EFFECT OF CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS OF MILD STEEL IN TURNING OPERATION

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JUDUL: **EFFECT OF CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS OF MILD STEEL IN TURNING OPERATION**

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our 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.

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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.

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ABSTRACT

In metal cutting and manufacturing industries, surface finish of a product is very crucial in determining the quality. Good surface finish not only assures quality, but also reduces manufacturing cost. Surface finish is important in terms of tolerances, it reduces assembly time and avoids the need for secondary operation, thus reduces operation time and leads to overall cost reduction. Besides, good-quality turned surface is significant in improving fatigue strength, corrosion resistance, and creep life. In this research, the main objective is to study the effect of cutting speed and depth of cut on surface roughness of mild steel in turning operation. And MINITAB 15 software was used to predict the surface roughness. Both predicted and experimental results were then compared. Different cutting parameters have different influential on the surface finish. In the experiment conducted in this research, 3 cutting speed and 5 depth of cut were used. Using Taguchi Orthogonal Array as design of experiment, the total set of experiments carried out is 15 sets. At first, the mild steel was undergone chemical composition test using Arc Spectrometer, and was decide that it might be of grade AISI 1022. The cutting speed and depth of cut were decide using the suitable range recommended; which were 490rpm, 810rpm and 1400rpm for cutting speed, 0.1mm, 0.2mm, 0.3mm, 0.4mm, and 0.5mm for depth of cut. The specimen was turned under different level of parameters and was measured the surface roughness using a Perthometer. From the result, it is concluded that higher cutting speed or lower depth of cut produce better surface finish. The optimum cutting speed and depth of cut in this case were 1400rpm and 0.1mm, which produced average surface roughness 4.695µm. Response Surface Method (RSM) was used to predict the surface roughness. And from the result generated, the correlation for surface roughness with the cutting parameters satisfies a reasonable degree of approximation. Both cutting speed and depth of cut are a significant parameter in influencing the surface roughness.

ABSTRAK

Dalam industri pemotongan logam dan industri pembuatan, permukaan akhir sesuatu produk adalah sangat penting dalam menentukan mutunya. Permukaan baik bukan sahaja menjamin kualiti, malah mengurangkan kos pembuatan. Permukaan akhirnya adalah penting dalam aspek toleransi, ia mengurangkan masa pemasangan dan mengelakkan keperluan operasi kedua, dengan demikian mengurangkan waktu operasi dan mengarah pada pengurangan kos keseluruhan. Selain itu, berkualiti baik permukaan adalah kritikal dalam meningkatkan 'fatigue strength', 'corrosion resistance', dan 'creep life'. Dalam kajian ini, tujuan utama adalah untuk mempelajari pengaruh kelajuan pemotongan dan kedalaman pemotongan terhadap kekasaran permukaan logam baja ringan dalam operasi 'turning'. Perisian Minitab 15 digunakan untuk menganggari kekasaran permukaan. Kedua-dua keputusan ramalan dan keputusan eksperimen tersebut kemudian dibandingkan. Parameter pemotongan yang berbeza memberi kesan yang berbeza terhadap 'surface finish'. Dalam kajian ini, 3 kelajuan pemotongan dan 5 kedalaman pemotongan digunakan. Taguchi Orthogonal Array adalah digunalan sebagai rancangan percubaan, jumlah siri percubaan yang dilakukan adalah 15 set. Pada awalnya, logam baja ringan dijalani ujian komposisi kimia menggunakan 'Arc Spectrometer', dan dari keputusan boleh memutuskan bahawa ia mungkin dari kelas AISI 1022. Kelajuan pemotongan dan kedalaman pemotongan adalah ditentukan berdasarkan rangkuman sesuai yang disyorkan; iaitu 490 rpm, 810 rpm dan 1400 rpm untuk kelajuan pemotongan, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, dan 0.5 mm untuk kedalaman pemotongan. Operasi 'turning' dijalankan terhadap specimen-spesimen di bawah tahap parameter yang berbeza, dan kemudiannya diukurkan kekasaran permukaan menggunakan 'Perthometer'. Dari keputusan, maka disimpulkan bahawa kelajuan pemotongan yang lebih tinggi atau kedalaman pemotongan yang lebih kecil menghasilkan permukaan yang lebih baik. Kelajuan dan kedalaman pemotongan optimum dalam kes ini adalah 1400 rpm dan 0.1 mm, yang menghasilkan kekasaran permukaan 4.695 μm. 'Response Surface Method (RSM)' digunakan untuk meramal kekasaran permukaan. Dan dari keputusan yang dihasilkan, korelasi untuk kekasaran permukaan dengan parameter pemotongan memenuhi tahap pendekatan yang sewajarnya. Kedua-dua parameter, iaitu kelajuan pemotongan dan kedalaman pemotongan merupakan parameter yang signifikan dalam mempengaruhi kekasaran permukaan.

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D1	Initial diameter
D2	Final diameter
f	Feed rate
r	Tool nose radius
Ra	Surface roughness
T	Cutting time
v	Cutting speed

LIST OF ABBREVIATIONS

Al	Aluminum
ANOVA	Analysis of Variance
As	Arsenic
B	Boron
BHN	Brinell Hardness Number
Bi	Bismuth
BUE	Build Up Edge
C	Carbon
Ca	Calcium
Co	Cobalt
Cr	Chromium
Cu	Copper
DOC	Depth of Cut
DOE	Design of Experiment
Fe	Iron
Mn	Manganese
Mo	Molybdenum
Nb	Niobium
Ni	Nickel
P	Phosphorus

Pb	Lead
RSM	Response Surface Method
S	Sulphur
Sn	Tin
Ti	Titanium
V	Vanadium
W	Tungsten
Zr	Zirconium

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Steel had a major influence on our lives. The cars we drive, the buildings we work in, the homes in which we live and countless other facets in between. Steel is used in our electricity-power-line towers, natural-gas pipelines, machine tools, military weapons and so on. Steel has also earned a place in our homes in protecting our families, making our lives convenient, its benefits are undoubtedly clear. The backbone of developed economies was laid on the strength and inherent uses of steel.

Steel is by far the most important, multi-functional and most adaptable materials. Compared to other materials of its type, it has low production costs. The energy required for extracting iron from ore is about 25 % of what is needed for extracting aluminum. Steel is environment friendly for it is recycle-able. 5.6 % of element iron is present in earth's crust, representing a secure raw material base. Steel production is 20 times higher as compared to production of all non-ferrous. Steel is widely used in manufacturing processes to produce various products.

Metal cutting processes are industrial processes in which metal parts are shaped or removal of unwanted material. It is one of the most important and widely used manufacturing processes in engineering industries. In the study of metal cutting, the output quality is rather important. A significant improvement in output quality may be obtained by optimizing the cutting parameters. Optimization of parameters not only improves output quality, but also ensures low cost manufacturing. Cutting parameters include feed rate, cutting speed, depth of cut, cutting fluids and so on. In turning process, cutting parameters play critical roles in the efficient use of machine tool.

Lathe machine is the oldest machine tool that is still the most common used machine in the manufacturing industry to produce cylindrical parts. For instance, shaft, axis and bearing, are crucial in machining motions. It is widely used in variety of manufacturing industries including aerospace and automotive sectors, where 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, 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.

1.2 PROBLEM STATEMENT

Surface finish is a quality that is specified by customer for machined parts. There are many parameters that have effect on surface roughness, but most are difficult to quantify adequately. In turning operation, there are many parameters such as cutting speed, depth of cut and feed rate that have great impact on the surface finish. In order to maximize the gains from turning operation, an accurate model of process must be constructed. In this research, an attempt has been made to generate a surface roughness prediction.

Besides in manufacturing application, surface roughness is also important in hygienic process applications. For example, system integrity and ease of cleaning/sterilization is dependent upon valve design and internal surface finish. A smooth surface finish reduces the risk of system contamination, and increases the speed of cleaning and sterilization.

All these while, there are numbers of studies are done to investigate the general effects of feed, cutting speed and depth of cut on the surface roughness. Thus, in this research, turning operations will be carried out to generate the optimum surface finish by using cutting speed and depth of cut as parameters. The material that will be used is mild steel.

1.3 PROJECT OBJECTIVES

The objectives of this research are as following:

i. Identify the composition and grade of mild steel.
ii. Study the effect of cutting parameters on the surface quality of the machined surfaces.
iii. Develop surface prediction technique which is termed response surface methodology.
iv. Evaluate prediction ability of model.

1.4 SCOPE OF PROJECT

In this project, mild steel is used as specimen. The specification of the mild steel will be identified using spectrometer. Turning operation is performed using lathe machine. Turning operation will be done on mild steel based on 2 machining parameters. The 2 parameters that will be used are cutting speed and depth of cut (DOC). Feed rate in this case is set as a constant throughout the whole experiments. The surface roughness of each of the specimen will be studied and compared.

1.5 SUMMARY

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project on the effects of cutting speed and depth of cut on the surface roughness of mild steel using turning operation. This chapter is as a fundamental for the project and act as a guidelines for project research completion.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

From the early stage of the project, various literature studies have been done. Research journal, reference books, printed or online conference article were the main source in the project guides as they contain the current knowledge on particular research. The reference sources emphasize on effect of cutting speed and depth of cut on the surface roughness of mild steel using lathe machine for turning operation. Then, the effects of cutting speed and depth of cut on mild steel will be justified using surface roughness value.

2.2 CARBON STEEL

Carbon steel is a metal alloy, a combination of two elements that are iron and carbon, where other elements are present in quantities too small to affect the properties. It is by far the most frequent used steel. The feasibility of using carbon steels depend on whether or not their properties (tensile, yield, and fatigue strength; impact resistance, need for heat treating, etc.) are suitable for parts to be used (Isakov, 2009). Carbon steels may be further classified into 3 major groups: low carbon steel, medium carbon steel and high carbon steel.

Standard wrought-steel compositions (for both carbon and alloy steels) are designated by an AISI or SAE four-digit code, the last two digits of which indicate the nominal carbon content. The carbon-steel grades are:

- 10xx: Plain carbon
- 11xx: Resulfurized
- 12xz: Resulfurized and rephosphorized
- 15xx: Nonresulfurized, Mn over 1.0 %

2.2.1 Low Carbon Steel

Low carbon steel, also known as mild steel, contains 0.05 % to 0.26 % of carbon (e.g. AISI 1018, AISI 1020 steel). These steels are ductile and have properties similar to iron. They cannot be modified by heat treatment. They are cheap, but engineering applications are restricted to non-critical components and general paneling and fabrication work. These steels cannot be effectively heat treated. Consequently, there are usually no problems associated with heat affected zones in welding process. The surface properties can be enhanced by carburizing and then heat treating the carbon-rich surface. High ductility characteristic results in poor machinability.

2.2.2 Medium Carbon Steel

Medium carbon steel contains 0.29 % to 0.54 % of carbon (e.g. AISI 1040, AISI 1045 steel). These steels are highly susceptible to thermal treatments and work hardening. They easily flame harden and can be treated and worked to yield high tensile strengths provided that low ductility can be tolerated. The corrosion resistance of these steels is similar to low carbon steel, although small additions of copper can lead to significant improvements when weathering performance is important. Medium carbon steels which are still cheap and command mass market. They are general purpose but can be specified for use in stressed applications such as rails and rail products, couplings, crankshafts, axles, bolts, rods, gears, forgings, tubes, plates and constructional steels.

2.2.3 High Carbon Steel

High carbon steel contains 0.55 % to 0.95 % carbon (e.g. AISI 1086, AISI 1090). Cold working is not possible with any of these steels, as they fracture at very low elongation. They are highly sensitive to thermal treatments. Machinability is good, although their hardness requires machining in the normalized condition. Welding is not recommended and these steels must not be subjected to impact loading. They are normally used for components that require high hardness such as cutting tools and blades.

2.3 LATHE MACHINE

Lathes are generally considered as the oldest machine tools. Wood-working lathes originally were developed during the period 1000-1001 B.C.. However metalworking lathes with leadscrew were only built during late 1700s. The most common laths originally was called an engine lathes, because it was powered with overhead pulleys and belts from nearby engines on the factory floor. Today, these lathes are all equipped with individual electric motors (Kalpakjian, 2006).

Lathe machine is considered as the backbone of machine shop, and a through knowledge of it is essential for machinist. Lathe machine is a machine which work is held so that it can be rotated about an axis while the cutting tool is traversed past the work from one end to the other thereby forming it to the required shape (Steeds, 1964).

Common operations performed on a lathe are: facing, parallel turning, taper turning, knurling, thread cutting, drilling, reaming, and boring (Krar, undated). The spindle is the part of the lathe that rotates. Various workholding attachments such as three jaw chucks, collets, and centers can be held in the spindle. The spindle is driven by an electric motor through a system of belt drives and/or gear trains. Spindle speed is controlled by varying the geometry of the drive train. The main function of lathe is to provide a means of rotating a workpiece against a cutting tool, thereby removing metal. All lathes, regardless of size and design are basically the same and serve 3 functions:

- A support for the lathe accessories or the workpiece
- A way of holding and revolving the workpiece
- A means of holding and moving the cutting tool

Size of the engine lathe is determined by the max diameter of work which may be revolved or swung over the bed, and the longest part that can be held between lathe centers. Lathes found in training programs generally have swing of 9.0 to 13.0 in (230-330 mm) and bed length from 20.0 to 60.0 in (500-1500 mm). Lathes used in industry may be much larger, doubling in swing and capacity (Krar, undated).

Bed is a heavy rugged casting made to support the working parts of the lathe. On its top section are major parts of lathe. Commonly, lathes are made with flame-hardened and ground ways to reduce wear and to maintain accuracy.

Headstock is attached to the left side of the bed. The headstock spindle is a hollow cylindrical shaft supported by bearing. It provides a drive from the motor to workholding devices. Live center, sleeve, face plate or a chuck can be fitted to the spindle nose to hold and drive the work. The live center has 60^o point that provides a bearing surface for the work to turn between centers. Most modern lathes are geared-head and the spindle is driven by series of gears in the headstock. Through a series of levers, different gears can be engaged to set various spindle speeds for different types of sizes of work (Krar, undated). The types of speed-change levers or controls used on each lathe machine are varying, depending on the manufacturers. The feed-reverse lever can be place in three positions. One position provides forward direction; the center position is neutral while the other position reverses the feed rod direction and leadscrew.

Tailstock is made up of two units. The top half can be adjusted on the base by two adjusting screws for aligning the tailstock and headstock center for parallel turning. These screws can also be used to offset the tailstock for taper turning between centers. Tailstock can be lock at any position along the bed of lathe by clamping the lever or tighten the nut.

At one end of dead center is tapered to fit into the tailstock spindle, while the other end has 60^o point to provide a bearing support for work turned between the centers. A spindle-binding-lever or lock handle is used to hold the tailstock spindle in a fixed position. The tailstock handwheel moves the spindle in and out of the tailstock casting. It can also use to provide a hand feed for drilling and reaming operation.

2.3.1 Lathe Safety

1. Do not operate a lathe until the proper procedures are known and make sure the machine is checked by instructor on its safety.
2. Never operate lathe while senses are impaired by medication or other substances.
3. Wear appropriate attire. Roll up sleeves and remove neck-tie.
4. Remove any necklace or dangling jewelry including wristwatch.
5. Use correct tool size and make sure work piece is clamped solidly.
6. Wear safety glasses to protect eyes.
7. Never leave a chuck wrench in a chuck.
8. Remove chips with brush or hook, never by hand.
9. Keep floor and machine free from grease, oil, metal cutting or tools to prevent tripping and slipping accidents.

2.3.2 Operations That Can Be Done Using Lathe machine

Turning is one of the general machining processes. That is, the part is rotated while a single point cutting tool is moved parallel to the axis of rotation. Turning can be done either on the external or internal surface of the part. It is to produce straight, conical, curved, or grooved workpieces. Following are some of the operations that can be done using Lathe Machine:

- Facing is part of the turning process. It is to produce a flat surface at the end of the part and perpendicular to its axis. It is useful for parts that are assembled with other components.

- Parting is also called cutting off. It is used to create deep grooves which will remove a completed or part-complete component from its parent stock into discrete products.
- Grooving is like parting, except that grooves are cut to a specific depth by a form tool instead of severing a completed/part-complete component from the stock. Grooving can be performed on internal and external surfaces, as well as on the face of the part.
- Drilling is used to remove material from the inside of a workpiece, producing a hole. It may follow by boring to improve its dimensional accuracy and surface finish.
- Boring is an operation in which a hole or cylindrical cavity made by previous process is enlarged with a single point cutting tool. A boring bar is used to support the cutting tool as it extends into the hole. Because of the extension of the boring bar, the tool is supported less rigidly and is more likely to chatter.

2.3.3 Turning of low-carbon-steels

Metal removing during the turning of clean low carbon steel is by plastic shear and ductile fracture along a plane inclined to the direction of cutting. As the steel progressively deformed microvoids starts to form at the ferrite grain boundaries and at any inclusions that present. Turning of low-carbon steels produce long chips. Built-up edge will form on an indexable insert if a chipbreaker doesn’t create a sufficient shear angle to curl the chip away from the insert’s rake face. Low cutting speed is another cause of BUE, which acts as an extension of the cutting tool, changing part dimensions and imparting rough surface finishes. When that’s the case, the cutting speed should be increased 15 to 20 percent or more until the surface finish improves (Isakov, 2007).

2.3.4 Turning of medium-carbon steel

Metal removal during turning of medium carbon steel occurs by both plastic shear and microcracking. These plain carbon steels contain 40 to 75 % pearlite. The cementite phase, which is hard and nondeformable, causes microvoids in the shear zone that enhance metal removal. Surface finish is smoother on turned medium carbon steel than the low carbon steel. Cutting forces and tool wear, however increase as the carbon content of medium carbon steels is increased. Cutting speed should therefore be reduced with the increasing of carbon content. The increased amount of pearlite and cementite platelets, are abrasive to the cutting tool. Coarse grain structures are also preferred for machining medium carbon steel. When turning medium carbon steels, it will produces discontinuous chips resulting in a finer surface finish compared to low-carbon steels. Cutting forces and tool wear increase as the carbon content and hardness increase. With increased hardness, cutting speeds should be reduced (Isakov, 2007).

2.3.5 Turning of high carbon steel

For high carbon steel, cutting forces and tool wear are higher than those for medium carbon steels because of the greater amounts of cementite in high carbon steel. Thus, lower feeds and speeds are necessary to minimize tool wear. Metal removal occurs mainly by the micovoid to microcrack sequence around the hard cementite platelets and grain-boundary network. Cutting forces and tool wear are higher when turning high-carbon steels than they are when turning medium carbon steels due to the higher carbon content. According to Isakov (2007), lower cutting speeds are necessary to minimize tool wear. The effect of hardness on the cutting speed is similar to that for low and medium-carbon steels.

2.4 PARAMETERS THAT AFFECTING SURFACE ROUGHNESS IN TURNING OPERATION

2.4.1 Tool life/ Tool wear

Tool life/tool wear is the most meaningful criteria in machinability. It affects both the quality and cost of the machined part. Machinability is to increase when the tool wear rate decreases or tool life rate increases (Stephenson, 1997). As tool damage, by wear or fracture increases, the surface roughness and accuracy of the machined surface deteriorates (Childs, 2000). Ratings based on wear rates are generally applicable to a restricted range of cutting conditions. That is, when the cutting speed is substantially increased or decreased, the dominant tool wear mechanism and tool wear rate may change. However, the use of very low cutting speed and feed to prolong the life of tool is not economical, as it leads to low production rate (Boothroyd, 1989). It is particularly relevant when ranking the machinability of a group of materials under different cutting conditions.

2.4.2 Achievable surface finish

Generally, roughness of surface is the common parameter used to assess surface quality (Stephenson, 1997). Surface roughness is affected by cutting speed, feed rate, and chip formation. Higher cutting speed and feed rate will produce smoother surface and vice-versa. On the other hand, the formation of continuous chip that got entangled on workpiece will scratch the surface of workpiece. Thus, causes surface roughness.

2.4.3 Cutting force and cutting speed

Cutting force is often measured in machinability testing and research. Machinability increases as cutting forces and power consumption decrease for the cutting conditions of interest. Lower cutting forces generally imply lower tool wear rates, better dimensional accuracy due to decreased of deflection, and increased machine tool life due to reduced loads on bearings and ways (Stephenson, 1997). Cutting speed is defined as the speed at which the work moves with respect to the tool (usually measured in feet per minute). According to National Maritime Research Institute, when the rotating speed is high, processing speed becomes quick, and a processing surface is finely finished.

Cutting speed is one of the parameters that control the surface roughness. At low cutting speed, build-up-edge (BUE) tends to build up at the edge of material during turning. BUE scratches the material surface and causes the roughness of surface to be not constant. This is because the vibrations produced lift the tool and snaps it back when the BUE fractures. As the cutting speed increases, the temperature rises and separates the BUE from tool. The repeating of build up and removal of BUE will eventually ruins the cutting tool.

On the other hand, higher cutting speed results in good surface roughness. However, it might also cause burn marks to appear on the surface of material turned.

2.4.4 Feed rate

The feed of lathe may be defined as the distance the cutting tool advances along the length of the work for every revolution of the spindle (Krar and Check, 1997). For instance, if the feed is set to 0.15 mm, the cutting tool will travel along the length of the work for 0.15 mm. It is depend on the speed of lead screw or feed rod. Feed rate is one of the factors that leave its own characteristic marks on the surface of specimen being machined.

Different feed rate used during turning operation somehow leaves impact on the surface roughness. When the feed rate is high, the processing speed becomes quick. When the feed rate is low, the surface is finished beautiful. Hence, an appropriate feed must be use to gives an acceptable surface finish. There are 'manual feeding' which turns and operates a handle, and 'automatic feeding' which advances a byte automatically (National Maritime Research Institute, undated). An equation had been derived in predicting the surface roughness result. The equations are as Eq. (2.1) and Eq. (2.2)

$$R_a = 2.95 f^{0.7} r^{-0.4} T^{0.3} \tag{2.1}$$

Where;

Ra = surface roughness (μm)

f = feed rate (mm per revolution)

r = tool nose radius (mm)

T = cutting time (minutes)

or

$$Ra = 1.22x10^5 \, M \, f^{1.004} \, v^{-1.252} \quad (2.2)$$

Where;

v = cutting speed (m/min)

$M = r^{-0.714} (BHN)^{-0.323}$

BHN = material hardness on the Brinell scale

The equations above can only be computed when all other cutting parameters are known. Thus, it is very difficult to use. Most researchers agree that the main cause of surface roughness is due to feed tool marks.

2.4.5 Depth of Cut

Depth of cut (DOC) is defined as the depth of chip remove by the cutting tool. It is half of the total amount removed from the work piece in one cut. DOC varies greatly with lathe condition, material hardness, speed, feed, amount of material to be removed, and whether it is to be roughing or finishing cut (Walker, 2004). The equation of depth of cut is shown in Eq. (2.3)

$$\text{Depth of Cut (DOC)} = \frac{D_1 - D_2}{2} \quad (2.3)$$

Where,

D_1 – Initial diameter

D_2 – Final diameter

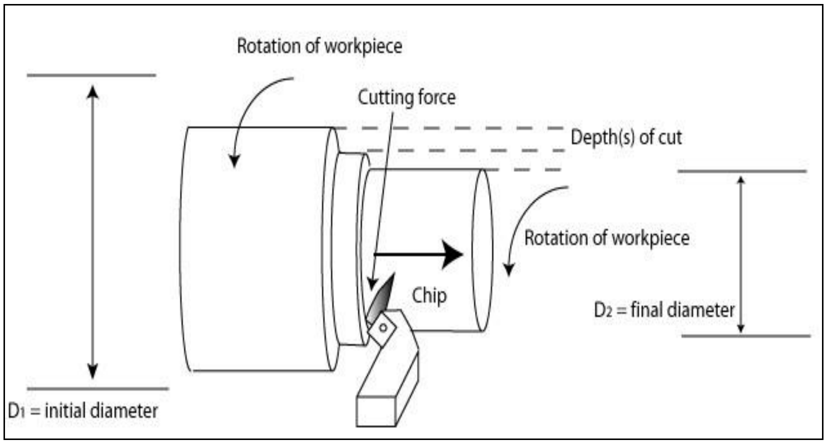

Figure 2.1: Turning mechanism

2.5 CUTTING TOOL

The selection of cutting tool materials for particular application is among the most important factors in machining operations. Cutting tool is subjected to high temperatures, high contact-stress, and rubbing along the tool-chip interface and along the machined surface (Kalpakjian, 2006). Consequently, the cutting-tool material must possess the following characteristics:

- Hot hardness: so that the hardness, strength and wear resistance of the tool are maintained at the temperatures encountered in machining operations. This characteristic ensures the tool does not undergo any plastic deformation and can retain its shape and sharpness.
- Toughness and impact strength (mechanical shock): so that the impact forces on the tool encountered repeatedly in interrupted cutting operations do not chip or fracture the tool.
- Thermal shock resistance: to withstand the rapid temperature cycling encountered in interrupted cutting.
- Wear resistance: so that an acceptable tool life is obtained before the tool has to be replaced.

- Chemical stability and inertness: to avoid or minimize any adverse reactions, adhesion, and tool-chip diffusion that would contribute to tool wear.

2.6 CUTTING FLUID

Cutting fluid is used to improve cutting conditions by applying it at the chip formation zone during machining operations. A cutting fluid is used to keep the tool cool to prevent it from heated to a temperature at which the hardness and resistance to abrasion are reduced; to keep the work piece cool preventing it from machined into inaccurate dimensions; by lubricating, the friction, tool wear and power consumption can be reduced. It often is found in liquid form. The improvements can take account on several forms, depending on the tool and work materials, the type of cutting fluid and to an extent the cutting conditions.

There are 2 usage of cutting fluid, it can either acts as coolant or lubricant, or both. Most cutting fluids have a mineral- or vegetable-oil base, mineral oil being the more widely used. Cutting fluids are classified into 3 categories, which are emulsions, oil, and solutions. According to Boothroyd ad Knight (1989), oil and water emulsions are used when cooling action is the most important requirement because these emulsions have much larger heat-conducting capacity than neat oil. On the other hand, neat oil is used for operation which lubricating action is the most important consideration.

2.7 ARC SPECTROMETER

An arc spectrometer is also known as the spark emission spectrometers. They are use for elemental analysis of metals and alloys. Spark and arc excitation sources use a current spark or a continuous electrical discharge (arc) between two electrodes to vaporize and excite atoms. The electrode use is either metal or graphite. Arc and spark sources can be used to excite atoms for atomic-emission spectroscopy or to ionize atoms for mass spectrometry. Nowadays, arc and spark excitation sources have been replaced in many applications with plasma or laser sources, but are still widely used in the metals industry. In this research, arc spectrometer is use to identify the composition of carbon in mild steel. And, precise analysis will be done on grade determination.

2.8 ROCKWELL HARDNESS TEST

Rockwell hardness testing is a general method for measuring the bulk hardness of metallic and polymer materials. Rockwell test method is the most commonly used hardness test method, as defined in ASTM E-18. It is because this test is generally easier to perform and more accurate than other types of hardness testing. It is suitable to be used for all metals except in certain conditions. Such as where the test metal structure or surface conditions would introduce too much variation; or where the indentations would be too large for the application; or where the sample size or shape prohibits its use.

The functions of Rockwell hardness tester are as following;

- Quality control for metal heat treatment
- Incoming material inspection
- Weld evaluations in steels and other alloys
- Grade verification for hard plastics
- Failure analysis

This test is differs from Brinell hardness testing in that the hardness is determined by the depth of indentation made by constant load impressing on an indenter. The Rockwell method measures the permanent depth of indentation produced by a force on an indenter. First, a preliminary test is done, where a standard minor load is applied to set a hardened steel ball or a diamond cone in the surface of the metal. This is the zero or reference position that breaks through the surface to reduce the effects of surface finish. Then, a major load is applied to reach the total required test force. This force is held for a predetermined amount of time to allow for elastic recovery. The additional test force is then released and the final position is measured against the preliminary position and converted to a hardness number. The hardness is measured by the depth of penetration.

The indenter used in the test is either a conical diamond (brale) or a hard steel ball. Different indenter ball diameters from 1/16 to 1/2 in. are used depending on the test scale.

There are separate scales for ferrous metals, nonferrous metals, and plastics. Common Rockwell hardness scales include A, B, C and F for metals, and M and R for polymers.

Table 2.1: Test scale for Rockwell hardness test

Rockwell Hardness Test Scales		
Scale Symbol	**Penetrator**	**Load kg**
A	Brale	60
B	1/16-in Ball	100
C	Brale	150
D	Brale	100
E	1/8-in Ball	100
F	1/16-in Ball	60
G	1/16-in Ball	150
H	1/8-in Ball	60
K	1/8-in Ball	150
L	1/4-in Ball	60
M	1/4-in Ball	100
P	1/4-in Ball	150
R	1/2-in Ball	60
S	1/2-in Ball	100
V	1/2-in Ball	150
Superficial Tester Scales		
15N, 30N, 45N	N Brale	15, 30, 45
15T, 30T, 45T	1/16-in Ball	15, 30, 45
15W, 30W, 45W	1/8-in Ball	15, 30, 45
15X, 30X, 45X	1/4-in Ball	15, 30, 45
15Y, 30Y, 45Y	1/2-in Ball	15, 30, 45

2.9 SURFACE FINISH

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.

Surface finish influences not only the dimensional accuracy of machined parts but also their properties and their performance in service. The term 'surface finish' describes the geometric features of a surface, and surface integrity pertains to material properties such as fatigue life and corrosion resistance, in which are strongly influenced by the nature of the surface produced (Kalpakjian, 2006).

According to Rao (2002), machining operations are utilized in view of the better surface finish that could be achieved by it compared to other manufacturing operations. Thus, it is important to know what would be the effective surface finish that can be achieved in a machining operation. There are 2 types of surface finish; ideal surface finish and natural surface finish.

Ideal surface finish is a result of geometry of the manufacturing process, which can be determined by considering the geometry of the machining operation (Rao, 2002). Ideal finish can be calculated from the feed rate per tooth, then tool nose radius, and the tool lead angle (Stephenson, 1997).

Natural surface finish is resulted from tool wear, vibration, machine motion errors, and work material effects such as inhomogeneity, built-up-edge formation, and rupture at low cutting speed (Stephenson, 1997). This kind of surface finish is more difficult to predict in general compared to ideal surface finish.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the ways, methods and procedures used to conduct this experiment are discussed step by step. A clear and systematic planning of methodology is essential to keep the experiment run smoothly.

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 doing literature study based on related topic. Machining work started by determining the grade of mild steel then using conventional lathe machine to do turning. Next step is determining the surface roughness by using Perthometer. The final step is comparison between results obtained with predicted result from using Response Surface Method (RSM) to decide the significance of parameters on surface roughness..

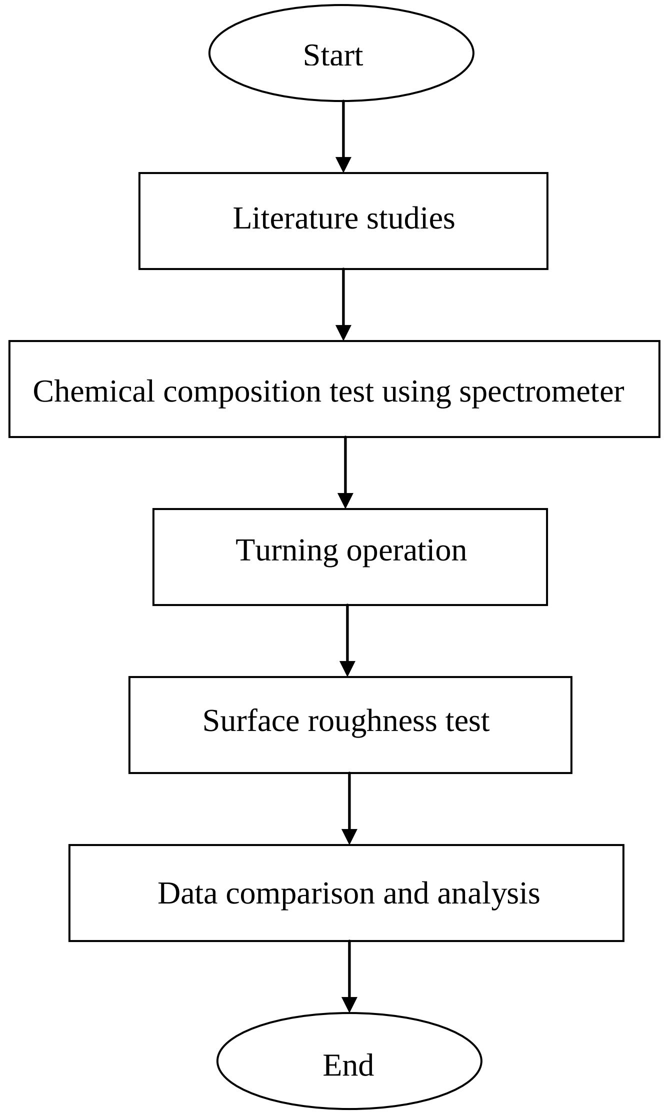

Figure 3.1: Methodology Flow Chart

3.3 LITERATURE STUDY

First and for most, literature studies on various sources such as research journal, reference books, printed or online conference article are done to help in developing better understanding of this thesis. Main focus would be on effects of cutting speed and depth of cut on the surface roughness of mild steel.

3.4 MATERIAL SELECTION

One specific types of plain carbon steel bar are chosen in this experiment, which is mild steel. The dimension of the round bar desired is 150 mm x 50 mm. That is 150 mm in length and 38 mm in diameter. The carbon steel bar is to take from available mild steel at Mechanical Laboratory. Carbon steel bar required in performing the turning process is 3 in quantity, each piece for each level of parameter. As the specification of mild steel is unknown, test will be run to identify its grade using arc spectrometer.

3.5 IDENTIFICATION OF GRADE OF MILD STEEL

The grade of mild steel taken from Mechanical Laboratory is unknown. Therefore, Spectrometer machine is used to detect the carbon composition in the mild steel in order to identify its grade. The brand of the spectrometer used is FOUNDRY-MASTER, Oxford Instrument (Figure 3.4).

In order to perform this test, a mild steel bar less than 50 mm is cut using bandsaw as shown in Table 3.2. The size must be less than 50 mm in order to fit the specimen in the spectrometer machine. Then, specimen’s surface must be grinded until a smooth surface is achieved using a portable grinding machine, as shown in Figure 3.3. Then only it is ready for test.

(Refer to Appendix A2)

The procedure to use an arc spectrometer is as following:

1. The specimen is placed on the platform, with the smooth surface facing the electrode.
2. The plunger is put on top of specimen to fix the specimen on its position.
3. Log in ‘WAS’ software, click on ‘Analysis’ button.
4. Select ‘FE’ icon and ‘Fe-low alloy steel’ category.
5. Go to ‘mode’ and click on ‘Argon Flush’.

6. After 2 minutes, click on the ‘Start’ icon to start the test.
7. Result will be shown on computer.

3.6 ROCKWELL HARDNESS TEST

The Rockwell hardness test method by indenting the test material with a 1/16 inches diameter hard steel ball subjected to a load of 100 kg. The type of Rockwell hardness test use is the B scale, as it is suitable for soft metal. The test is run 3 times to get an average and more accurate result. RHB value from the result are then convert into Brinell hardness number (BHN) using the hardness conversion chart. The Rockwell Hardness Tester used is shown in Figure 3.6.

The following is the working mechanism for the Rockwell hardness tester;

1. A standard minor load is applied to set a hardened steel ball in the surface of the metal (preliminary test).
2. A major load is applied to reach the total required test force.
3. The force is held for a predetermined amount of time.
4. Test force is then released and the hardness measurement number is taken.

(Refers to Appendix A1 and A2)

3.7 SELECTION OF CUTTING SPEED AND DEPTH OF CUT

The cutting speed, depth of cut (DOC) and feed rate that is suitable to apply is selected base on as recommended in the reference book. The cutting tool used is coated carbide. An appropriate feed rate is chosen and is set as constants, while selection of cutting speeds and DOC are based on Table 3.1:

Table 3.1: Parameters for AISI 1016, 1017, 1018, 1019, 1021 and 1022 grades

Brinell hardness (HB)	DOC (in.)	Feed rate (ipr)	Cutting speed (sfm)	Cutting tool material specification (ANSI/ISO)
85 to 125	0.300	0.020	525	CC-6/CP30
	0.150	0.015	675	CC-6/CP20
	0.040	0.007	1,025	CC-7/CP10
125 to 175	0.300	0.020	500	CC-6/CP30
	0.150	0.015	625	CC-6/CP20
	0.040	0.007	950	CC-7/CP10
175 to 225	0.300	0.020	450	CC-6/CP30
	0.150	0.015	550	CC-6/CP20
	0.040	0.007	850	CC-7/CP10

Source: Carbon content: guidelines of turning carbon steels (2007)

From the Rockwell hardness test, the converted hardness number is in range of 118-120 BHN. Thus, the suitable range to use falls in the first range in Table 3.1, which is 85-125 BHN. The suitable range for DOC is between 0.18 to 7.62 mm and suitable cutting speed is between range 1340 to 2617 rpm.

3.8 STEEL BAR CUTTING

Before the turning operation is done, the specimen has to be cut into desired dimension. That is 150 mm in length for each bar. The steel is cut using a cutting machine, as shown in Figure 3.7. The quantity of bar cut is 3 pieces.

(Refer to Appendix A2)

3.9 TURNING OPERATION

All of the machining experiments were carried out on a conventional lathe machine as on Figure 3.8. The experiment will be carrying out using design of experiment (DOE) method. The DOE method used is called Taguchi Orthogonal Array. 3 cutting speed and 5 depth of cut (DOC) are used. 3 cutting speed to the factor of 1, and 5 DOC to the factor of 1, come out with total experiments of 15 sets.

Set of experiments = 3^1 x 5^1

= 15 set

As the range of rpm on the lathe machine is limited, so the cutting speed is selected based on the available rpm that are 490 rpm, 810 rpm and 1400 rpm. A new cutting edge is use for every cut. A series of 5 temptations will be run on each specimen using different level of parameters as shown in DOC and cutting speed are decided using Table 3.1. The turning process is to be run under constant feed rate of 0.15 mm/rev and conventional coolant supply.

(Refer to Appendix A2)

Table 3.2: 15 sets of machining parameter

Cutting Speed (rpm)	Depth of Cut (mm)
490	**0.1**
490	**0.2**
490	**0.3**
490	**0.4**
490	**0.5**
810	**0.1**
810	**0.2**
810	**0.3**

Table 3.2: Continued

810	**0.4**
810	**0.5**
1400	**0.1**
1400	**0.2**
1400	**0.3**
1400	**0.4**
1400	**0.5**

3.10 SURFACE ROUGHNESS TEST

Surface roughness plays an important role in many areas and is a factor of great importance in the evaluation of machining accuracy. The surface roughness was measured by using Perthometer, the surface roughness tester as shown in Figure 3.9. The value of surface roughness of the specimens in each level of parameter of turning operation are stated down for further analyze. Surface roughness value is taken 3 times for in account of accuracy.

(Refer to Appendix A2)

3.11 DATA COMPARISON

After all the machining, surface roughness test will be done. All data are comparing to decide which category of parameter level produce lowest surface roughness value. The lowest the surface roughness value indicates better surface finish. Response surface method (RSM) modeling will be used to decide which the most significant parameter that affects surface roughness is.

3.12 SUMMARY

Overall, this experiment is about carrying out turning process using different set of parameters. Surface roughness of specimens is then measure using Perthometer. The effects of cutting speed and depth of cut on the ease of machining for mild steel is analyze base on surface roughness.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter is about the result and discussion on the experiment conducted. 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. Recommendation will be given for future improvements.

4.2 RESULT

4.2.1 Result of Chemical Composition Test of Mild Steel

As the grade of mild steel used is unknown, a chemical analysis test is run on the specimen to identify the grade of specimen. The test is run using an arc spectrometer. The test is run 3 times on the surface of mild steel to get a more accurate result.

Table 4.1: Result from arc spectrometer tester

Composition	Fe	C	Mn	Si	P	S	Cr	Mo
1st Run	98.8000	0.2210	0.5310	0.1470	0.1000	0.0794	0.0252	0.0050
2nd Run	98.7000	0.2240	0.5360	0.1410	0.1000	0.0858	0.0238	0.0050
3rd Run	98.8000	0.2260	0.5270	0.1370	0.1000	0.0873	0.0250	0.0050
Average	**98.8000**	**0.2240**	**0.5310**	**0.1420**	**0.1000**	**0.0842**	**0.0247**	**0.0050**

Table 4.1: Continued

Composition	Ni	Al	Co	Cu	Nb	Ti	V	W
1st Run	0.0060	0.0010	0.0027	0.0335	0.0020	0.0020	0.0206	0.0150
2nd Run	0.0050	0.0055	0.0029	0.0354	0.0020	0.0020	0.0213	0.0150
3rd Run	0.0050	0.0011	0.0029	0.0349	0.0020	0.0020	0.0199	0.0150
Average	**0.0050**	**0.0022**	**0.0029**	**0.0346**	**0.0020**	**0.0020**	**0.0206**	**0.0150**

Table 4.1: Continued

Composition	Pb	Sn	B	Ca	Zr	As	Bi
1st Run	0.0250	0.0020	0.0010	0.0003	0.0020	0.0050	0.0300
2nd Run	0.0250	0.0020	0.0010	0.0003	0.0020	0.0050	0.0300
3rd Run	0.0250	0.0020	0.0010	0.0002	0.0020	0.0050	0.0300
Average	**0.0250**	**0.0020**	**0.0010**	**0.0003**	**0.0020**	**0.0050**	**0.0300**

Based on the result shown in Table 4.1 above, the grade of the mild steel is basically determined using the 3 main compositions as shown in table above. The specimen contains average 98.8 % of iron, 0.22 % of carbon and 0.53 % manganese. Since it contains high, nearly 100% iron, we can assume that the specimen has not undergone any treatment. The 0.22 % carbon content indicate that the specimen maybe from grade AISI 1022. Besides, theoretically, low carbon steel contain around 0.5 % manganese. The other composition result above contain very slight amount in the specimen. Therefore, there are no particular composition take significant effects on the mechanical properties of specimen. In a nutshell, it can be conclude and assume that the specimen used is grade AISI 1022.

4.2.2 Analysis of Surface Roughness Value in Respond to Depth of Cut for Different Cutting Speed

In the experiment, there are 3 different levels of parameters. 3 different cutting speeds are applied for different depth of cut, ranging 0.1 mm to 0.5 mm. The feed rate was set as a constant throughout the experiment at 0.15 mm/rev. The 3 spindle speeds are 490 rpm, 810 rpm and 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. As for the depth of cut (DOC) used are 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, and 0.5 mm.

Table 4.2: Result for 490 rpm

Depth of Cut (DOC)	**Surface Roughness, Ra (µm)**			**Average Surface Roughness**
	1st	**2^{nd}**	**3rd**	
0.1	6.201	6.221	6.319	6.247
0.2	6.279	6.435	6.389	6.368
0.3	6.745	6.545	6.662	6.651
0.4	6.901	7.075	6.894	6.957
0.5	7.576	7.603	7.779	7.653

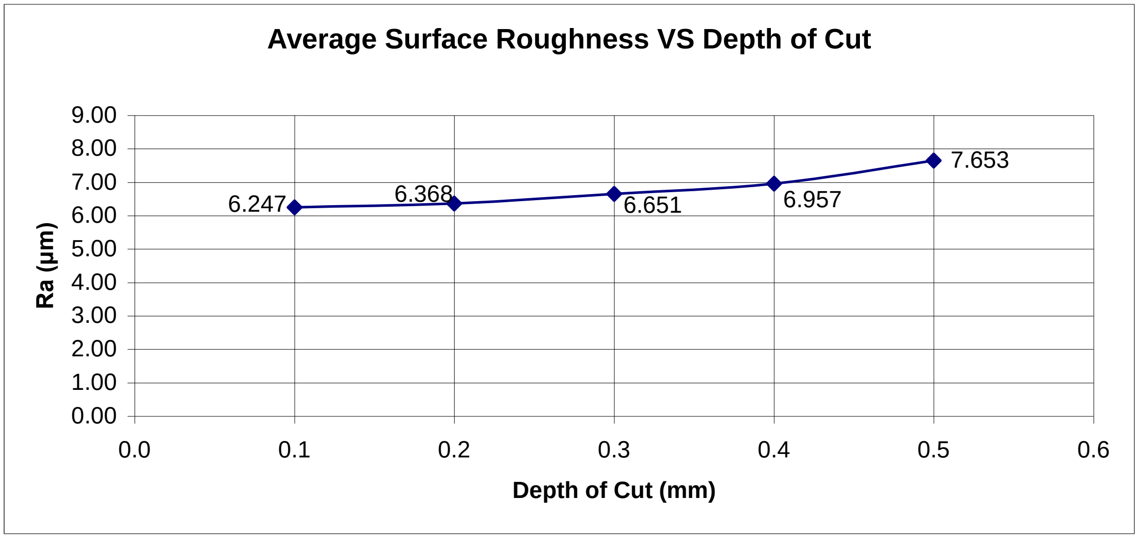

Figure 4.1: Graph of average surface roughness vs. depth of cut for 490 rpm

The Table 4.2 and Figure 4.1 above displays the surface roughness values for DOC of 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, and 0.5 mm respectively. The spindle speed used was 490 rpm (which cutting speed is approximately 58034.64 mm/min) and the feed rate is set at 0.15 mm/rev. The surface roughness is measured using a Perthometer, and 3 measurements are taken for each DOC. The average value for DOC 0.1 mm is 6.247 µm, DOC 0.2 mm is 6.368 µm, DOC 0.3 mm is 6.651 µm, DOC 0.4 mm is 6.957 µm and DOC 0.5 mm is 7.653 µm. The surface roughness increases as the DOC increases, which are from 6.247 µm to 7.653 µm. In other words, it means that the surface finish is better at smaller value of DOC.

Table 4.3: Result for 810 rpm

Depth of Cut (DOC)	**Surface Roughness, Ra (µm)**			**Average Surface Roughness**
	1st	**2nd**	**3rd**	
0.1	5.775	5.775	5.772	5.774
0.2	5.916	6.096	6.098	6.037
0.3	6.431	6.191	6.465	6.362
0.4	6.325	6.360	6.303	6.329
0.5	7.458	7.533	7.699	7.563

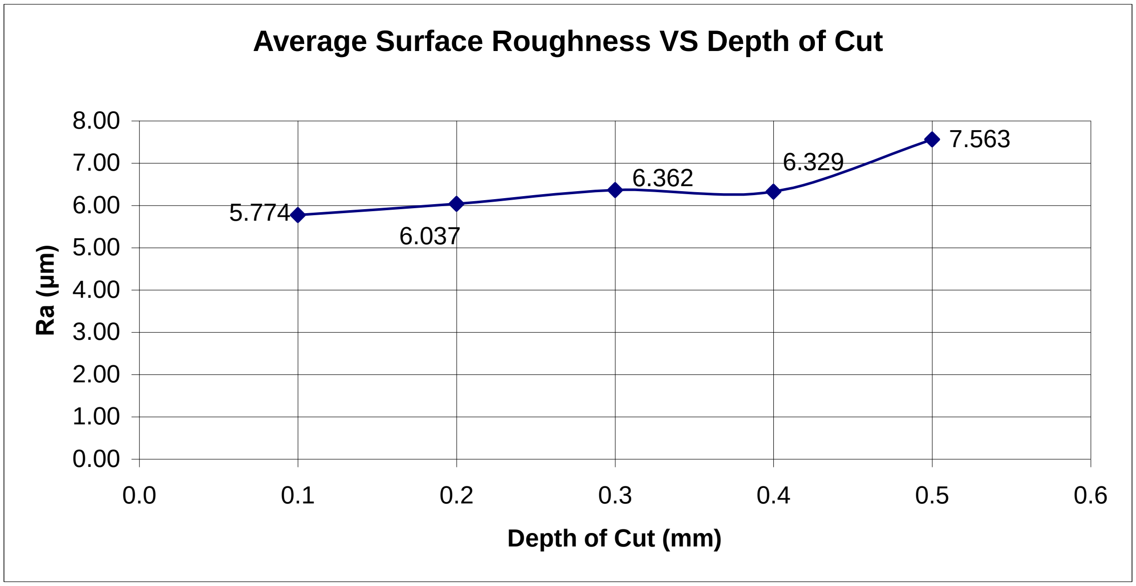

Figure 4.2: Graph of average surface roughness vs. depth of cut for 810 rpm

The Tables 4.3 and Figure 4.2 above displays the surface roughness values for DOC of 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, and 0.5 mm respectively. The spindle speed used was 810 rpm (which cutting speed is approximately 95934.81 mm/min) and the feed rate is set at 0.15 mm/rev. The surface roughness is measured using a Perthometer, and 3 measurements are taken for each DOC. The average value for DOC 0.1 mm is 5.774 μm, DOC 0.2 mm is 6.037 μm, DOC 0.3 mm is 6.362 μm, DOC 0.4 mm is 6.329 μm and DOC 0.5 mm is 7.563 μm. According to the graph roughly, the surface roughness increases as the DOC increases, which are from 5.774 μm to 7.563 μm. In other words, it means that the surface finish is better at smaller value of DOC. The value for DOC 0.3 mm is slightly higher than the DOC 0.4 mm value. This might happen due to several conditions, such as scratches from the chips during turning, or the built up edge (BUE).

Table 4.4: Result for 1400 rpm

Depth of Cut (DOC)	Surface Roughness, Ra (μm)			Average Surface Roughness
	1st	2nd	3rd	
0.1	4.658	4.812	4.615	4.695
0.2	4.873	4.928	4.754	4.852
0.3	5.015	5.033	5.129	5.059
0.4	5.022	5.190	5.236	5.149
0.5	5.545	5.376	5.873	5.598

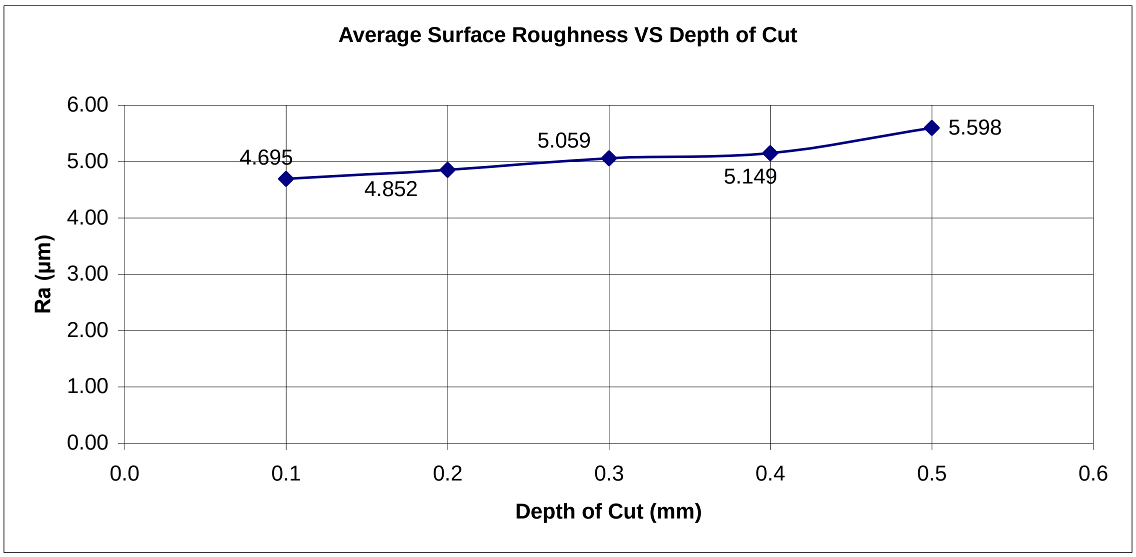

Figure 4.3: Graph of average surface roughness vs. depth of cut for 1400 rpm

The Tables 4.4 and Figure 4.3 above displays the surface roughness values for DOC of 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, and 0.5 mm respectively. The spindle speed used was 1400 rpm (which cutting speed is approximately 165813.26 mm/min) and the feed rate is set at 0.15 mm/rev. The surface roughness is measured using a Perthometer, and 3 measurements are taken for each DOC. The average value for DOC 0.1 mm is 4.695 μm, DOC 0.2 mm is 4.852 μm, DOC .03mm is 5.059 μm, DOC 0.4 mm is 5.149 μm and DOC 0.5 mm is 5.598 μm. According to the graph roughly, the surface roughness increases as the DOC increases, which are from 4.695 μm to 5.598 μm. In other words, it means that the surface finish is better at smaller value of DOC.

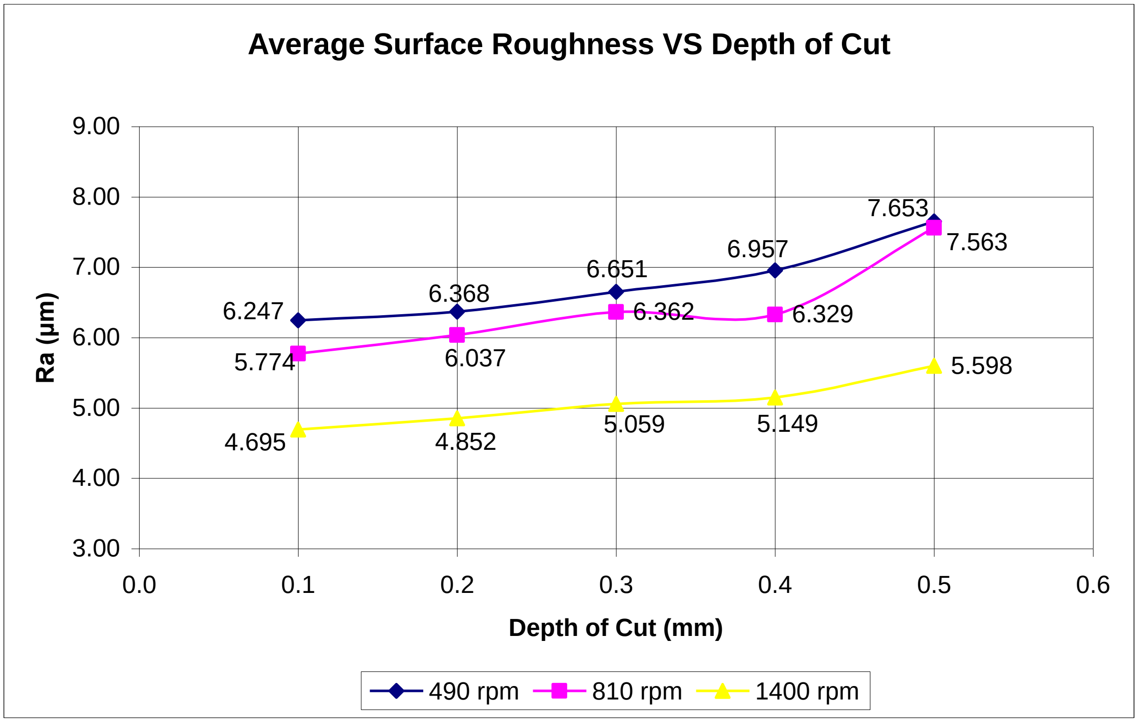

Figure 4.4: Graph of average surface roughness vs. depth of cut for different rpm

Figure 4.4 above is the graph of surface roughness value of different DOC under different spindle speed. As can see, the surface roughness is increasing as the depth of cut increasing. And in comparison of the 3 cutting speed, the surface roughness for higher RPM produced lower value of surface roughness. This also indicates that higher cutting speed produced finer surface finish. However, the graph line is not smooth. This may be due to other factors such as the production of build up edge (BUE) that might scratches the surface, uneven clamping of workpiece that cause vibration and uneven surface finish. Theoretically, the graph has met the expected result. The smallest DOC value yields better surface finish; and the higher cutting speed also yields better surface finish.

4.2.3 Analysis of Surface Roughness Value in Respond to Cutting Speed for Different Depth of Cut

Table 4.5: Result for 0.1 mm

Cutting Speed	Surface Roughness			Average Surface Roughness
	1st	2nd	3rd	
490	6.201	6.221	6.319	6.247
810	5.775	5.775	5.772	5.774
1400	4.658	4.812	4.615	4.695

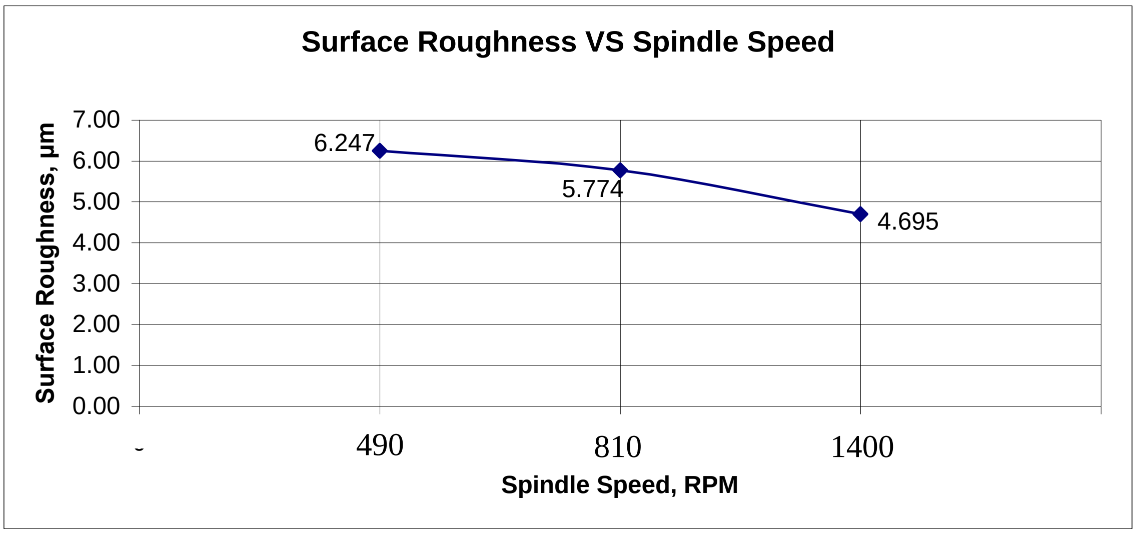

Figure 4.5: Graph of surface roughness vs. spindle speed for 0.1 mm depth of cut

The Figure 4.5 above shows graph for surface roughness of 3 different speeds, which are 490 rpm, 810 rpm, 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. The feed rate is set at 0.15 mm/rev. The workpiece diameter is reduced from 37.7 mm to 37.5 mm. The surface roughness value decreases from 6.247 μm to 4.695 μm. The graph obviously shows that the surface roughness value is decreasing significantly when the RPM is higher. In other words, the surface finish will be improved as the cutting speed increased.

Table 4.6: Result for 0.2 mm

Cutting Speed	Surface Roughness			Average Surface Roughness
	1st	2nd	3rd	
490	6.279	6.435	6.389	6.368
810	5.916	6.096	6.098	6.037
1400	4.873	4.928	4.754	4.852

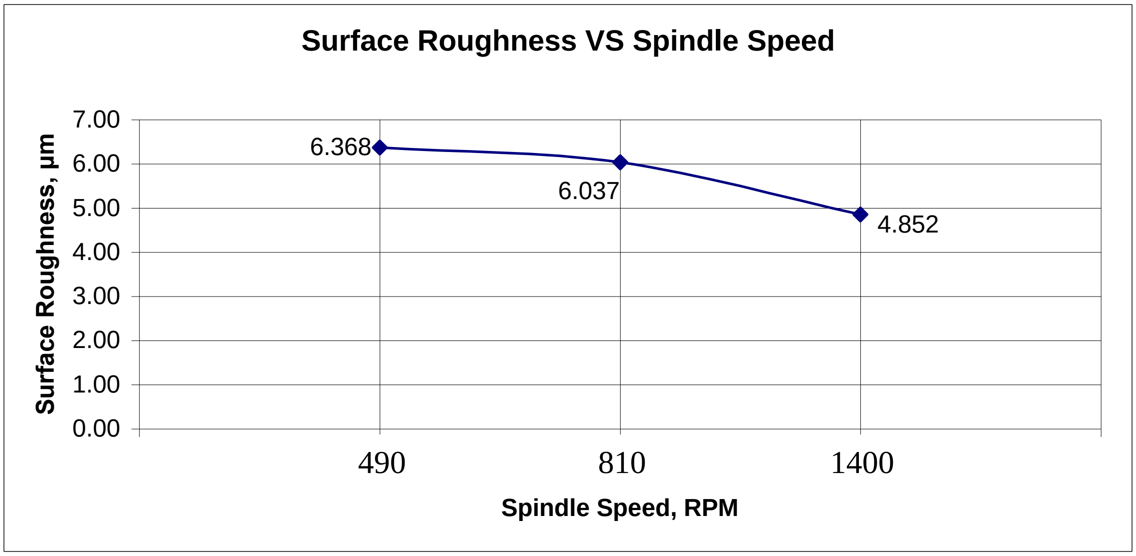

Figure 4.6: Graph of surface roughness vs. spindle speed for 0.2 mm depth of cut

The Figure 4.6 above shows graph for surface roughness of 3 different speeds, which are 490 rpm, 810 rpm, 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. The feed rate is set at 0.15 mm/rev. The workpiece diameter is reduced from 37.5 mm to 37.1 mm. The surface roughness value decreases from 6.368 μm to 4.852 μm. The graph obviously shows that the surface roughness value is decreasing significantly when the RPM is higher. In other words, the surface finish will be improved as the cutting speed increased.

Table 4.7: Result for 0.3 mm

Cutting Speed	Surface Roughness			Average Surface Roughness
	1st	2nd	3rd	
490	6.745	6.545	6.662	6.651
810	6.431	6.191	6.465	6.362
1400	5.015	5.033	5.129	5.059

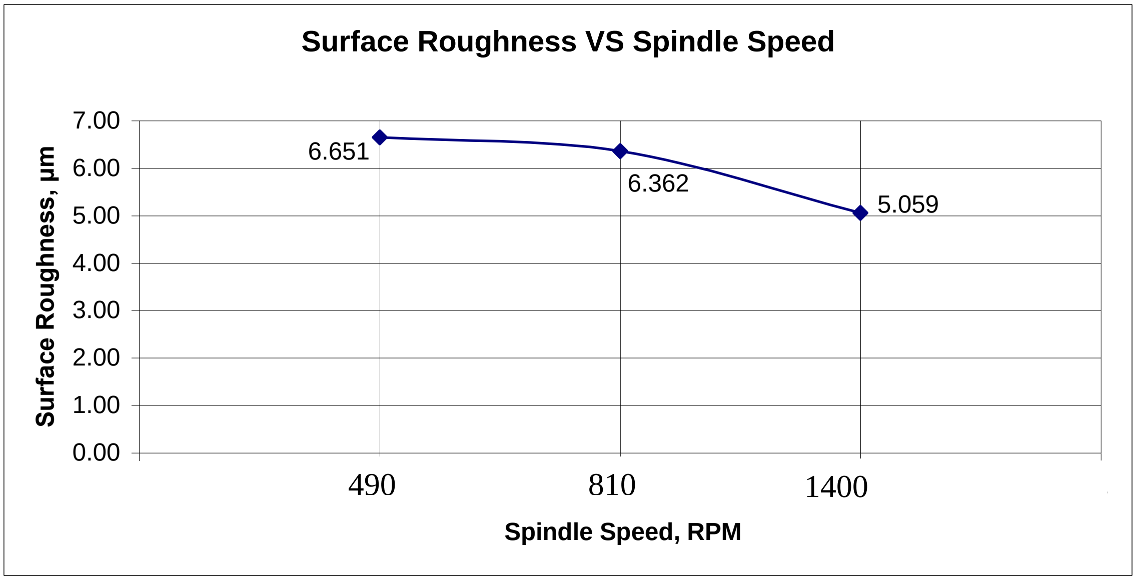

Figure 4.7: Graph of surface roughness vs. spindle speed for 0.3 mm depth of cut

The Figure 4.7 above shows graph for surface roughness of 3 different speeds, which are 490 rpm, 810 rpm, 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. The feed rate is set at 0.15 mm/rev. The workpiece diameter is reduced from 37.1 mm to 36.5 mm. The surface roughness value decreases from 6.651 µm to 5.059 µm. The graph obviously shows that the surface roughness value is decreasing significantly when the RPM is higher. In other words, the surface finish will be improved as the cutting speed increased.

Table 4.8: Result for 0.4 mm

Cutting Speed	Surface Roughness			Average Surface Roughness
	1st	2nd	3rd	
490	6.901	7.075	6.894	6.957
810	6.325	6.360	6.303	6.329
1400	5.022	5.190	5.236	5.149

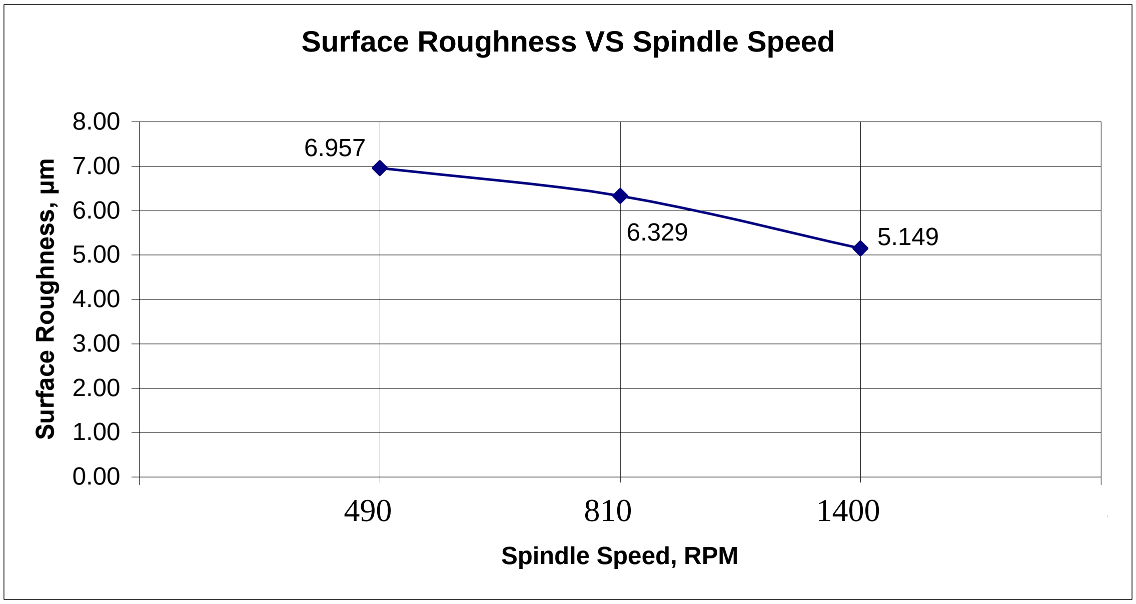

Figure 4.8: Graph of surface roughness vs. spindle speed for 0.4 mm depth of cut

The Figure 4.8 above shows graph for surface roughness of 3 different speeds, which are 490 rpm, 810 rpm, 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. The feed rate is set at 0.15 mm/rev. The workpiece diameter is reduced from 36.5 mm to 35.7 mm. The surface roughness value decreases from 6.957 μm to 5.149 μm. The graph obviously shows that the surface roughness value is decreasing significantly when the RPM is higher. In other words, the surface finish will be improved as the cutting speed increased.

Table 4.9: Result for 0.5 mm

Cutting Speed	Surface Roughness			Average Surface Roughness
	1st	2nd	3rd	
490	7.576	7.603	7.779	7.653
810	7.458	7.533	7.699	7.563
1400	5.545	5.376	5.873	5.598

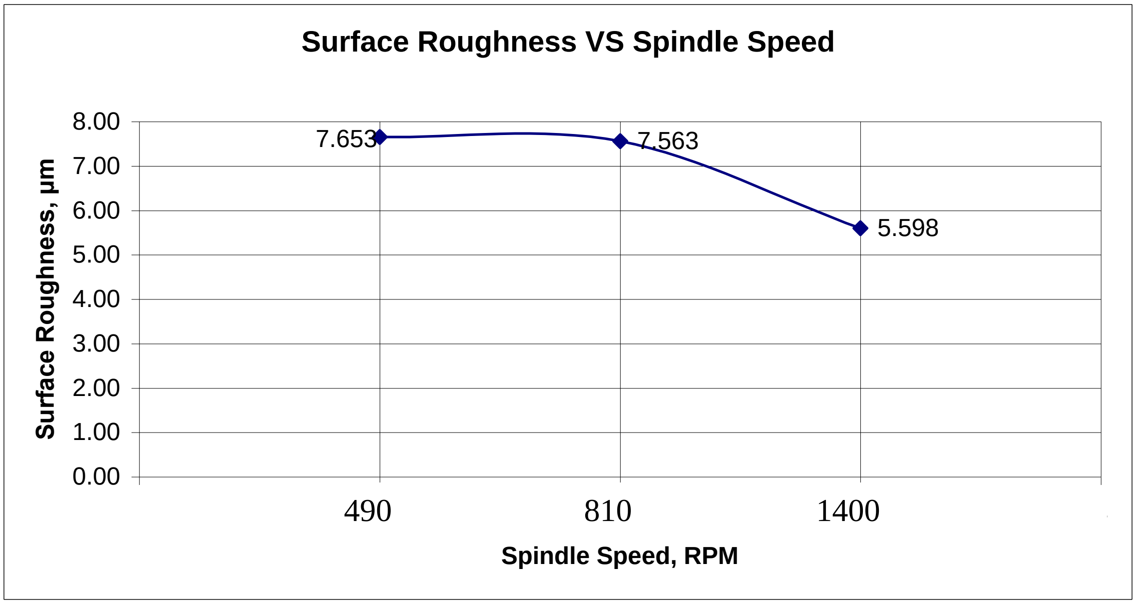

Figure 4.9: Graph of surface roughness vs. spindle speed for 0.5 mm depth of cut

The Figure 4.9 above shows graph for surface roughness of 3 different speeds, which are 490 rpm, 810 rpm, 1400 rpm, which are approximately 58034.64 mm/min, 95934.81 mm/min, and 165813.26 mm/min respectively. The feed rate is set at 0.15 mm/rev. The workpiece diameter is reduced from 35.7 mm to 34.7 mm. The surface roughness value decreases from 7.653 µm to 5.598 µm. The graph obviously shows that the surface roughness value is decreasing significantly when the RPM is higher. In other words, the surface finish will be improved as the cutting speed increased.

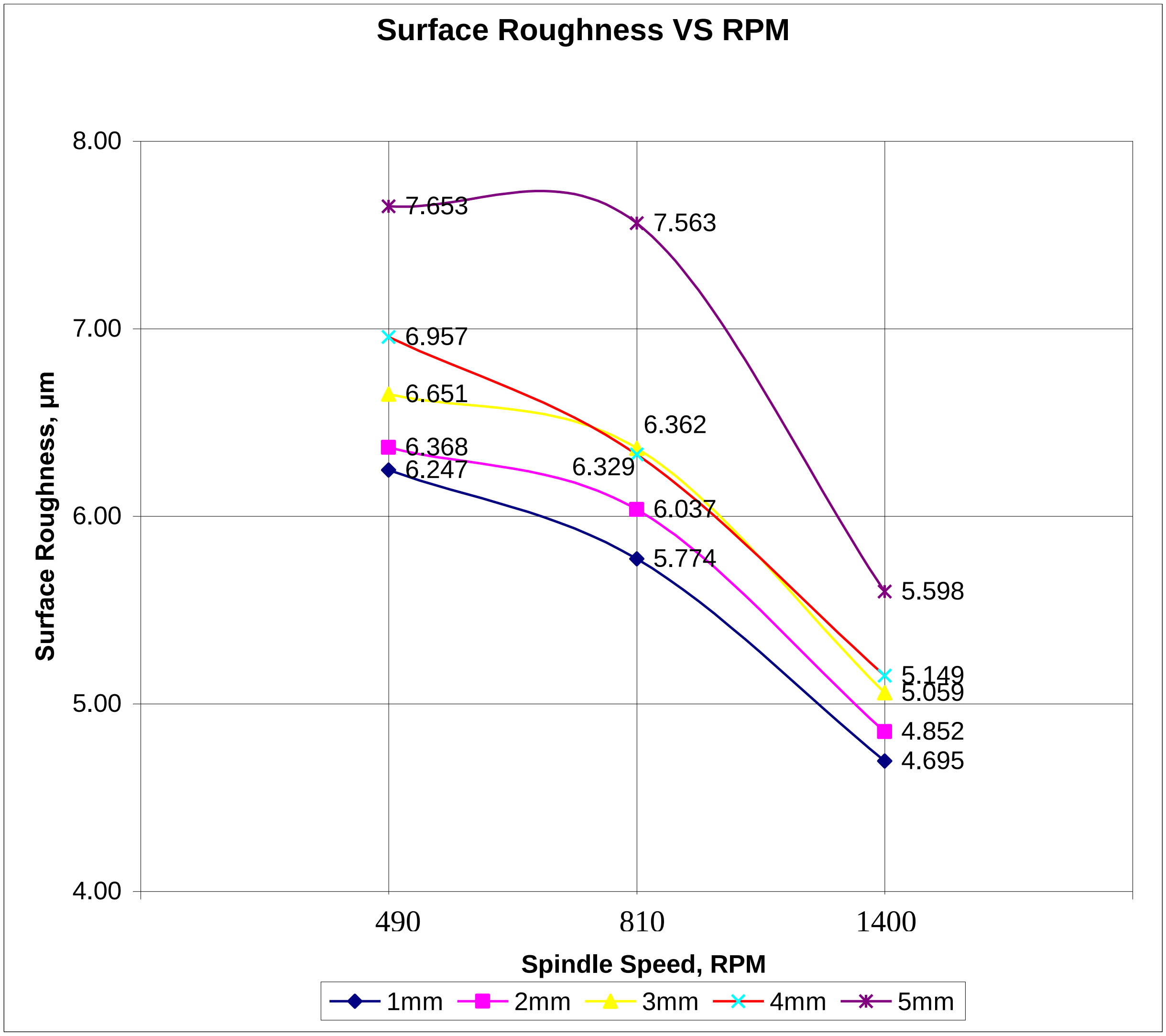

Figure 4.10: Graph of surface roughness vs. spindle speed for different depth of cut

The Figure 4.10 above shows graph for the comparison of all 5 different DOC used for the 3 different value of RPM. From this graph, can conclude that the surface roughness value are decreasing when the RPM increasing. This also indicates that he surface finish will improve when uses higher cutting speed. Besides, in comparison of the DOC, it can be conclude that the larger the value of DOC, the larger the value for surface roughness. In other words means the surface finish is better when smaller DOC is used.

4.2.4 Relation between Cutting Speed and Depth of Cut on Surface Finish

From the experiment conducted, we can conclude that the higher RPM is, the lower the value of surface roughness. This means that higher cutting speed produces better surface finish. Cutting speed is one of the parameters that control the surface roughness. At low cutting speed, build-up-edge (BUE) tends to build up at the edge of material during turning. BUE tends to scratch the material surface and causes the surface roughness value higher than it suppose to be. 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 ruins the cutting tool eventually. This is because the vibrations produced lift the tool and snaps it back when the BUE fractures. Even though, higher cutting speed results in good surface roughness, it might also cause burn marks to appear on the surface of material turned. In addition, the heat generated can flow into the cutting edge and that will negatively affect tool life by shortening it

In aspect of depth of cut (DOC), surface roughness value increases as the DOC value increases. In other words it means 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. Lower value of DOC produce continuous chip, so this indicates that the surface finishing for lower DOC is better.

4.3 PREDICTION RESULTT OF SURFACE ROUGHNESS USING MINITAB15

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

Table 4.10: Estimated regression coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	5.9997	0.07010	85.586	0.000
Depth of Cut	0.6249	0.09844	6.348	0.000
RPM	-0.8751	0.08403	-10.414	0.000

S = 0.269588 PRESS = 1.37722

R-Sq = 92.54% R-Sq(pred) = 88.21% R-Sq(adj) = 91.29%

Table 4.11: Analysis of variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	2	10.8116	10.8116	5.40582	74.38	0.000
Linear	2	10.8116	10.8116	5.40582	74.38	0.000
Residual Error	12	0.8721	0.8721	0.07268		
Total	14	11.6838				

Table 4.12: Unusual observations for Ra

Obs	StdOrder	Ra	Fit	SE Fit	Residual	St Resid
10	10	7.563	6.884	0.122	0.679	2.82 R

R denotes an observation with a large standardized residual.

Table 4.13: Estimated linear regression equation

Term	Coef
Constant	6.87982
Depth of Cut	3.12467
RPM	-0.00192328

Table 4.14: Predicted response for new design points using model for Ra

Point	Fit	SE Fit	95% CI	95% PI
1	6.24988	0.142368	(5.93969, 6.56007)	(5.58562, 6.91413)
2	6.56234	0.114021	(6.31391, 6.81078)	(5.92459, 7.20010)
3	6.87481	0.102850	(6.65072, 7.09890)	(6.24613, 7.50349)
4	7.18728	0.114021	(6.93885, 7.43571)	(6.54952, 7.82504)
5	7.49974	0.142368	(7.18955, 7.80994)	(6.83549, 8.16400)
6	5.63443	0.121704	(5.36926, 5.89960)	(4.98997, 6.27889)
7	5.94690	0.086856	(5.75765, 6.13614)	(5.32978, 6.56401)
8	6.25936	0.071564	(6.10344, 6.41529)	(5.65164, 6.86709)
9	6.57183	0.086856	(6.38258, 6.76107)	(5.95471, 7.18894)
10	6.88430	0.121704	(6.61913, 7.14946)	(6.23983, 7.52876)
11	4.49969	0.151861	(4.16882, 4.83057)	(3.82553, 5.17386)
12	4.81216	0.125674	(4.53834, 5.08598)	(4.16409, 5.46023)
13	5.12463	0.115635	(4.87268, 5.37657)	(4.48549, 5.76376)
14	5.43709	0.125674	(5.16327, 5.71091)	(4.78902, 6.08516)
15	5.74956	0.151861	(5.41868, 6.08044)	(5.07540, 6.42372)

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

Table 4.15: Estimated regression coefficients for Ra

Term	Coef	SE Coef	T	P
Constant	6.0295	0.11289	53.410	0.000
Depth of Cut	0.6103	0.07045	8.663	0.000
RPM	-0.8523	0.06058	-14.068	0.000
Depth of Cut*Depth of Cut	0.307	0.11824	2.597	0.029
RPM*RPM	-0.2601	0.11674	-2.228	0.053
Depth of Cut*RPM	-0.1476	0.08445	-1.748	0.114

S = 0.191578 PRESS = 0.909955

R-Sq = 97.17% R-Sq(pred) = 92.21% R-Sq(adj) = 95.60%

Table 4.16: Analysis of variance

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	11.3535	11.3535	2.27069	61.87	0.000
Linear	2	10.8116	10.0187	5.00936	136.49	0.000
Square	2	0.4297	0.4297	0.21486	5.85	0.024
Interaction	1	0.1121	0.1121	0.11210	0.11	0.114
Residual Error	9	0.3303	0.3303	0.03670		
Total	14	11.6838				

Table 4.17: Unusual observations for Ra

Obs	**StdOrder**	**Ra**	**Fit**	**SE Fit**	**Residual**	**St Resid**
9	9	6.329	6.663	0.098	-0.334	-2.03 R
10	10	7.563	7.221	0.127	0.342	2.38 R

R denotes an observation with a large standardized residual.

Table 4.18: Estimated quadratic regression equation

Term	**Coef**
Constant	5.99318
Depth of Cut	-0.0214301
RPM	0.000988063
Depth of Cut*Depth of Cut	7.67619
RPM*RPM	-1.25646E-06
Depth of Cut*RPM	-0.00162180

Table 4.19: Predicted response for new design points using model for Ra

Point	**Fit**	**SE Fit**	**95% CI**	**95% PI**
1	6.17080	0.146697	(5.83895, 6.50265)	(5.62496, 6.71665)
2	6.31948	0.104333	(6.08346, 6.55549)	(5.82600, 6.81296)
3	6.62168	0.104096	(6.38620, 6.85716)	(6.12845, 7.11490)
4	7.07740	0.104333	(6.84138, 7.31342)	(6.58392, 7.57088)
5	7.68664	0.146697	(7.35479, 8.01850)	(7.14080, 8.23249)
6	5.91240	0.126525	(5.62618, 6.19862)	(5.39303, 6.43176)
7	6.00918	0.097506	(5.78860, 6.22975)	(5.52289, 6.49546)
8	6.25948	0.104096	(6.02400, 6.49496)	(5.76625, 6.75270)

Table 4.19: Continued

Point	Fit	SE Fit	95% CI	95% PI
9	6.66330	0.097506	(6.44273, 6.88388)	(6.17702, 7.14958)
10	7.22065	0.126525	(6.93443, 7.50687)	(6.70128, 7.74001)
11	4.76137	0.156016	(4.40844, 5.11430)	(4.20246, 5.32028)
12	4.76246	0.107660	(4.51892, 5.00600)	(4.26534, 5.25959)
13	4.91708	0.104096	(4.68160, 5.15256)	(4.42385, 5.41030)
14	5.22521	0.107660	(4.98167, 5.46876)	(4.72809, 5.72234)
15	5.68688	0.156016	(5.33394, 6.03981)	(5.12797, 6.24579)

4.3.3 Discussion of Response Surface Methodology Modeling Results

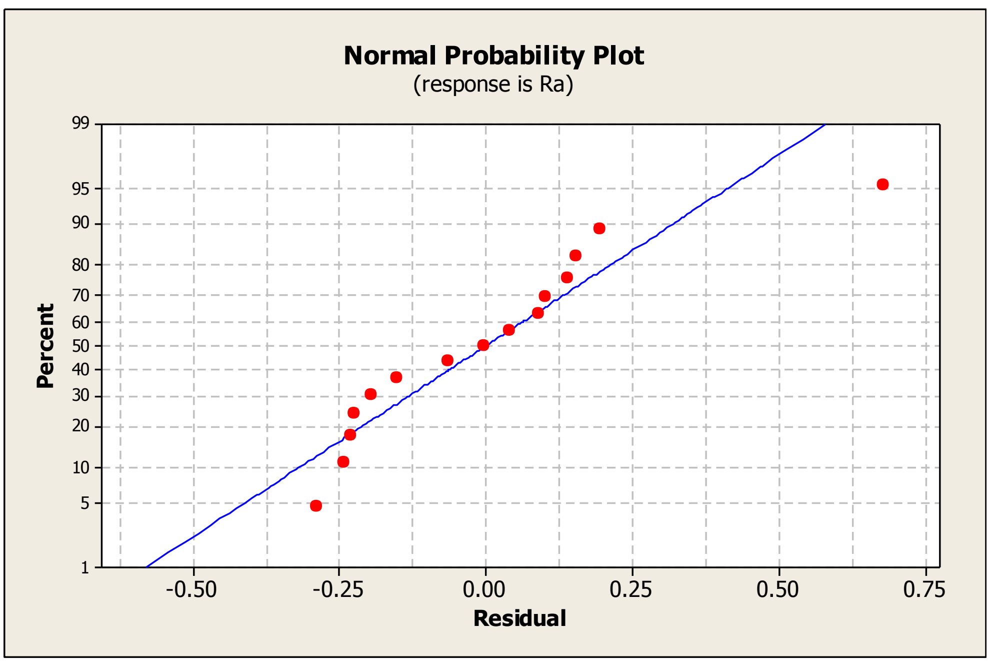

Figure 4.11: Linear normal plot

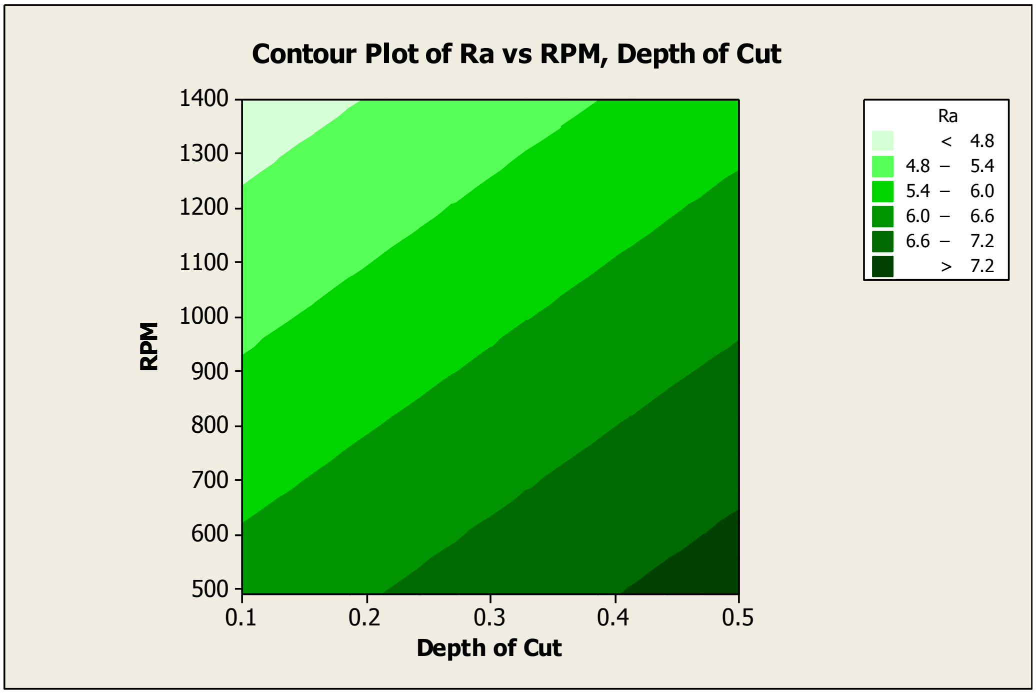

Figure 4.12: Linear contour plot

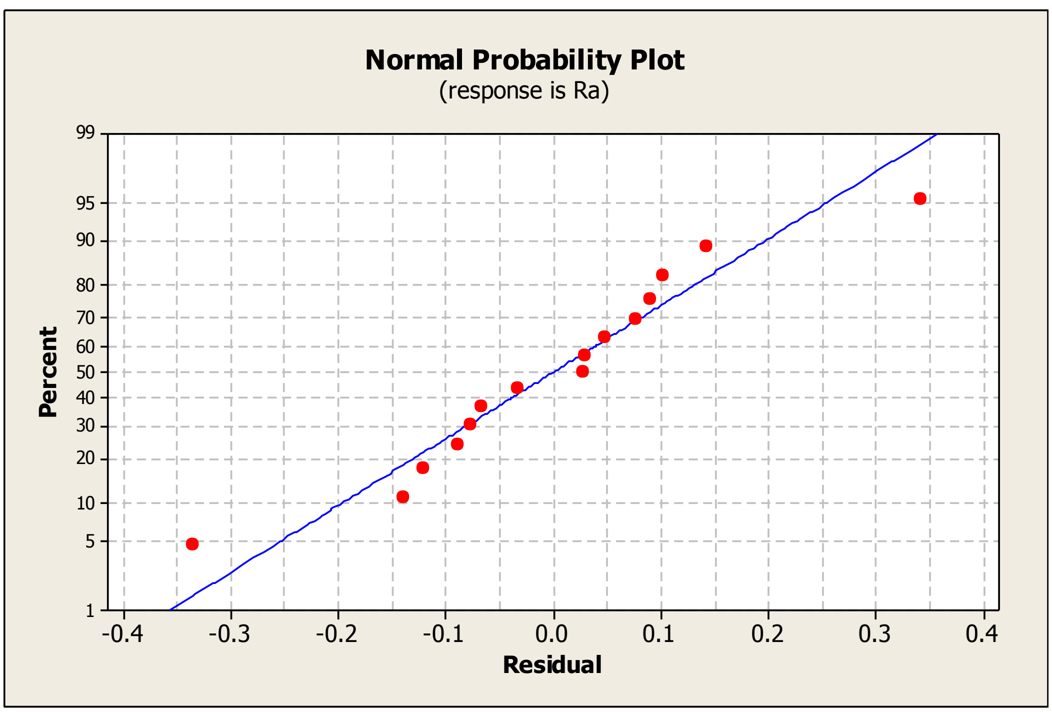

Figure 4.13: Quadratic normal plot

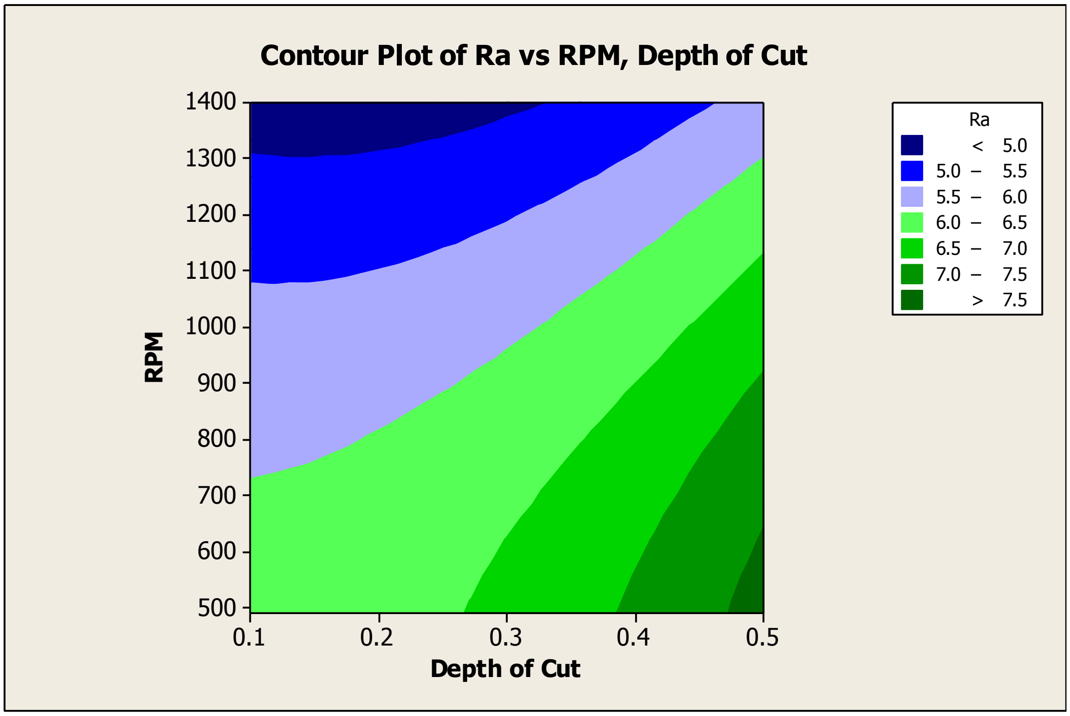

Figure 4.14: Quadratic contour plot

Table 4.20: Data set used for checking the accuracy of RS model

Depth of Cut	RPM	Ra (Experimental)	1st Order Prediction	2nd Order Prediction	1st Order Error (%)	2nd Order Error (%)
0.1	490	6.247	6.250	6.171	-0.046	1.220
0.2	490	6.368	6.562	6.319	-3.052	0.762
0.3	490	6.651	6.875	6.622	-3.365	0.441
0.4	490	6.957	7.187	7.077	-3.310	-1.731
0.5	490	7.653	7.500	7.687	2.003	-0.440
0.1	810	5.774	5.634	5.912	2.417	-2.397
0.2	810	6.037	5.947	6.009	1.493	0.461
0.3	810	6.362	6.259	6.259	1.613	1.612
0.4	810	6.329	6.572	6.663	-3.837	-5.282
0.5	810	7.563	6.884	7.221	8.974	4.527

Table 4.20: Continued

Depth of Cut	RPM	Ra (Experimental)	1st Order Prediction	2nd Order Prediction	1st Order Error (%)	2nd Order Error (%)
0.1	1400	4.695	4.500	4.761	4.160	-1.414
0.2	1400	4.852	4.812	4.762	0.821	1.845
0.3	1400	5.059	5.125	4.917	-1.297	2.805
0.4	1400	5.149	5.437	5.225	-5.595	-1.480
0.5	1400	5.598	5.750	5.687	-2.707	-1.588

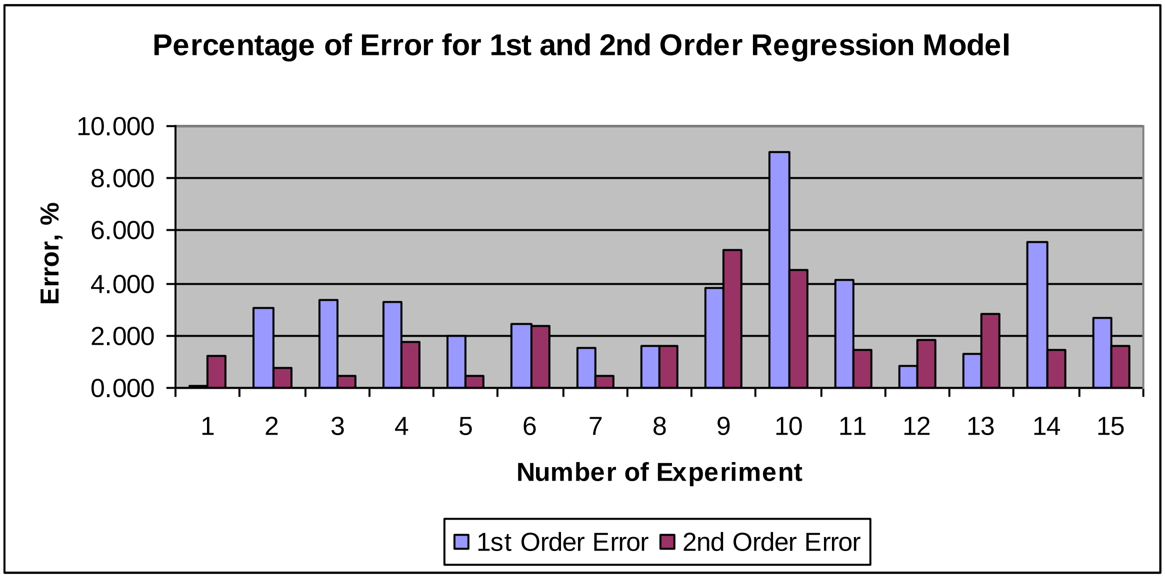

Figure 4.15: Comparison of error for 1st and 2nd order model

The test plan was developed using MINITAB 15, with the aim of relating the influence of cutting speed and depth of cut on the surface roughness. The statistical treatment data consist of analysis of variance (ANOVA) and the effect of factors and the interactions, and the correlations between the parameters.

ANOVA table reflects the influence of cutting speed and depth of cut on the total variance of the results is performed. The number of replication is one and the experimental results are shown in Table 4.11 and Table 4.15. Table 4.12 and Table 4.16 show the results of the significant of parameters on the surface roughness. 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 both rpm and depth of cut (DOC) display 0.000. This indicates that both parameters took effect and are highly significant on surface roughness. As for second order regression, that is the quadratic regression modeling, DOC and rpm show 0.000, DOC*DOC is 0.029, rpm*rpm is 0.053, and interaction between DOC and rpm (DOC*rpm) is 0.114. This means that all this parameters take effects on the surface roughness. However, still the main dominant effect is from DOC or rpm only. Significance of rpm also indicates significance of cutting speed.

The correlations between the factors (cutting speed and depth of cut) and the response (surface roughness) were obtained by both linear regression and quadratic regression analysis. The linear mathematical model (first-order modeling predicting equation) suggested is in Eq. (4.1) following;

$$y = 6.87982 + 3.12467x_1 – 0.00192328x_2 \tag{4.1}$$

The quadratic mathematical model (second-order modeling predicting equation) suggested is in Eq. (4.2);

$$y = 5.99318 – 0.0214301x_1 + 0.000988063x_2 + 7.67619x_1^2 – 1.25646E\text{-}6x_2^2 – 0.00162180x_1x_2 \tag{4.2}$$

Where, y is the performance output term, which refers to surface roughness. x_1 refers to depth of cut and x_2 refers to rpm. 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. For linear regression, the r^2 of experimental result is 0.925(92.5 %) and predicted result is 0.882 (88.21 %). And as for quadratic regression, r^2 of experimental result is 0.971(97.1 %) and predicted result is 0.922(92.21 %). The r^2 is measure of the proportion of total variability explained by the model, and r^2=1 is the most desirable value. In this experiment, 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.

In Figure 4.11, 4.12, 4.13, 4.14 are the normal plot and contour plot of predicted linear and quadratic regression. From the normal plot Figure 4.12 and 4.14, the linear line is 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 better prediction. So, it is obvious that the residual value for quadratic plot is more persistent and closer to regression line. In Table 4.20 is the comparison made between values obtained experimentally and values predicted using RSM. From the table can be observed that the estimated error is small. And 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 4.15, the graph shows that the error for 2^{nd} order model's error is smaller than that 1^{st} order model. So, quadratic regression model shows better prediction.

CHAPTER 5

RECOMMENDATION AND CONCLUSION

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. Recommendations will also be given on improving future work and studies.

5.2 CONCLUSION

From the results, it can be conclude that higher cutting speed produce better surface roughness. Lower cutting speed as well improves surface finish. Surface finish can be concluded as proportional to the cutting speed. This is explained by the theory where increasing of speed, leads to increase of temperature. As the temperature arise, separates the build up edge from cutting tool. There is no formation of built up edge at low cutting speed since the temperature of the surface of the chip is not sufficient to cause the it to behave in a ductile manner As the cutting speed increases, the friction between chip and tool will increase. Heat generated at the shearing plane can make the cutting action easier. In this experiment, the optimum parameter is 0.1 mm for depth of cut and 165813.26 mm/min for cutting speed as the surface finish show most promising quality at this level of parameter. However, it can flow into the cutting edge and that shorten tool’s life. As for the response surface modeling, the predicted results for surface roughness are not much difference from the experimental results. This is a good sign as it indicates that the results for this experiment are quite accurate. Nevertheless, the quadratic regression modeling shown more accuracy compared to the linear regression modeling.

5.3 RECOMMENDATIONS

For every studies and researches that has been done, there is always room for further improvements. So is this research. There are some suggestion and method that can be taken into account when running this research in the future.

Firstly, researchers may select more cutting speed and depth of cut when carry out the experiment. More level of parameter can helps to eliminate errors and leads to accuracy. In this research, only 3 cutting speed and 5 depth of cut are used, and the surface finish did improves when the cutting speed increases and increases when the depth of cut decreases. Figure 5.1 shows one of the specimens after turned. However, if there were more level of parameters, there might be a possibility that at certain point, the surface finish will not improve when increasing the cutting speed further more. That certain point, is considered as the optimum cutting speed.

Secondly, is the problem of conventional lather machine that is used in this research. The old conventional lathe machine has very limited spindle speed (rpm), as shown in Figure 5.2. The highest rpm available is only 1400 rpm. Thus, the choice for rpm is not many and it limits the researcher with the choice of cutting speed. Suggestion is that future researcher may use the new model Lathe machine, or CNC Lathe machine so that there is a wide range of choice for rpm. This also means that a great variety of cutting speed is provided.

Furthermore, it is suggested that the future researchers use one design of experiment (DOE) when carry out the experiment. Be it 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.

Lastly, it is recommended that the cutting tool is changed every time after using high cutting speed. Usually after cutting on high speed, 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.

(Refer to Appendix A3)

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APPENDIX A1

HARDNESS CONVERSION CHART

Rockwell						Rockwell Superficial				Brinell		Vickers	Shore	
A	B	C	D	E	F	15-N	30-N	45-N	30-T	3000 kg	500 kg	136		Approx Tensile Strength (psi)
60kg Brale	100kg 1/16" Ball	150kg Brale	100kg Brale	100kg 1/8" Ball	60kg 1/16" Ball	15kg Brale	30kg Brale	45kg Brale	30 kg 1/16" Ball	10mm Ball Steel	10mm Ball Steel	Diamond Pyramid	Sciero-scope	
86.5	---	70	78.5	---	---	94	86	77.6	---	---	---	1076	101	---
86	---	69	77.7	---	---	93.5	85	76.5	---	---	---	1044	99	---
85.6	---	68	76.9	---	---	93.2	84.4	75.4	---	---	---	940	97	---
85	---	67	76.1	---	---	92.9	83.6	74.2	---	---	---	900	95	---
84.5	---	66	75.4	---	---	92.5	82.8	73.2	---	---	---	865	92	---
83.9	---	65	74.5	---	---	92.2	81.9	72	---	739	---	832	91	---
83.4	---	64	73.8	---	---	91.8	81.1	71	---	722	---	800	88	---
82.8	---	63	73	---	---	91.4	80.1	69.9	---	705	---	772	87	---
82.3	---	62	72.2	---	---	91.1	79.3	68.8	---	688	---	746	85	---
81.8	---	61	71.5	---	---	90.7	78.4	67.7	---	670	---	720	83	---
81.2	---	60	70.7	---	---	90.2	77.5	66.6	---	654	---	697	81	320,000
80.7	---	59	69.9	---	---	89.8	76.6	65.5	---	634	---	674	80	310,000
80.1	---	58	69.2	---	---	89.3	75.7	64.3	---	615	---	653	78	300,000
79.6	---	57	68.5	---	---	88.9	74.8	63.2	---	595	---	633	76	290,000
79	---	56	67.7	---	---	88.3	73.9	62	---	577	---	613	75	282,000
78.5	120	55	66.9	---	---	87.9	73	60.9	---	560	---	595	74	274,000
78	120	54	66.1	---	---	87.4	72	59.8	---	543	---	577	72	266,000
77.4	119	53	65.4	---	---	86.9	71.2	58.6	---	525	---	560	71	257,000
76.8	119	52	64.6	---	---	86.4	70.2	57.4	---	500	---	544	69	245,000
76.3	118	51	63.8	---	---	85.9	69.4	56.1	---	487	---	528	68	239,000
75.9	117	50	63.1	---	---	85.5	68.5	55	---	475	---	513	67	233,000
75.2	117	49	62.1	---	---	85	67.6	53.8	---	464	---	498	66	227,000
74.7	116	48	61.4	---	---	84.5	66.7	52.5	---	451	---	484	64	221,000
74.1	116	47	60.8	---	---	83.9	65.8	51.4	---	442	---	471	63	217,000
73.6	115	46	60	---	---	83.5	64.8	50.3	---	432	---	458	62	212,000
73.1	115	45	59.2	---	---	83	64	49	---	421	---	446	60	206,000
72.5	114	44	58.5	---	---	82.5	63.1	47.8	---	409	---	434	58	200,000
72	113	43	57.7	---	---	82	62.2	46.7	---	400	---	423	57	196,000
71.5	113	42	56.9	---	---	81.5	61.3	45.5	---	390	---	412	56	191,000
70.9	112	41	56.2	---	---	80.9	60.4	44.3	---	381	---	402	55	187,000
70.4	112	40	55.4	---	---	80.4	59.5	43.1	---	371	---	392	54	182,000

69.9	111	39	54.6	---	---	79.9	58.6	41.9	---	362	---	382	52	177,000
69.4	110	38	53.8	---	---	79.4	57.7	40.8	---	353	---	372	51	173,000
68.9	110	37	53.1	---	---	78.8	56.8	39.6	---	344	---	363	50	169,000
68.4	109	36	52.3	---	---	78.3	55.9	38.4	---	336	---	354	49	165,000
67.9	109	35	51.5	---	---	77.7	55	37.2	---	327	---	345	48	160,000
67.4	108	34	50.8	---	---	77.2	54.2	36.1	---	319	---	336	47	156,000
66.8	108	33	50	---	---	76.6	53.3	34.9	---	311	---	327	46	152,000
66.3	107	32	49.2	---	---	76.1	52.1	33.7	---	301	---	318	44	147,000
65.8	106	31	48.4	---	---	75.6	51.3	32.5	---	294	---	310	43	144,000
65.3	105	30	47.7	---	---	75	50.4	31.3	---	286	---	302	42	140,000
64.7	104	29	47	---	---	74.5	49.5	30.1	---	279	---	294	41	137,000
64.3	104	28	46.1	---	---	73.9	48.6	28.9	---	271	---	286	41	133,000
63.8	103	27	45.2	---	---	73.3	47.7	27.8	---	264	---	279	40	129,000
63.3	103	26	44.6	---	---	72.8	46.8	26.7	---	258	---	272	39	126,000
62.8	102	25	43.8	---	---	72.2	45.9	25.5	---	253	---	266	38	124,000
62.4	101	24	43.1	---	---	71.6	45	24.3	---	247	---	260	37	121,000
62	100	23	42.1	---	---	71	44	23.1	82	240	201	254	36	118,000
61.5	99	22	41.6	---	---	70.5	43.2	22	81.5	234	195	248	35	115,000
61	98	21	40.9	---	---	69.9	42.3	20.7	81	228	189	243	35	112,000
60.5	97	20	40.1	---	---	69.4	41.5	19.6	80.5	222	184	238	34	109,000
59	96	18	---	---	---	---	---	---	80	216	179	230	33	106,000
58	95	16	---	---	---	---	---	---	79	210	175	222	32	103,000
57.5	94	15	---	---	---	---	---	---	78.5	205	171	213	31	100,000
57	93	13	---	---	---	---	---	---	78	200	167	208	30	98,000
56.5	92	12	---	---	---	---	---	---	77.5	195	163	204	29	96,000
56	91	10	---	---	---	---	---	---	77	190	160	196	28	93,000
55.5	90	9	---	---	---	---	---	---	76	185	157	192	27	91,000
55	89	8	---	---	---	---	---	---	75.5	180	154	188	26	88,000
54	88	7	---	---	---	---	---	---	75	176	151	184	26	86,000
53.5	87	6	---	---	---	---	---	---	74.5	172	148	180	26	84,000
53	86	5	---	---	---	---	---	---	74	169	145	176	25	83,000
52.5	85	4	---	---	---	---	---	---	73.5	165	142	173	25	81,000
52	84	3	---	---	---	---	---	---	73	162	140	170	25	79,000
51	83	2	---	---	---	---	---	---	72	159	137	166	24	78,000
50.5	82	1	---	---	---	---	---	---	71.5	156	135	163	24	76,000
50	81	0	---	---	---	---	---	---	71	153	133	160	24	75,000
49.5	80	---	---	---	---	---	---	---	70	150	130	---	---	73,000
49	79	---	---	---	---	---	---	---	69.5	147	128	---	---	---
48.5	78	---	---	---	---	---	---	---	69	144	126	---	---	---
48	77	---	---	---	---	---	---	---	68	141	124	---	---	---

47	76	---	---	---	---	---	---	---	67.5	139	122	---	---	---
46.5	75	---	---	---	99.5	---	---	---	67	137	120	---	---	---
46	74	---	---	---	99	---	---	---	66	135	118	---	---	---
45.5	73	---	---	---	98.5	---	---	---	65.5	132	116	---	---	---
45	72	---	---	---	98	---	---	---	65	130	114	---	---	---
44.5	71	---	---	100	97.5	---	---	---	64.2	127	112	---	---	---
44	70	---	---	99.5	97	---	---	---	63.5	125	110	---	---	---
43.5	69	---	---	99	96	---	---	---	62.8	123	109	---	---	---
43	68	---	---	98	95.5	---	---	---	62	121	107	---	---	---
42.5	67	---	---	97.5	95	---	---	---	61.4	119	106	---	---	---
42	66	---	---	97	94.5	---	---	---	60.5	117	104	---	---	---
41.8	65	---	---	96	94	---	---	---	60.1	116	102	---	---	---
41.5	64	---	---	95.5	93.5	---	---	---	59.5	114	101	---	---	---
41	63	---	---	95	93	---	---	---	58.7	112	99	---	---	---
40.5	62	---	---	94.5	92	---	---	---	58	110	98	---	---	---
40	61	---	---	93.5	91.5	---	---	---	57.3	108	96	---	---	---
39.5	60	---	---	93	91	---	---	---	56.5	107	95	---	---	---
39	59	---	---	92.5	90.5	---	---	---	55.9	106	94	---	---	---
38.5	58	---	---	92	90	---	---	---	55	104	92	---	---	---
38	57	---	---	91	89.5	---	---	---	54.6	102	91	---	---	---
37.8	56	---	---	90.5	89	---	---	---	54	101	90	---	---	---
37.5	55	---	---	90	88	---	---	---	53.2	99	89	---	---	---
37	54	---	---	89.5	87.5	---	---	---	52.5	---	87	---	---	---
36.5	53	---	---	89	87	---	---	---	51.8	---	86	---	---	---
36	52	---	---	88	86.5	---	---	---	51	---	85	---	---	---
35.5	51	---	---	87.5	86	---	---	---	50.4	---	84	---	---	---
35	50	---	---	87	85.5	---	---	---	49.5	---	83	---	---	---
34.8	49	---	---	86.5	85	---	---	---	49.1	---	82	---	---	---
34.5	48	---	---	85.5	84.5	---	---	---	48.5	---	81	---	---	---
34	47	---	---	85	84	---	---	---	47.7	---	80	---	---	---
33.5	46	---	---	84.5	83	---	---	---	47	---	79	---	---	---
33	45	---	---	84	82.5	---	---	---	46.2	---	79	---	---	---
32.5	44	---	---	83.5	82	---	---	---	45.5	---	78	---	---	---
32	43	---	---	82.5	81.5	---	---	---	44.8	---	77	---	---	---
31.5	42	---	---	82	81	---	---	---	44	---	76	---	---	---
31	41	---	---	81.5	80.5	---	---	---	43.4	---	75	---	---	---
30.8	40	---	---	81	79.5	---	---	---	43	---	74	---	---	---
30.5	39	---	---	80	79	---	---	---	42.1	---	74	---	---	---
30	38	---	---	79.5	78.5	---	---	---	41.5	---	73	---	---	---
29.5	37	---	---	79	78	---	---	---	40.7	---	72	---	---	---

29	36	---	---	78.5	77.5	---	---	---	40	---	71	---	---	---
28.5	35	---	---	78	77	---	---	---	39.3	---	71	---	---	---
28	34	---	---	77	76.5	---	---	---	38.5	---	70	---	---	---
27.8	33	---	---	76.5	75.5	---	---	---	37.9	---	69	---	---	---
27.5	32	---	---	76	75	---	---	---	37.5	---	68	---	---	---
27	31	---	---	75.5	74.5	---	---	---	36.6	---	68	---	---	---
26.5	30	---	---	75	74	---	---	---	36	---	67	---	---	---
26	29	---	---	74	73.5	---	---	---	35.2	---	66	---	---	---
25.5	28	---	---	73.5	73	---	---	---	34.5	---	66	---	---	---
25	27	---	---	73	72.5	---	---	---	33.8	---	65	---	---	---
24.5	26	---	---	72.5	72	---	---	---	33.1	---	65	---	---	---
24.2	25	---	---	72	71	---	---	---	32.4	---	64	---	---	---
24	24	---	---	71	70.5	---	---	---	32	---	64	---	---	---
23.5	23	---	---	70.5	70	---	---	---	31.1	---	63	---	---	---
23	22	---	---	70	69.5	---	---	---	30.4	---	63	---	---	---
22.5	21	---	---	69.5	69	---	---	---	29.7	---	62	---	---	---
22	20	---	---	68.5	68.5	---	---	---	29	---	62	---	---	---
21.5	19	---	---	68	68	---	---	---	28.1	---	61	---	---	---
21.2	18	---	---	67.5	67	---	---	---	27.4	---	61	---	---	---
21	17	---	---	67	66.5	---	---	---	26.7	---	60	---	---	---
20.5	16	---	---	66.5	66	---	---	---	26	---	60	---	---	---
20	15	---	---	65.5	65.5	---	---	---	25.3	---	59	---	---	---
---	14	---	---	65	65	---	---	---	24.6	---	59	---	---	---
---	13	---	---	64.5	64.5	---	---	---	23.9	---	58	---	---	---
---	12	---	---	64	64	---	---	---	23.5	---	58	---	---	---
---	11	---	---	63.5	63.5	---	---	---	22.6	---	57	---	---	---
---	10	---	---	62.5	63	---	---	---	21.9	---	57	---	---	---
---	9	---	---	62	62	---	---	---	21.2	---	56	---	---	---
---	8	---	---	61.5	61.5	---	---	---	20.5	---	56	---	---	---
---	7	---	---	61	61	---	---	---	19.8	---	56	---	---	---
---	6	---	---	60.5	60.5	---	---	---	19.1	---	55	---	---	---
---	5	---	---	60	60	---	---	---	18.4	---	55	---	---	---
---	4	---	---	59	59.5	---	---	---	18	---	55	---	---	---
---	3	---	---	58.5	59	---	---	---	17.1	---	54	---	---	---
---	2	---	---	58	58	---	---	---	16.4	---	54	---	---	---
---	1	---	---	57.5	57.5	---	---	---	15.7	---	53	---	---	---
---	0	---	---	57	57	---	---	---	15	---	53	---	---	---

Source: http://www.carbidedepot.com/formulas-hardness.htm (2009)

APPENDIX A2

MACHINES AND EQUIPMENTS USED IN EXPERIMENT

Figure 3.2: Bandsaw

Figure 3.3: Portable grinder

Figure 3.4: Arc Spectrometer

Figure 3.5: Specimens after undergone spark-spectrometer test

Figure 3.6: Rockwell Hardness Tester

Figure 3.7: Cutting Machine

Figure 3.8: Conventional Lathe Machine

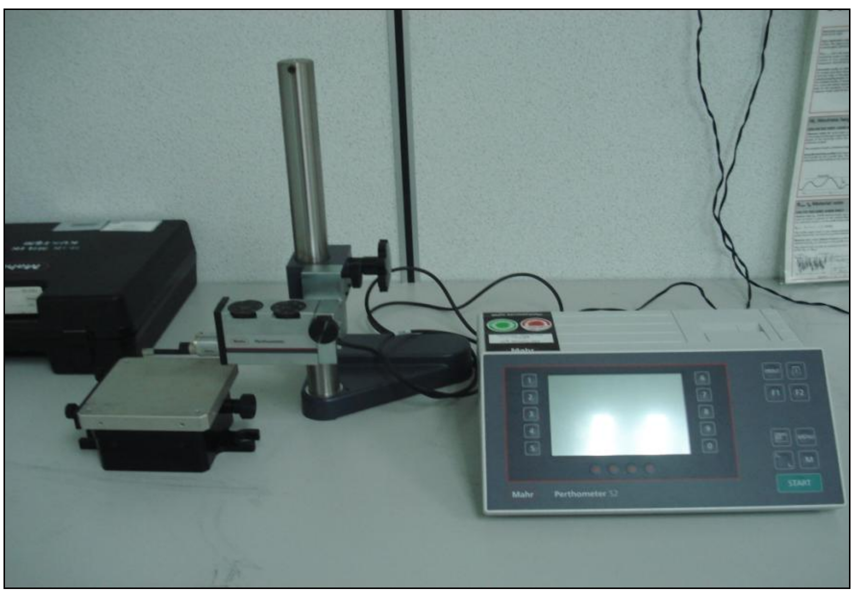

Figure 3.9: Surface Roughness Tester, Perthometer

APPENDIX A3

FIGURES RELATED TO DISCUSSION

Figure 5.1: Steel bar after turned

Figure 5.2: Available spindle speed on lathe machine