is increase when depth of cut increases. It shows that the surface roughness is better produce in minimum quantity lubrication for small value of depth of cut.

Figure 4.11 showed that the value of surface roughness is decreased from 1.296 µm to 1.479 µm for wet machining, 1.112 µm to 1.13 µm for dry machining, and 1.046 µm to 1.069 µm for minimum quantity lubrication condition (MQL). Figure 4.12 showed the value of surface roughness is decrease for all condition when cutting speed is increased. For wet machining the value decreased from 1.479 µm to 1.289 µm, and for dry machining the value decrease from 1.13 µm to 1.094 µm. For minimum quantity lubrication, the value decrease from 1.069 µm to 0.985 µm. It shows the surface finish is better producing using minimum quantity lubrication for greater cutting speed.

### 4.2.5 Effect of lubrication conditions on surface roughness

Based on the conducted experiment, it was observed that surface roughness much finer under minimum quantity lubricant. From Figure 4.1 until Figure 4.12, it can be observed, exists an interaction between quantities of lubrication with surface roughness.

From the results, it showed the value of surface roughness is lower under minimum quantity lubrication (MQL). It is because of intensive temperature and stresses at tool chips. The function of lubrication is to reduce friction and adhesion between the workpiece, the chip and the tool. As a result, the amount of friction heat generated is also reduced. Consequently, the tool and the workpiece are exposed to less heat under MQL, specific cutting force decreases due to reduction in cutting temperature especially at main cutting edge where built-up edge formation is more predominant. Further, the MQL improves surface roughness depending upon work-tool material through controlling the deterioration of auxiliary cutting edge of abrasion, chipping and built-up edge formation. Minimum quantity lubricant had delivered better surface roughness because in minimum quantity lubricant gives optimum concentration of lubrication and focused on cutting tool. Minimum quantity lubricant can also eliminate abrasive particles suspended in lubricant.

From the results, in dry machining, surface roughness is higher as compared to minimum quantity lubricant because in dry machining, higher order friction between tool and workpiece, and between tool and chip can lead to high temperatures in the machining zone. Without lubricant, the surface roughness grows high under dry machining due to more intensive temperature and stresses at the tool-tips. When the minimum quantity lubrication used, it reduce friction between the workpiece, the chip and the tool. As a result, the amount of friction heat generated is also reduced. From the results above, it shows the surface roughness under minimum quantity lubricant, is much better than dry machining. The effectiveness of lubricants is minimizing the frictional affects at the tool and work-piece interaction.

From Figure 4.1 until Figure 4.12, show the difference in value of surface roughness according to the cooling-lubrication environments. In all the cases, the MQL turning process showed better surface roughness compared with the general wet turning process. From the results show, in the wet condition surfaces roughness (Ra) values were high. A cooling effect, due to the high volume of cutting fluid applied, kept tool and workpiece at lower temperatures, which did not allow the softening of the workpiece and chip material, thus increasing cutting forces and vibration and, consequently, surface roughness (Diniz et al., 2003). The fluid cooling effect did not allow the softening of the chip/workpiece material near the cutting zone and, therefore, there was just the influence of the bigger amount of material rubbing the tool flank face as cutting speed increased, which caused the abrasion process and flank wear to increase.

Those results could also caused by abrasive particles suspended in lubricant. Therefore, if we consider only surface roughness and cutting force, switching from wet turning to MQL turning could affect environmental and economical advantages. In comparison, for the same cutting parameters, with dry cutting and wet cutting, the minimum quantity of cutting fluid method lead to lower cutting forces, temperatures, better surface finish, longer tool life.

### 4.2.6 Relation between Cutting Speed and Depth of Cut on Surface Roughness

From the experiment conducted, it is observed that the lower the cutting speed, the higher the value of surface roughness. This is understood that an increase in cutting speed improves the surface roughness. Cutting speed is one of the parameters that control the surface roughness. Decreasing cutting forces with decreasing cutting speeds when turning workpieces at lower cutting speeds can be attributed to higher Build Up Edge (BUE) formation tendency. As a result, this BUE tends to scratch the material surface and causes the surface roughness value increased in lower cutting speed. On the other hand, as the cutting speed increases, the temperature rises and separates the BUE from tool. Heat generated at the shearing plane can make the cutting action easy. Thus, at higher speed, the surface roughness value is smaller. However, the repeating of build up and removal of BUE will ruin the cutting tool eventually. This is because the vibrations produced lift the tool and snaps it back when the BUE fractures. In addition, the tool life is not longer because the heat generated can flow into the cutting edge and that will negatively affect tool life.

In the aspect of depth of cut (DOC), the value of surface roughness is increased when the DOC value increases. From the results, it shows that lower value of DOC produces better surface finish. This is due to the chip formation during the turning operation. BUE also tend to form when turning workpiece with large DOC value. BUE material usually gets carried away on the tool side of the chip, and the rest are deposited randomly on the surface of workpiece. For the conclusion, better surface finish produces at lower DOC because it produce continuous chip.

## 4.3 PREDICTION RESULTS OF SURFACE ROUGHNESS FOR 1060 ALUMINUM ALLOY

**Table 4.7:** General Linear Model: Ra versus C, CS, and DOC

| Factor | Type | Levels | Value |
|---|---|---|---|
| C | fixed | 3 | 0,1,2 |
| CS | fixed | 2 | 810,1400 |
| DOC | fixed | 2 | 0.2,0.4 |

**Table 4.8:** Multilevel Factorial Design

| Factors | Base Runs | Base Blocks | Replicates | Total Runs | Total Blocks |
|---|---|---|---|---|---|
| 3 | 12 | 1 | 1 | 12 | 1 |

### 4.3.1 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Linear Regression)

**Table 4.9:** Estimated regression coefficients for Ra

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.05966 | 0.05183 | 20.44 | 0.000 |
| C | 0.19475 | 0.01256 | 15.50 | 0.000 |
| CS | -0.00015904 | 0.00003477 | -4.57 | 0.002 |
| DOC | 0.2308 | 0.1026 | 2.25 | 0.055 |

S = 0.0355356 PRESS = 0.0213857

R-Sq = 97.1% R-Sq (pred) = 93.83% R-Sq (adj) = 96.00%

**Table 4.10:** Analysis of variance

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 3 | 0.336229 | 0.336229 | 0.112076 | 88.75 | 0.000 |
| Linear | 3 | 0.336229 | 0.336229 | 0.112076 | 88.75 | 0.000 |
| Residual Error | 8 | 0.010102 | 0.010102 | 0.001263 | | |
| Total | 11 | 0.346331 | | | | |

**Table 4.11:** Estimated linear regression equation

| Term | Coef |
|---|---|
| Constant | 1.06 |
| C | 0.195 |
| CS | -0.000159 |
| DOC | 0.231 |

**Table 4.12:** Predicted response for new design points sing model for Ra

| StdOrder | C | CS | DOC | Ra | FIT |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 0.942 | 0.97700 |
| 2 | 0 | 810 | 0.4 | 1.028 | 1.02317 |
| 3 | 0 | 1400 | 0.2 | 0.873 | 0.88317 |
| 4 | 0 | 1400 | 0.4 | 0.939 | 0.92933 |
| 5 | 1 | 810 | 0.2 | 1.231 | 1.17175 |
| 6 | 1 | 810 | 0.4 | 1.255 | 1.21792 |
| 7 | 1 | 1400 | 0.2 | 1.071 | 1.07792 |
| 8 | 1 | 1400 | 0.4 | 1.096 | 1.12408 |
| 9 | 2 | 810 | 0.2 | 1.341 | 1.36650 |
| 10 | 2 | 810 | 0.4 | 1.372 | 1.41267 |
| 11 | 2 | 1400 | 0.2 | 1.291 | 1.27267 |
| 12 | 2 | 1400 | 0.4 | 1.336 | 1.31883 |

### 4.3.2 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Quadratic Regression)

**Table 4.13:** Estimated regression coefficients for Ra

| Predictor | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.05252 | 0.168799 | 6.24 | 0.003 |
| C | 0.23554 | 0.090783 | 2.59 | 0.060 |
| CS | -0.00019 | 0.0001420 | -1.31 | 0.262 |
| DOC | 0.34144 | 0.502072 | 0.68 | 0.534 |
| C*C | -0.02300 | 0.026195 | -0.88 | 0.430 |
| C*CS | 0.00003 | 0.000051 | 0.60 | 0.584 |
| C*DOC | -0.09500 | 0.151240 | -0.63 | 0.564 |
| CS*DOC | -0.00001 | 0.000419 | -0.03 | 0.975 |

S = 0.0042770 PRESS = 0.059712

R-Sq = 97.9% R-Sq (pred) = 82.76% R-Sq (adj) = 94.2%

**Table 4.14:** Analysis of variance

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 7 | 0.339011 | 0.339011 | 0.048430 | 26.47 | 0.003 |
| Linear | 3 | 0.336229 | 0.037819 | 0.012606 | 6.89 | 0.047 |
| Square | 1 | 0.001411 | 0.001411 | 0.001411 | 0.77 | 0.430 |
| Interaction | 3 | 0.001372 | 0.001372 | 0.000457 | 0.25 | 0.858 |
| Residual Error | 4 | 0.007319 | 0.007319 | 0.001830 | | |
| Total | 11 | 0.346331 | | | | |

**Table 4.15:** Estimated quadratic regression equation

| **Term** | **Coef** |
|---|---|
| Constant | 1.05 |
| C | 0.236 |
| CS | -0.000185 |
| DOC | 0.341 |
| C*C | -0.0230 |
| C*CS | 0.000031 |
| C*DOC | -0.095 |
| CS*DOC | -0.000014 |

* CS*CS is highly correlated with other X variables
* CS*CS has been removed from the equation.
* DOC*DOC is highly correlated with other X variables
* DOC*DOC has been removed from the equation.

**Table 4.16:** Predicted response for new design points using model for Ra

| **StdOrder** | **C** | **CS** | **DOC** | **Ra** | **FIT** |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 0.942 | 0.96842 |
| 2 | 0 | 810 | 0.4 | 1.028 | 1.03442 |
| 3 | 0 | 1400 | 0.2 | 0.873 | 0.85742 |
| 4 | 0 | 1400 | 0.4 | 0.939 | 0.92175 |
| 5 | 1 | 810 | 0.2 | 1.231 | 1.18667 |
| 6 | 1 | 810 | 0.4 | 1.255 | 1.23367 |
| 7 | 1 | 1400 | 0.2 | 1.071 | 1.09367 |
| 8 | 1 | 1400 | 0.4 | 1.096 | 1.13900 |
| 9 | 2 | 810 | 0.2 | 1.341 | 1.35892 |
| 10 | 2 | 810 | 0.4 | 1.372 | 1.38692 |
| 11 | 2 | 1400 | 0.2 | 1.291 | 1.28392 |
| 12 | 2 | 1400 | 0.4 | 1.336 | 1.31025 |

### 4.3.3 Discussion of Response Surface Methodology Modeling Results

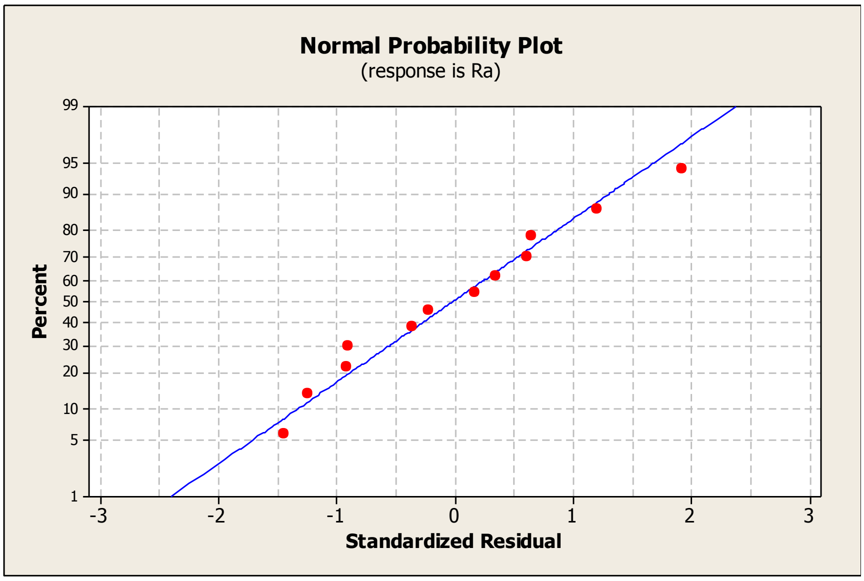


**Figure 4.13:** Linear normal plot

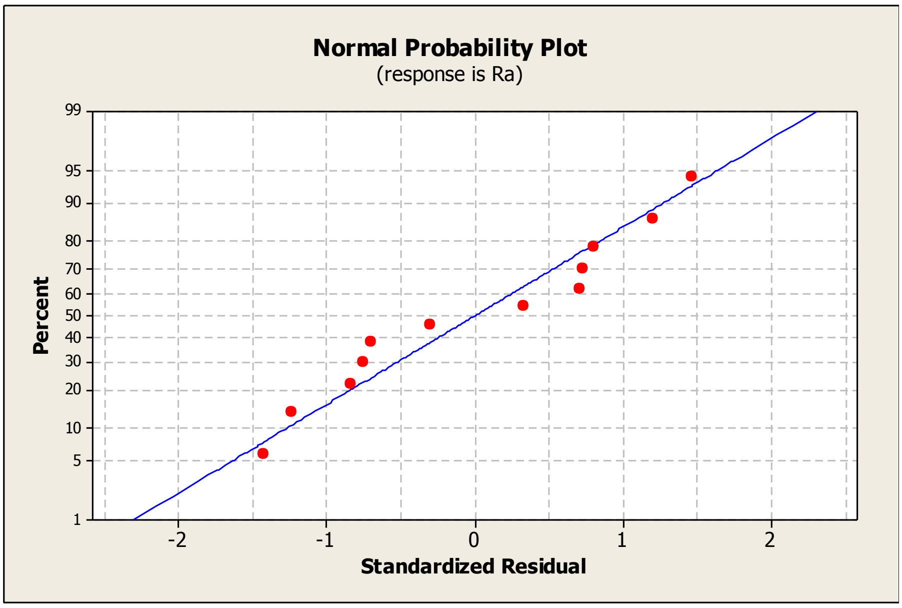


**Figure 4.14:** Quadratic normal plot

**Table 4.17:** Data set used for checking the accuracy of RS model

| StdOrder | C | CS | DOC | Ra (experimental) | 1st Order Prediction | 2nd Order Prediction | 1st Order Error (%) | 2nd Order Error (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 0.942 | 0.977 | 0.968 | 3.716 | 2.804 |
| 2 | 0 | 810 | 0.4 | 1.028 | 1.023 | 1.034 | -0.470 | 0.624 |
| 3 | 0 | 1400 | 0.2 | 0.873 | 0.883 | 0.857 | 1.165 | -1.785 |
| 4 | 0 | 1400 | 0.4 | 0.939 | 0.929 | 0.922 | -1.029 | -1.837 |
| 5 | 1 | 810 | 0.2 | 1.231 | 1.172 | 1.187 | -4.813 | -3.601 |
| 6 | 1 | 810 | 0.4 | 1.255 | 1.218 | 1.234 | -2.955 | -1.700 |
| 7 | 1 | 1400 | 0.2 | 1.071 | 1.078 | 1.094 | 0.646 | 2.116 |
| 8 | 1 | 1400 | 0.4 | 1.096 | 1.124 | 1.139 | 2.562 | 3.923 |
| 9 | 2 | 810 | 0.2 | 1.341 | 1.367 | 1.359 | 1.902 | 1.336 |
| 10 | 2 | 810 | 0.4 | 1.372 | 1.413 | 1.387 | 2.964 | 1.087 |
| 11 | 2 | 1400 | 0.2 | 1.291 | 1.273 | 1.284 | -1.420 | -0.549 |
| 12 | 2 | 1400 | 0.4 | 1.336 | 1.319 | 1.310 | -1.285 | -1.927 |

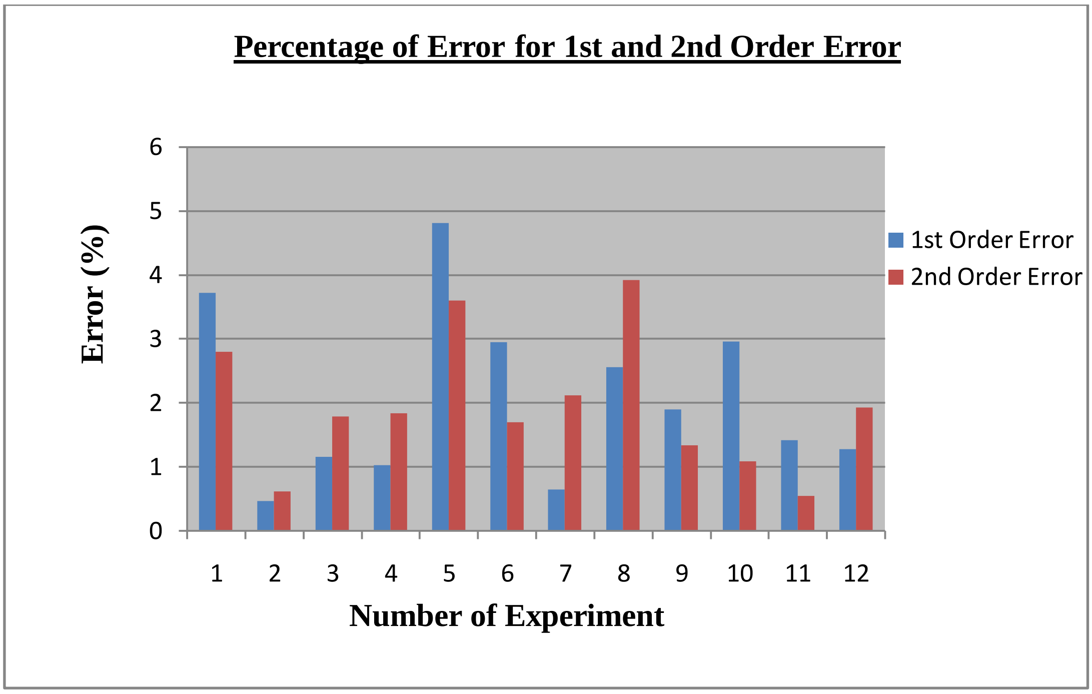


**Figure 4.15:** Comparison of error for 1st and 2nd order model

The test plan was developed using MINITAB 15, with the aim of relating the effects of lubrication conditions, cutting speed and depth of cut on the surface roughness. The statistical treatment data consist of regression, analysis of variance (ANOVA) and the effect of factors and relations between the parameters. The value lubrication condition is defined as 0, 1 and 2 for MQL, dry machining and wet machining respectively.

The ANOVA table shows the influence of lubrication conditions, cutting speed and depth of cut on the total variance of the results. The number of replication is one and the experimental results for regression are shown in Table 4.9 and Table 4.13. Table 4.10 and Table 4.14 show the results analysis of variation (ANOVA) of the results. Those analyses were undertaken under level of confidence of 95 %, which is level of significant of 5 %.

The p-value showed at last column of Table 4.9 and Table 4.13 is used to determine the significance of each parameter on surface roughness. For Table 4.9, first order regression, shows the p-value is 0.000 condition parameters. It means that condition parameters took effect and are highly significant on surface roughness. As for the p-value for cutting speed and dept of cut is 0.002 and 0.055 respectively, means it has an interaction with the surfaces roughness. As for Table 4.13, second order regression, that is the quadratic regression modeling, constant is 0.003, C is 0.060, CS is 0.262, DOC is 0.534, C*C is 0.4340, C*CS is 0.584, C*DOC is 0.564 and interaction between CS and DOC (CS*DOC) is 0.975. This means that the parameters have effect on the surface roughness. However, the value of CS*CS and DOC*DOC is removed from the equation because they are highly correlated with other X-variables.

The dependent variable Ra can be conceived as a linear combination of the independent variables, namely lubrication conditions, cutting speed, and cutting depth. Therefore, the general equation for linear equation will be as below:

$$y = k_0 + k_1 x_1 + k_2 x_2 + k_3 x_3 \tag{4.1}$$

When a linear regression analysis is applying to the experimental data, the following equation is attained:

$$y = 1.06 + 0.95\, x_1 - 0.000159\, x_2 + 0.231\, x_3 \tag{4.2}$$

It can be assumed that the equation demonstrates the relationship between the dependent variable Ra and the independent variables lubrication condition, cutting speed, and cutting depth. The quadratic mathematical model (second-order modeling predicting equation) suggested is in Eq. (4.3);

$$y = k_0 + k_1 x_1 + k_2 x_2 + k_3 x_3 + k_4 x_1^2 + k_5 x_2^2 + k_6 x_3^2 + k_7\, x_1 x_2 + k_8\, x_1 x_3 + k_9\, x_2\, x_3 \tag{4.3}$$

If the regression analysis utilizing least squares method is performed, the following equation is established:

$$y=1.05+0.236\,x_1-0.000185\,x_2+0.341\,x_3-0.0230\,x_1^2+0.000031\,x_1x_2-0.095\,x_1x_3$$
$$-0.000014\,x_2x_3 \qquad (4.4)$$

where, y is the performance output term, which refers to surface roughness, where $x_1$ refers to lubrication condition, $x_2$ refers to cutting speed and $x_3$ refers to depth of cut. Correlation coefficient, $r^2$ is an indicator on how well the model fits the data. The higher value of correlation coefficients, $r^2$ confirm the suitability of the models and accurateness of the calculated constants. From linear regression, the value of $r^2$ from experimental result is 0.971 (97.1 %) and predicted result is 0.9383 (93.83 %). For the value of $r^2$ for quadratic regression from experimental result is 0.979 (97.9 %) and predicted result is 0.8276 (82.76 %). The value of $r^2$ is a measure of the proportion of total variability explained by the model, and if $r^2$ =1, is the most desirable value. From this experiment, for 1060 Aluminum Alloy, the $r^2$ experimental result is closer to 1 compared to the predicted result. Nevertheless, the predicted $r^2$ value is not significantly different from the experimental $r^2$ value. This indicates that the experiment is more significant.

From the normal plot Figure 4.13 and 4.14, is shows the linear and quadratic normal plot respectively. The straight line refers to the regression line. This regression line shows the best prediction of dependent variable based on the surface roughness. The residual values are the points deviate from regression line. The smaller the variability of residual values from the regression line means the better the prediction. Table 4.17 shows the comparison between experimental and predicted values obtained using response surface methodology (RSM). From the table it can be observed that the estimated error is small. Therefore, it can be concluded that the correlation for surface roughness with the cutting parameters satisfies a reasonable degree of approximation. From the table, it can be observed that the percentage error from quadratic regression is closer to the experimental value. In addition, from the calculation, the average percentage value for linear and quadratic is 2.0772 and 1.9421 respectively. Therefore, it can be concluded that the quadratic model is suitable for RSM model because its error is less than linear model.

## 4.4 PREDICTION RESULT OF SURFACE ROUGHNESS FOR AISI 304 STAINLESS STEEL

**Table4.18:** General Linear Model: Ra versus C, CS, and DOC

| Factor | Type | Levels | Value |
|---|---|---|---|
| C | fixed | 3 | 0,1,2 |
| CS | fixed | 2 | 810,1400 |
| DOC | fixed | 2 | 0.2,0.4 |

**Table 4.19:** Multilevel Factorial Design

| Factors | Base Runs | Base Blocks | Replicates | Total Runs | Total Blocks |
|---|---|---|---|---|---|
| 3 | 12 | 1 | 1 | 12 | 1 |

### 4.4.1 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Linear Regression)

**Table 4.20:** Estimated regression coefficients for Ra

| Term | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.06637 | 0.082832 | 12.87 | 0.000 |
| C | 0.15262 | 0.020078 | 7.60 | 0.000 |
| CS | -0.00017 | 0.000056 | -3.04 | 0.016 |
| DOC | 0.35500 | 0.163933 | 2.17 | 0.062 |

S = 0.0567882  PRESS = 0.0569139

R-Sq = 90.0%  R-Sq (pred) = 77.86%  R-Sq (adj) = 86.2%

**Table 4.21:** Analysis of variance

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 3 | 0.231278 | 0.231278 | 0.077093 | 23.91 | 0.000 |
| Linear | 3 | 0.231278 | 0.231278 | 0.077093 | 23.91 | 0.000 |
| Residual Error | 8 | 0.025799 | 0.025799 | 0.003225 | | |
| Total | 11 | 0.257078 | | | | |

**Table 4.22:** Unusual observation

| Obs | C | Ra | Fit | SE Fit | Residual | St Resid |
|---|---|---|---|---|---|---|
| 10 | 2.00 | 1.4790 | 1.3768 | 0.0348 | 0.1022 | 2.28R |

* R denotes an observation with a large standardized residual.

**Table 4.23:** Estimated linear regression equation

| Term | Coef |
|---|---|
| Constant | 1.07 |
| C | 0.153 |
| CS | -0.000169 |
| DOC | 0.355 |

**Table 4.24:** Predicted response for new design points using model for Ra

| StdOrder | C | CS | DOC | Ra | FIT |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.046 | 1.000542 |
| 2 | 0 | 810 | 0.4 | 1.069 | 1.071542 |
| 3 | 0 | 1400 | 0.2 | 0.921 | 0.900875 |
| 4 | 0 | 1400 | 0.4 | 0.985 | 0.971875 |
| 5 | 1 | 810 | 0.2 | 1.112 | 1.153167 |
| 6 | 1 | 810 | 0.4 | 1.130 | 1.224167 |
| 7 | 1 | 1400 | 0.2 | 1.067 | 1.053500 |
| 8 | 1 | 1400 | 0.4 | 1.094 | 1.124500 |
| 9 | 2 | 810 | 0.2 | 1.296 | 1.305792 |
| 10 | 2 | 810 | 0.4 | 1.479 | 1.376792 |
| 11 | 2 | 1400 | 0.2 | 1.178 | 1.206125 |
| 12 | 2 | 1400 | 0.4 | 1.289 | 1.277125 |

### 4.4.2 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Quadratic Regression)

**Table 4.25:** Estimated regression coefficients for Ra

| Predictor | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.09608 | 0.201938 | 5.43 | 0.006 |
| C | 0.00710 | 0.108605 | 0.07 | 0.951 |
| CS | -0.00011 | 0.000170 | -0.64 | 0.558 |
| DOC | 0.16492 | 0.600641 | 0.27 | 0.797 |
| C*C | 0.05712 | 0.031338 | 1.82 | 0.142 |
| C*CS | -0.00004 | 0.000061 | -0.68 | 0.532 |
| C*DOC | 0.258875 | 0.180931 | 1.43 | 0.226 |
| CS*DOC | -0.00006 | 0.000501 | -0.12 | 0.907 |

S = 0.0511751 PRESS = 0.0965737

R-Sq = 95.9% R-Sq (pred) = 62.43% R-Sq (adj) = 88.8%

**Table 4.26:** Analysis of variance

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 7 | 0.246602 | 0.246602 | 0.035229 | 13.45 | 0.012 |
| Linear | 3 | 0.231278 | 0.006218 | 0.002073 | 0.79 | 0.559 |
| Square | 1 | 0.008702 | 0.008702 | 0.008702 | 3.32 | 0.142 |
| Interaction | 3 | 0.006622 | 0.006622 | 0.002207 | 0.84 | 0.537 |
| Residual Error | 4 | 0.010476 | 0.010476 | 0.002619 | | |
| Total | 11 | 0.257078 | | | | |

**Table 4.27:** Estimated quadratic regression equation

| Term | Coef |
|---|---|
| Constant | 1.10 |
| C | 0.007 |
| CS | -0.000108 |
| DOC | 0.165 |
| C*C | 0.0571 |
| C*CS | -0.000042 |
| C*DOC | 0.259 |
| CS*DOC | -0.000062 |

* CS*CS is highly correlated with other X variables

* CS*CS has been removed from the equation.

* DOC*DOC is highly correlated with other X variables

* DOC*DOC has been removed from the equation.

**Table 4.28:** Predicted response for new design points using model for Ra

| StdOrder | C | CS | DOC | Ra | FIT |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.046 | 1.03125 |
| 2 | 0 | 810 | 0.4 | 1.069 | 1.05417 |
| 3 | 0 | 1400 | 0.2 | 0.921 | 0.96000 |
| 4 | 0 | 1400 | 0.4 | 0.985 | 0.97558 |
| 5 | 1 | 810 | 0.2 | 1.112 | 1.11325 |
| 6 | 1 | 810 | 0.4 | 1.130 | 1.18792 |
| 7 | 1 | 1400 | 0.2 | 1.067 | 1.01725 |
| 8 | 1 | 1400 | 0.4 | 1.094 | 1.08458 |
| 9 | 2 | 810 | 0.2 | 1.296 | 1.30950 |
| 10 | 2 | 810 | 0.4 | 1.479 | 1.43592 |
| 11 | 2 | 1400 | 0.2 | 1.178 | 1.18875 |
| 12 | 2 | 1400 | 0.4 | 1.289 | 1.30783 |

### 4.4.3 Discussion of Response Surface Methodology Modeling Results

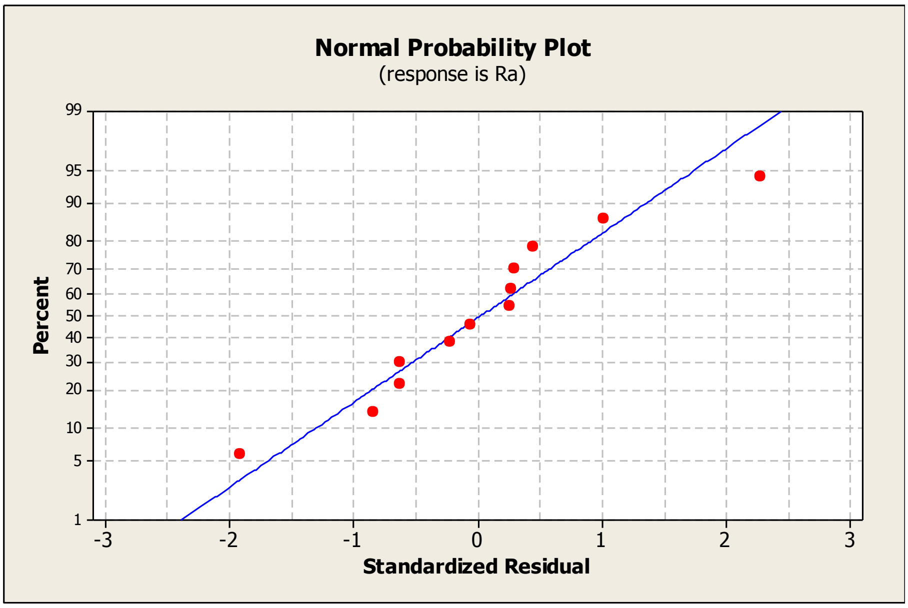


**Figure 4.16:** Linear normal plot

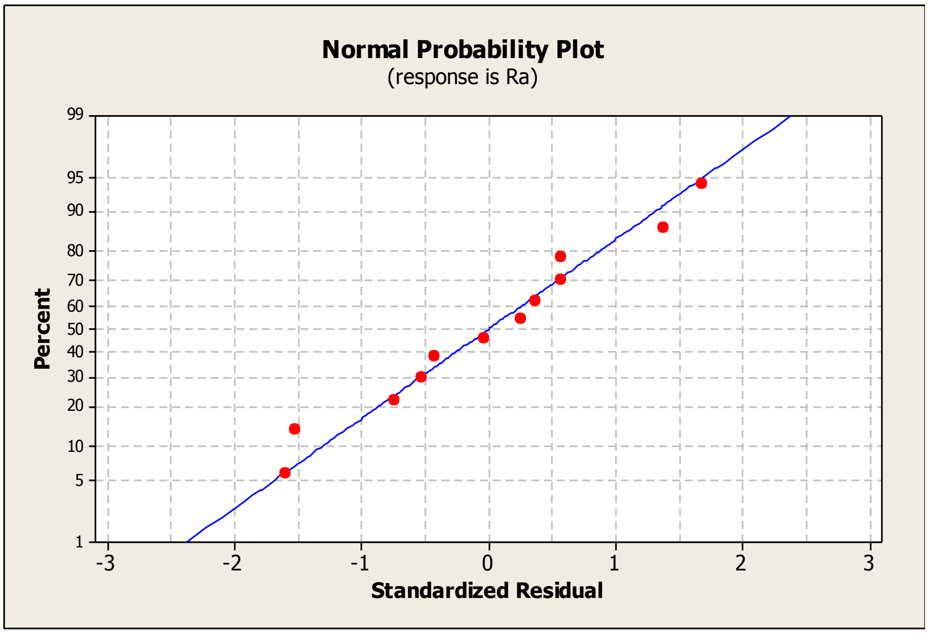


**Figure 4.17:** Quadratic normal plot

**Table 4.29:** Data set used for checking the accuracy of RS model

| StdOrder | C | CS | DOC | Ra (experimental) | 1st Order Prediction | 2nd Order Prediction | 1st Order Error (%) | 2nd Order Error (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.046 | 1.000 | 1.031 | -4.346 | -1.410 |
| 2 | 0 | 810 | 0.4 | 1.069 | 1.072 | 1.054 | 0.238 | -1.388 |
| 3 | 0 | 1400 | 0.2 | 0.921 | 0.901 | 0.960 | -2.185 | 4.235 |
| 4 | 0 | 1400 | 0.4 | 0.985 | 0.972 | 0.976 | -1.332 | -0.956 |
| 5 | 1 | 810 | 0.2 | 1.112 | 1.153 | 1.113 | 3.702 | 0.112 |
| 6 | 1 | 810 | 0.4 | 1.130 | 1.224 | 1.188 | 8.333 | 5.125 |
| 7 | 1 | 1400 | 0.2 | 1.067 | 1.054 | 1.017 | -1.266 | -4.663 |
| 8 | 1 | 1400 | 0.4 | 1.094 | 1.125 | 1.085 | 2.788 | -0.861 |
| 9 | 2 | 810 | 0.2 | 1.296 | 1.306 | 1.310 | 0.756 | 1.042 |
| 10 | 2 | 810 | 0.4 | 1.479 | 1.377 | 1.436 | -6.911 | -2.913 |
| 11 | 2 | 1400 | 0.2 | 1.178 | 1.206 | 1.189 | 2.388 | 0.913 |
| 12 | 2 | 1400 | 0.4 | 1.289 | 1.277 | 1.308 | -0.921 | 1.461 |

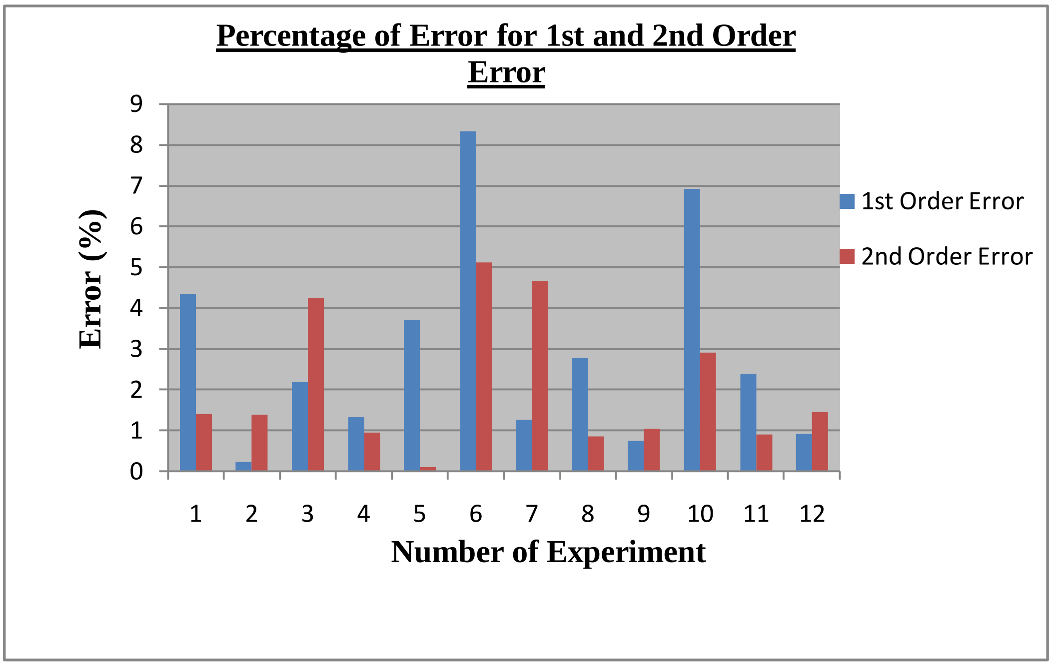


**Figure 4.18:** Comparison of error for 1st and 2nd order model

In Table 4.20 and Table 4.25 show the estimation regression coefficients for Ra for linear and quadratic respectively. The ANOVA table shows the influence of lubrication conditions, cutting speed and depth of cut on the total variance of the results. The number of replication is one. Table 4.21 and Table 4.26 show the results analysis of variation (ANOVA) of the results. Those analyses were undertaken under level of confidence of 95 %, which is level of significant of 5 %.

The last column in the ANOVA table displayed the P-value which used to determine the significance of each parameter surface roughness. For first order regression, this is the linear regression modeling, the P-value for C is 0.000, CS is 0.016, and DOC is 0.062. This means that parameters took effect and highly significant on surface roughness. As for Table 4.25, second order regression, that is the quadratic regression modeling, constant is 0.006, C is 0.951, CS is 0.558, DOC is 0.797, C*C is 0.142, C*CS is 0.532, C*DOC is 0.226 and interaction between CS and DOC (CS*DOC) is 0.907. This means that all parameters have effect on surface roughness.

However, the value of CS*CS and DOC*DOC is removed from the equation because they are highly correlated with other X-variables.

The dependent variable Ra can be conceived as a linear combination of the independent variables, namely lubrication conditions, cutting speed, and cutting depth. Therefore, for linear model, the equation will be the same as Eq (4.1).

When a linear regression analysis is applying to the experimental data, the following equation is attained:

$$y=1.06+0.95x_1-0.000159x_2+0.231x_3 \quad (4.5)$$

It can be assumed that the equation demonstrates the relationship between the dependent variable Ra and the independent variables which are lubrication condition, cutting speed, and cutting depth. The quadratic mathematical model (second-order modeling predicting equation) suggested is the same with Eq. (4.3) before.

The quadratic mathematical model (second-order modeling predicting equation) suggested is in Eq. (4.6);

$$y=1.05+0.236x_1-0.000185x_2+0.341x_3-0.0230x_1^2+0.000031x_1x_2-0.095x_1x_3$$
$$-0.000014x_2x_3 \quad (4.6)$$

where, y is the performance output term, which refers to surface roughness, where $x_1$ refers to lubrication condition, $x_2$ is refer to cutting speed and $x_3$ refers to depth of cut. Correlation coefficient, $r^2$ is an indicator on how well the model fits the data. The higher value of correlation coefficients, $r^2$ confirm the suitability of the models and accurateness of the calculated constants. From linear regression, the value of $r^2$ from experimental result is 0.900 (90.00 %) and predicted result is 0.7786 (77.86 %). For the value of $r^2$ for quadratic regression from experimental result is 0.959 (95.9 %) and predicted result is 0.6243 (62.43 %). The value of $r^2$ is measure of the proportion of total variability explained by the model, and $r^2=1$ is the most desirable value. From this experiment, for stainless steel, the $r^2$ experimental result is closer to 1 compared to the predicted result.

From the normal plot of Figure 4.16 and Figure 4.17, show the linear normal plot and quadratic normal plot respectively. The straight line indicates the regression line. The regression line is expressed as the best prediction of dependent variable based on given independent variables. The points deviate from regression line is called residual values. The smaller the variability of residual values from regression line means the better prediction. Table 4.29 shows the comparison between experimental values with predicted values obtained using RSM. From the table can be observed the percentage error for quadratic regression is closer to the experimental value. Therefore, it can state that the correlations for surface roughness with the cutting parameters satisfy a reasonable degree of approximation. From the calculation, the average percentage value for linear and quadratic is 2.9304 and 2.0898 respectively. Therefore, it can be concluded that the quadratic model is suitable for RSM model because its percentage error is less than linear model.

## 4.5 PREDICTION RESULT OF SURFACE ROUGHNESS FOR ASTM B176 BRASS

**Table4.30:** General Linear Model: Ra versus C, CS, and DOC

| **Factor** | **Type** | **Levels** | **Value** |
|---|---|---|---|
| C | fixed | 3 | 0,1,2 |
| CS | fixed | 2 | 810,1400 |
| DOC | fixed | 2 | 0.2,0.4 |

**Table 4.31:** Multilevel Factorial Design

| **Factors** | **Base Runs** | **Base Blocks** | **Replicates** | **Total Runs** | **Total Blocks** |
|---|---|---|---|---|---|
| 3 | 12 | 1 | 1 | 12 | 1 |

### 4.5.1 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Linear Regression)

**Table 4.32:** Estimated regression coefficients for Ra

| **Term** | **Coef** | **SE Coef** | **T** | **P** |
|---|---|---|---|---|
| Constant | 1.46617 | 0.06989 | 20.98 | 0.000 |
| C | 0.35325 | 0.01694 | 20.85 | 0.000 |
| CS | -0.00035000 | 0.00004689 | -7.46 | 0.000 |
| DOC | 0.6192 | 0.1383 | 4.48 | 0.002 |

S = 0.0479187 PRESS = 0.0440095

R-Sq = 98.5% R-Sq (pred) = 96.30% R-Sq (adj) = 97.9%

**Table 4.33:** Analysis of variance

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 3 | 1.17222 | 1.17222 | 0.390738 | 170.17 | 0.000 |
| Linear | 3 | 1.17222 | 1.17222 | 0.390738 | 170.17 | 0.000 |
| Residual Error | 8 | 0.01837 | 0.01837 | 0.002296 | | |
| Total | 11 | 1.19058 | | | | |

**Table 4.34:** Unusual observation

| Obs | C | Ra | Fit | SE Fit | Residual | St Resid |
|---|---|---|---|---|---|---|
| 10 | 2.00 | 2.2220 | 2.1368 | 0.0293 | 0.0852 | 2.25R |

**Table 4.35:** Estimated linear regression equation

| Term | Coef |
|---|---|
| Constant | 1.47 |
| C | 0.353 |
| CS | - 0.000350 |
| DOC | 0.619 |

**Table 4.36:** Predicted response for new design points using model for Ra

| StdOrder | C | CS | DOC | Ra | FIT |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.322 | 1.30650 |
| 2 | 0 | 810 | 0.4 | 1.402 | 1.43033 |
| 3 | 0 | 1400 | 0.2 | 1.172 | 1.10000 |
| 4 | 0 | 1400 | 0.4 | 1.211 | 1.22383 |
| 5 | 1 | 810 | 0.2 | 1.602 | 1.65975 |
| 6 | 1 | 810 | 0.4 | 1.772 | 1.78358 |
| 7 | 1 | 1400 | 0.2 | 1.434 | 1.45325 |
| 8 | 1 | 1400 | 0.4 | 1.573 | 1.57708 |
| 9 | 2 | 810 | 0.2 | 2.010 | 2.01300 |
| 10 | 2 | 810 | 0.4 | 2.222 | 2.13683 |
| 11 | 2 | 1400 | 0.2 | 1.799 | 1.80650 |
| 12 | 2 | 1400 | 0.4 | 1.902 | 1.93033 |

### 4.5.2 Response Surface Regression: Ra versus Condition, Depth of Cut, RPM (Quadratic Regression)

**Table 4.37:** Estimated regression coefficients for Ra

| Predictor | Coef | SE Coef | T | P |
|---|---|---|---|---|
| Constant | 1.2928 | 0.1099 | 11.76 | 0.000 |
| C | 0.29921 | 0.05913 | 5.06 | 0.007 |
| CS | -0.00011610 | 0.00009245 | -1.26 | 0.278 |
| DOC | 0.9392 | 0.3270 | 2.87 | 0.045 |
| C*C | 0.03475 | 0.01706 | 2.04 | 0.111 |
| C*CS | -0.00008051 | 0.00003339 | -2.41 | 0.073 |
| C*DOC | 0.24500 | 0.09850 | 2.49 | 0.068 |
| CS*DOC | -0.0005113 | 0.0002726 | -1.88 | 0.134 |

S = 0.0278605 PRESS = 0.0294627

R-Sq = 99.7% R-Sq (pred) = 97.53% R-Sq (adj) = 99.3%

**Table 4.38:** Analysis of variance

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 7 | 1.18748 | 0.16964 | 218.55 | 0.000 |
| Residual Error | 4 | 0.00310 | 0.00078 | | |
| Total | 11 | 1.19058 | | | |

**Table 4.39:** Estimated quadratic regression equation

| Term | Coef |
|---|---|
| Constant | 1.29 |
| C | 0.299 |
| CS | - 0.000116 |
| DOC | 0.939 |
| C*C | 0.0347 |
| C*CS | - 0.000081 |
| C*DOC | 0.245 |
| CS*DOC | - 0.000511 |

* CS*CS is highly correlated with other X variables
* CS*CS has been removed from the equation.
* DOC*DOC is highly correlated with other X variables
* DOC*DOC has been removed from the equation.

**Table 4.40:** Predicted response for new design points using model for Ra

| StdOrder | C | CS | DOC | Ra | FIT |
|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.322 | 1.30375 |
| 2 | 0 | 810 | 0.4 | 1.402 | 1.40875 |
| 3 | 0 | 1400 | 0.2 | 1.172 | 1.17492 |
| 4 | 0 | 1400 | 0.4 | 1.211 | 1.21958 |
| 5 | 1 | 810 | 0.2 | 1.602 | 1.62150 |
| 6 | 1 | 810 | 0.4 | 1.772 | 1.77550 |
| 7 | 1 | 1400 | 0.2 | 1.434 | 1.44517 |
| 8 | 1 | 1400 | 0.4 | 1.573 | 1.53883 |
| 9 | 2 | 810 | 0.2 | 2.010 | 2.00875 |
| 10 | 2 | 810 | 0.4 | 2.222 | 2.21175 |
| 11 | 2 | 1400 | 0.2 | 1.799 | 1.78492 |
| 12 | 2 | 1400 | 0.4 | 1.902 | 1.92758 |

### 4.5.3 Discussion of Response Surface Methodology Modeling Results

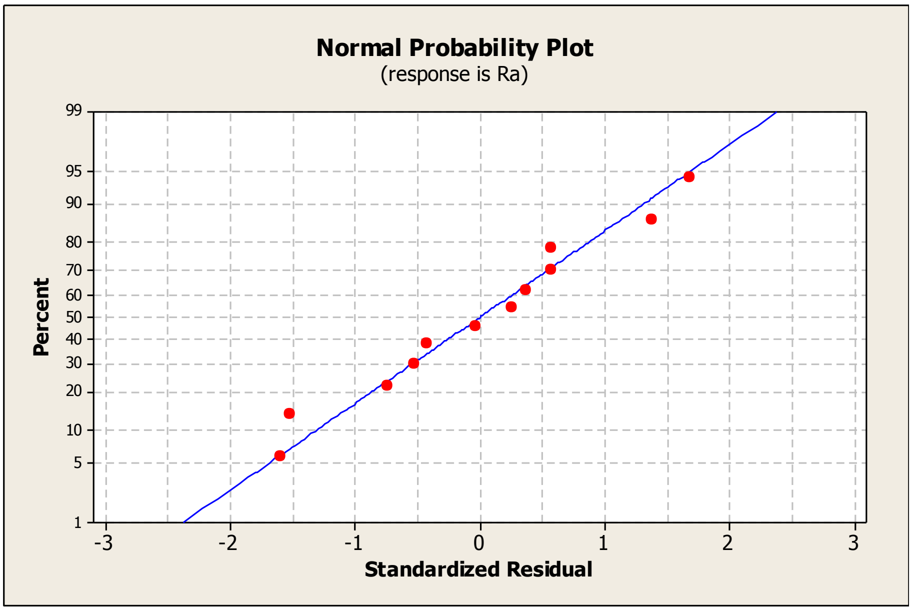


**Figure 4.19:** Linear normal plot

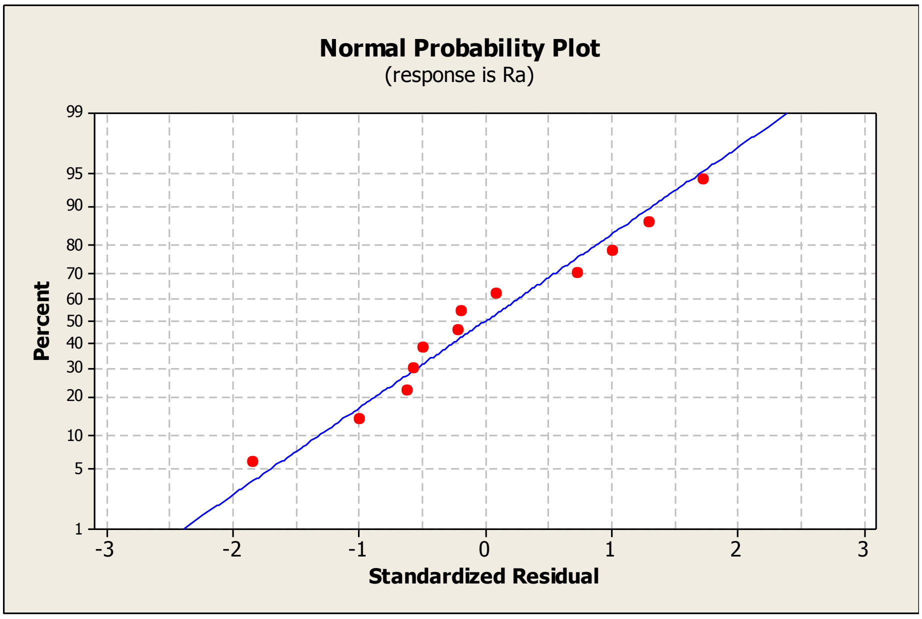


**Figure 4.20:** Quadratic normal plot

**Table 4.41:** Data set used for checking the accuracy of RS model

| StdOrder | C | CS | DOC | Ra (experimental) | 1st Order Prediction | 2nd Order Prediction | 1st Order Error (%) | 2nd Order Error (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 810 | 0.2 | 1.322 | 1.307 | 1.304 | -1.172 | -1.380 |
| 2 | 0 | 810 | 0.4 | 1.402 | 1.430 | 1.409 | 2.021 | 0.481 |
| 3 | 0 | 1400 | 0.2 | 1.172 | 1.100 | 1.175 | -6.143 | 0.249 |
| 4 | 0 | 1400 | 0.4 | 1.211 | 1.224 | 1.220 | 1.060 | 0.709 |
| 5 | 1 | 810 | 0.2 | 1.602 | 1.660 | 1.622 | 3.605 | 1.217 |
| 6 | 1 | 810 | 0.4 | 1.772 | 1.784 | 1.776 | 0.654 | 0.198 |
| 7 | 1 | 1400 | 0.2 | 1.434 | 1.453 | 1.445 | 1.342 | 0.779 |
| 8 | 1 | 1400 | 0.4 | 1.573 | 1.577 | 1.539 | 0.260 | -2.172 |
| 9 | 2 | 810 | 0.2 | 2.010 | 2.013 | 2.009 | 0.150 | -0.062 |
| 10 | 2 | 810 | 0.4 | 2.222 | 2.137 | 2.212 | -3.833 | -0.461 |
| 11 | 2 | 1400 | 0.2 | 1.799 | 1.807 | 1.785 | 0.417 | -0.783 |
| 12 | 2 | 1400 | 0.4 | 1.902 | 1.930 | 1.928 | 1.490 | 1.345 |

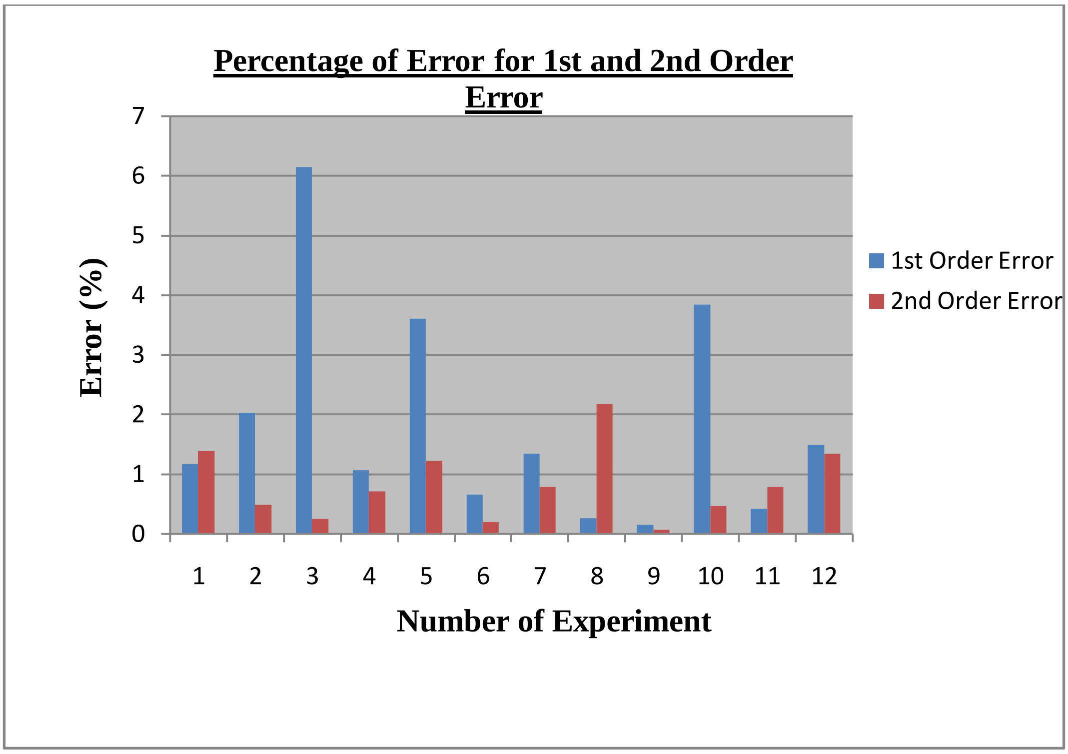


**Figure 4.21:** Comparison of error for 1st and 2nd order model

Table 4.31 and Table 4.36 show the estimation regression coefficients for Ra for linear and quadratic respectively. The ANOVA table shows the influence of lubrication conditions, cutting speed and depth of cut on the total variance of the results. Table 4.32 and Table 4.37 show the results analysis of variation (ANOVA) of the results. Those analyses were undertaken under level of confidence of 95 %, which is level of significant of 5 %.

The last column in the ANOVA table displayed the P-value which used to determine the significance of each parameter surface roughness. The parameters take effects on the surface roughness. However, the value of CS*CS and DOC*DOC is removed from the equation because they are highly correlated with other X-variables. The value C (the lubrication condition) was defined 0, 1 and 2 for MQL, dry machining and wet machining respectively.

The dependent variable Ra can be conceived as a linear combination of the independent variables, namely lubrication conditions, cutting speed, and cutting depth. Therefore, for linear model, the equation will be the same as Eq (4.1).

When a linear regression analysis is applying to the experimental data, the following equation is attained:

$$y=1.47+0.353\,x_1-0.000350\,x_2+0.619\,x_3 \tag{4.7}$$

It can be assumed that the equation below demonstrates the relationship between the dependent variable Ra and the independent variables lubrication condition, cutting speed, and cutting depth. The quadratic mathematical model (second-order modeling predicting equation) suggested is in Eq. (4.3).

The quadratic mathematical model (second-order modeling predicting equation) suggested is in Eq. (4.8);

$$y=1.29+0.299\,x_1-0.000116\,x_2+0.939\,x_3+0.347\,x_1^2-0.000081\,x_1x_2+0.245\,x_1x_3-0.00051\,x_2x_3 \tag{4.8}$$

where, y is the performance output term, which refers to surface roughness, where $x_1$ refers to lubrication condition, $x_2$ is refer to cutting speed and $x_3$ refers to depth of cut. Correlation coefficient, $r^2$ is an indicator on how well the model fits the data. The higher the value of correlation coefficient, $r^2$ confirm the suitability of the models and accurateness of the calculated constants. From linear regression, the value of $r^2$ from experimental result is 0.985 (98.50 %) and predicted result is 0.9630 (96.30 %). For the value of $r^2$ for quadratic regression from experimental result is 0.997 (99.7 %) and predicted result is 0.9753 (97.53 %). The value of $r^2$ is measure of the proportion of total variability explained by the model, and $r^2=1$ is the most desirable value. From this experiment, for ASTM B176 Brass, the $r^2$ experimental result is closer to 1 compared to the predicted result. Nevertheless, the predicted $r^2$ value is significantly different from the experimental $r^2$ value. This indicates that the experiment is more significant.

From the normal plot Figure 4.19 and 4.20, show the linear and quadratic normal plot respectively. The straight line indicates the regression line. The regression line is expressed as the best prediction of dependent variable based on given independent variables. The points deviate from regression line is called residual values. The smaller the variability of residual values from regression line means the better prediction. Table 4.40 shows the comparison between experimentally values with predicted values using RSM. From the table can be observed that the estimated error is small. It is also observed, that the predicted values from quadratic regression are closer to the experimental value. Therefore, it can be concluded that the correlations for surface roughness with the cutting parameters satisfies a reasonable degree of approximation. From Figure 4.21, the graph shows that the error for 2nd order model's error is smaller than that 1st order model. From the calculation, the average percentage value for linear and quadratic is 1.8455 and 0.8197 respectively. So, quadratic regression model shows better prediction.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 INTRODUCTION

This chapter is the summary of what this whole research is about. It concludes all the outcomes, observation of results and analysis, and discussion throughout the experiment. The conclusion is based on the results. Recommendations will also be given to improve this study in the future.

## 5.2 CONCLUSIONS

According to the experiment results, shows that lubrication condition is one of the factors affect the surface roughness. The effects of different lubrication conditions, including MQL, wet, and dry cutting, on the surface roughness, Ra was analyzed in this study. The conclusions are as follows:

i. The minimum lubrication condition (MQL) produced better surface finish than dry and wet machining. Average surface roughness, Ra is lower in minimum quantity lubricant condition.
ii. The surface roughness under MQL cutting condition is finer, because in minimum lubrication condition is less intensive temperature and stresses at tool chips and material surface.
iii. The linear and quadratic models were applied in the fit process of surface roughness. The results show that the fit precision of quadratic model is much higher than linear model. It is because, quadratic model is less percent of error compared with linear model.

iv. Minimum quantity lubricant an alternative replacement of dry and flood machining because it could reduce many cutting problems coming from high consumptions of lubricant such as high machining cost, environmental pollution and worker health problems.

## 5.3 RECOMMENDATIONS

For every studies and researches that has been done, there is always room for further improvements. There are some suggestion and method that can be taken into account in this research in the future. The recommendations to improve this study are:

i. Study another effect of lubrication condition on tool wear and flank wear.
ii. Use the latest model Lathe machine, or CNC Lathe machine so that there is an easy way and to get more accurate volume and speed of lubrication.
iii. Use new design of experiment (DOE) when carry out the experiment such as Taguchi method, Factorial method, or Response Surface method. By using these methods, the set of parameters that is generated will be more suitable and accurate in determining the relationship between factors affecting a process and the output of that process.
iv. The cutting tool is changed every time after using a set of lubrication condition. Usually after cutting on long time, the cutting tool may be worn out. Tool wear can affect the surface roughness of turned material. Therefore, using a new cutting tool is advisable.

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# APPENDIX A

# MACHINES AND EQUIPMENTS USED IN EXPERIMENT

## A.1 Vertical Bandsaw Machine


## A.2 Cutting Material Process by Using Vertical Bandsaw

## A.3 Lathe Machine


## A.4 Turning Process by Using Lathe Machine

## A.5 Perthometer

## A.6 Material Test On Perthometer

# APPENDIX B

# MATERIAL

## B.1 ASTM B176 Brass

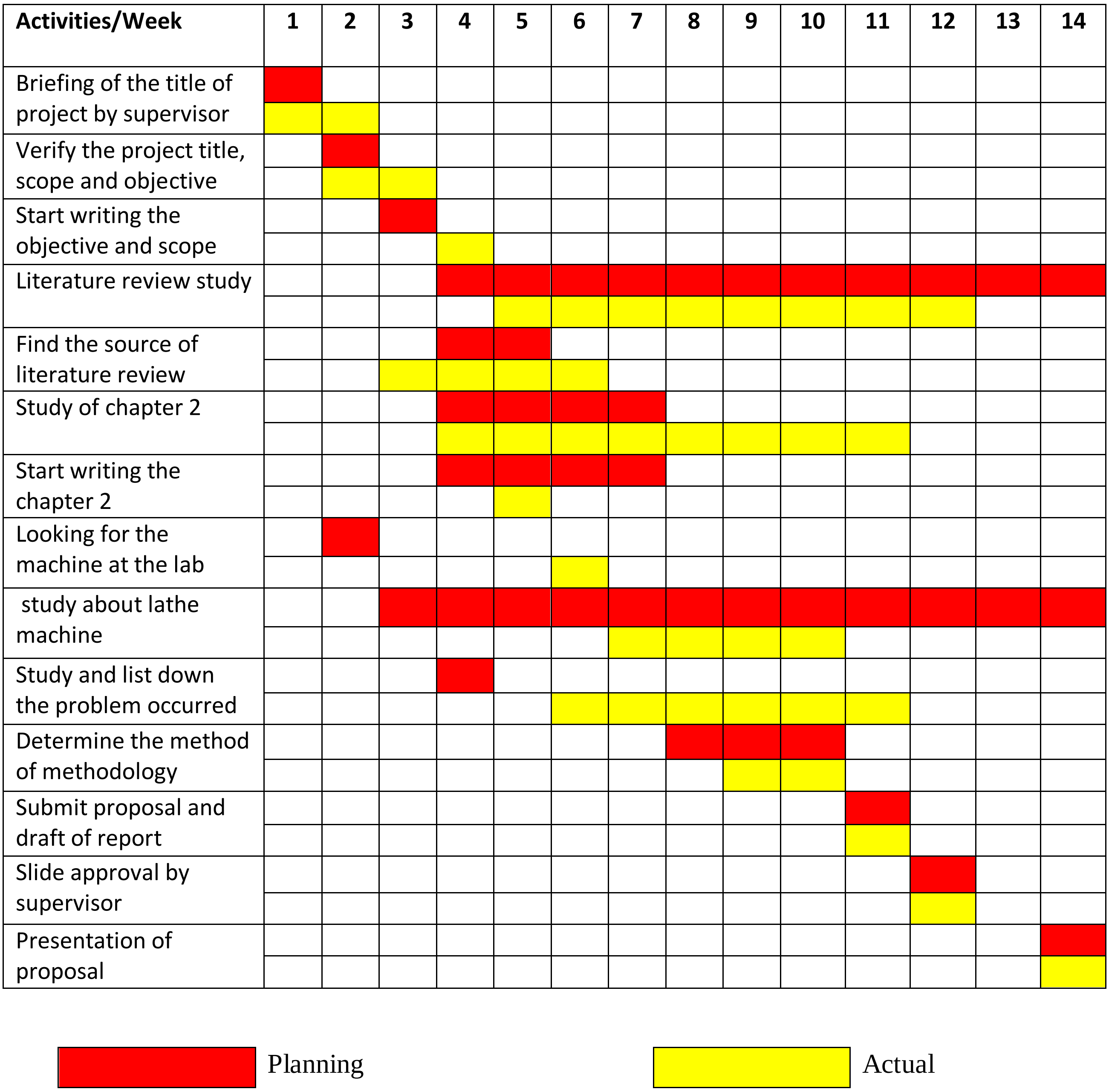
## B.2 AISI 304 Stainless Steel

## B.3 1060 Aluminum Alloy

# APPENDIX C

# GANTT CHART

## C1. Gantt Chart for FYP 1



## C2. Gantt Chart for FYP 2