EFFECT OF CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS OF OIL-QUENCHED MILD STEEL

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **EFFECT OF CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS OF OIL-QUENCHED MILD STEEL**

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EFFECT OF CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS OF OIL-QUENCHED MILD STEEL

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I hereby declare that the work in this project entitled "*effect of cutting speed and depth of cut on surface roughness of oil-quenched mild steel*" 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

Mild steels are often employed in high volume of screw machine parts such as shafts, spindles, pins, rods and varieties of component parts where high hardness is required. Although mild steel provides various advantages such as ease of formability, machinability and weldability but it is unimpressive in terms of strength and hardness. The most common problem encountered is the short tool life. Hence, the ability to make mild steels hard enough to be the tools that shape all other material is important. Mild steel ability to be hardened is produced in heat treatment and quenching process. Thus, the main objective of this project is to determine the effect of cutting speed and depth of cut on surface roughness of oil-quenched mild steel. Material is prepared by heating mild steel followed by quenching in oil. The hardness of quenched mild steel was tested with Rockwell hardness tester to determine suitable machining parameters. Taguchi and orthogonal array DOE was employed to set up experiments. The surface of oil-quenched mild steel was measured with perthometer and data were collected. Analysis of data obtained were made by using Analysis of Variance (ANOVA), Response Surface Methodology (RSM) and validation test were carried out to determine significant parameter affecting surface quality of specimen studied. Conclusions were then made based on results obtained.

ABSTRAK

Keluli biasanya digunakan untuk membuat komponen bahagian mesin seperti rod, pin, syaf, mata pemotong dan pelbagai komponen yang memerlukan kekerasan yang tinggi. Walaupun keluli mempunyai kelebihan kerana mudah dibentuk, senang untuk dimesin dan dikimpal tetapi keluli mempunyai kelemahan dari segi sifat kekuatan dan kekerasan yang kurang menyerlah jika dibandingkan dengan sifat bahan yang lain. Masalah yang paling ketara ialah jangka masa hayat mata pemotong yang pendek. Oleh itu, keluli harus diproses untuk meningkatkan jangka masa hayat alat-alat seperti mata pemotong. Untuk meningkatkan kekerasan keluli, keluli akan dirawat dengan memanaskan pada suhu yang tinggi dan melalui proses lindap kejut dalam medium yang sesuai. Dengan demikian, tujuan utama projek ini adalah untuk menentukan kesan daripada kelajuan dan kedalaman pemotongan keluli yang telah dilindap kejut dari segi tekstur permukaan yang dihasilkan dengan menggunakan mesin “lathe”. Bahan ini disediakan dengan memanaskan keluli diikuti dengan pendinginan dalam minyak selama lebih kurang sejam. Kekerasan dari keluli yang dilindap kejut diuji dengan Rockwell hardness tester untuk menentukan parameter pemesinan yang sesuai. “Taguchi dan Orthogonal Array Design of Experiment” digunakan untuk menentukan eksperimen yang akan dijalankan. Permukaan keluli selepas dimesin diukur dengan perthometer. Data yang diperolehi dianalisis dengan menggunakan ANOVA, RSM dan validasi ujian dilakukan untuk menentukan parameter yang signifikan mempengaruhi kualiti spesimen. Kesimpulan kemudiannya dibuat berdasarkan keputusan yang diperolehi.

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LIST OF SYMBOLS

R_a	average surface roughness value
f	feed rate
v	Cutting speed in m/min or mm/min
N	Spindle speed in RPM
MRR	Material Removal Rate

LIST OF ABBREVIATIONS

Al	Aluminium
ANOVA	Analysis of Variance
As	Arsenic
B	Boron
Bi	Bismuth
BUE	Built-up edge
C	Carbon
Ca	Calcium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Ni	Nickel
Nb	Niobium
Mn	Manganese
Mo	Molybdenum
P	Phosporus
Pb	Lead
RPM	Revolution per Minute
RSM	Response Surface Methodology
S	Sulphur

Si	Silicon
Sn	Tin
V	Vanadium
Zr	Zirconium

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Carbon steels are alloys of iron and carbon with carbon as the major strengthening agent. The handbook of the U.S. steel industry published by the Iron and Steel Society, describes carbon steels as steels with up to 2% carbon and only residual amounts of other elements except those added for deoxidation (e.g. aluminium), with silicon limited to 0.6%, copper to 0.6% and manganese to 1.65%. Other terms applied to this class of steels are plain carbon steels, mild steels, low carbon steels and straight-carbon steels (Budinski, 2005).

The family of carbon steels (it is a large family, with nearly 50 standard grades) is usually sub-divided into four sub- families: the low-carbon steels, which contain no more than 0.30% carbon; the medium-carbon steels, which range from 0.30 to 0.45% carbon; the high-carbon steels, from 0.45 to 0.75% carbon; and the very-high-carbon steels, which range up to 1.50% carbon (eSab.com, 2009). These families of carbon steels make up the largest fraction of steel production. They are available in almost all product forms: sheet, strip, bar, plates, tube, pipe, wire. They are used for high-production items such as automobiles and appliances, but they also play a major role in machine design for base plates, housings, chutes, structural members and countless machine components (eSab.com, 2009).

Low carbon steels generally contain less than 0.30% carbon. The low carbon material is relatively soft and weak, but has outstanding ductility and toughness. In addition, it is machinable, weldable, and is relatively inexpensive to produce. The low-carbon steels, which also termed as “mild” steels, are more widely used than the grades with higher carbon content. They are quite ductile, can be machined or formed with relative ease, and can be welded by any process (Myers, 2009).

The machinability of carbon steel is affected by various factors such as composition, microstructure and strength level of steel, the feeds, speeds, depth of cut and the choice of cutting fluid and cutting tool materials. These machining characteristics in turn affect the cost of producing steel parts particularly when the cost of machining represents a major part of the cost of the finished part.

The term machinability is used to indicate the ease or difficulty with which a material can be machined to the size, shape and desired surface finish. The term machinability index and machinability rating are used as qualitative and relative measures of the machinability of steel under specified conditions. Historically, machinability judgements have been based on tool life, cutting speed, power consumption, quality of surface finish and feeds resulting from a constant thrust force.

1.2 PROBLEM STATEMENT

The primary constituents in steels are iron and carbon. However there are many different types of steel that serve a multitude of applications. Low carbon steel which generally contains less than 0.3% of carbon is widely used for industrial fabrication and construction (Myers, 2009). Low carbon steel are often employed in high volume screw machine parts applications such as shafts, spindles, pins, rods and wide variety of component parts. Although low carbon steel provides various advantages such as ease of formability, machinability and weldability but it is unimpressive in terms of strength and hardness.

The ability to make low carbon steels hard enough to be the tools that shape all other materials is important. Low carbon steels ability to be hardened in heat treatment is produced through quenching process. Heat treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape (eFunda, 2009).

Since low carbon steel has wide applications especially in industries for fabrication and construction, it is very important to study on how to improve its mechanical properties through various methodologies. Among the method which can be conducted is by quenching the low carbon steel into quenching medium such as oil and analyze its microstructure as well as its machinability to see if quenching affects machinability of low carbon steel.

1.3 PROJECT OBJECTIVES

i. To determine effect of cutting speed and depth of cut on surface roughness of oil-quenched mild steel.

ii. To investigate the effect of oil-quenched mild steel on hardness.

iii. To investigate the chemical composition of oil-quenched mild steel.

iv. To predict the surface roughness of oil-quenched mild steel by developing first and second order mathematical model using Response Surface Methodology.

v. To determine significant parameter which affect surface roughness of oil- quenched mild steel.

1.4 SCOPES OF PROJECT

i. Mild steel containing not more than 0.30% carbon will be used in this study.

ii. Oil will be used as quenching medium for heat treated mild steel.

iii. Machining parameters such as cutting speed and depth of cut of oil-quenched mild steel will be studied using conventional lathe machine.

iv. Utilization of Digital Rockwell Hardness tester to compare the hardness of ordinary and oil-quenched mild steel.

vi. Perthometer will be used as a surface roughness tester to analyze the surface of mild steel workpiece after machining process is performed.

vii. Utilization of Response Surface Methodology (RSM) and Analysis of Variance (ANOVA) to analyze experimental data obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related to machinability of low carbon steel which use oil as the quenching medium. A review on other relevant research studies is also provided. The importance of heat treated steels and applications of carbon steels particularly low carbon steels at several sector will be discussed.

2.2 INTRODUCTION TO STEEL

The first production of steel was in China and Japan in about 600 to 800 A.D. Steel is the most common engineering material used for a wide range of applications from utensils to machine parts to cutting tools (Nagendra and Mittal, 2003). Steel is an alloy of iron and carbon but it may contain other alloying elements such as manganese, silicon, chromium and copper.

2.3 CLASSIFICATION OF STEEL

Standard carbon steels are listed by numbers assigned by the American Iron and Steel Institute (AISI) and the Society of Automotive Engineers (SAE). The only difference between AISI and SAE numbers is that AISI numbers may include a letter indicating the method of making that steel-B for Bessemer, C for crucible and etcetera.

The numbers indicate the type of iron, the amount of carbon present, and the presence of major alloying elements (Meyers and Slattery, 2001). The first two numbers indicate the type of steel; the next two indicate its carbon content. The carbon content range is from less than one-tenth of one percent (0.10 %) to one percent (1.00 %). AISI and SAE 1045 steel for example indicates a carbon steel (the 10) with 0.45% carbon content (the 45). As the carbon content increases, so does the difficulty in machining (Meyers and Slattery, 2001).

Steel is classified on the basis of the percentage of carbon present into three groups which consist of:

i. Low carbon steel or mild steel (0.05 to 0.3 %C)
ii. Medium carbon steel (0.3 to 0.6 %C)
iii. High carbon steel (0.6 to 1.5 %)

2.4 APPLICATIONS OF CARBON STEELS

Table 2.1 gives typical applications of carbon steels depending on its carbon content.

Table 2.1: Typical applications of carbon steels

Common Name	**Carbon content (%)**	**Applications**
Low carbon	0.05-0.125 0.15-0.3	Thin sheets, tubes, wire. Structural sections, boilers, general purpose applications.
Medium carbon	0.3-0.5 0.5-0.6	Agriculture implements, wheel axles, tube and wires. Hammers and other hand tools, wheel rims, spring.

Table 2.1: Continued

Common Name	**Carbon content (%)**	**Applications**
High carbon	0.7-0.9	Cutting blades, chisels, dies.
	0.9-1.1	Wood working tools, dies, chisels, cutting tools.
	1.1-1.5	Metal cutting tools, razor blades, files, drills, gauges.

Source: Nagendra and Mittal (2007)

One important feature of steel is that its properties can be easily controlled and manipulated. It can be made softer and ductile or it can be made more hard and brittle, using simple processes depending on the end use for which steel is required. These processes are known as heat treatment processes.

2.5 TESTING OF MATERIALS

The study of mechanical properties is essential for selecting the material and manufacturing process. To study the mechanical properties of a material, tests have been developed to measure properties such as strength, ductility and hardness. The tests can be classified into two categories which are destructive tests and non-destructive tests (Asoke, 2005).

Destructive tests determine the limit at which a particular material is destroyed. This limit is known as the fracture limit. The various type of destructive tests are tensile test, compression test, bending test, hardness test, impact test, fatigue test and creep test (Asoke, 2005).

2.5.1 Hardness Test

The hardness test measures the resistance of a material to penetration (Asoke, 2005). Hardness can be defined as the resistance of a material to wear and scratch (Asoke, 2005). Hardness of a material depends on the grain size, the yield strength, tensile strength and ductility. Various types of hardness test are Brinell hardness test, Vickers hardness test, Rockwell hardness test and shore scaleroscope hardness test.

2.5.1.1 Brinell Hardness Test

In this test, hardness is determined by applying a load up to 3000kg on ferrous metals for 10 seconds or for non-ferrous metals, a load up to 500 kg for 30 seconds (Kalpakjian and Schmid, 2006). The test uses an indenter which is a 10mm-diameter ball made of either high carbon steel or tungsten carbide (Kalpakjian and Schmid, 2006). After applying the load for a specific period, the load is gradually removed and indentation is measured using a traveling microscope.The syntax to calculate the Brinell Hardness Number (BHN) is (Kalpakjian and Schmid, 2006):

$$BHN = \frac{2F}{\pi D_b (D^b - \sqrt{D_b{}^2 - D_i{}^2)}} \tag{2.1}$$

where BHN is the Brinell Hardness Number, F is the indentation load, D_b is diameter of ball in mm and D_i is the diameter of indentation in mm.

The smaller the indentation, the harder the material (Asoke, 2005). High carbon steel indenters are used for materials which are less hard. If BHN hardness is more than 500, a tungsten carbide indenter is used (Asoke, 2005). According to Asoke, the approximate BHN value for mild steel is 130 BHN.

2.5.1.2 Rockwell Hardness Test

Rockwell hardness values are expressed as a combination of a hardness number and a scale symbol representing the indenter and the minor and major loads. The hardness number is expressed by the symbol HR and the scale designation.

There are 30 different scales. The majority of applications are covered by the Rockwell C and B scales for testing steel, brass, and other metals. However, the increasing use of materials other than steel and brass as well as thin materials necessitates a basic knowledge of the factors that must be considered in choosing the correct scale to ensure an accurate Rockwell test. The choice is not only between the regular hardness test and superficial hardness test, with three different major loads for each, but also between the diamond indenter and the 1/16, 1/8, 1/4 and 1/2 in. diameter steel ball indenters.

If no specification exists or there is doubt about the suitability of the specified scale, an analysis should be made of the following factors that control scale selection:

- Type of material
- Specimen thickness
- Test location
- Scale limitations

Table 2.2 shows various Rockwell scales, loads applied and types of indenter used for different types of materials.

Table 2.2: Various Rockwell scales

Scale	Abbreviation	Load	Indenter	Use
A	HRA	60 kgf	120 ° diamond cone	Tungsten carbide
B	HRB	100 kgf	1/16 in diameter steel sphere	Softer materials, e.g. Cu alloys, Al alloys, mild steel
C	HRC	150 kgf	120 ° diamond cone	Hard materials, e.g. steels, hard cast irons, alloy steels
D	HRD	100 kgf	120 ° diamond cone	Medium case hardened materials

2.6 HEAT TREATMENT OF CARBON STEEL

Heat treatment is necessary to obtain the required mechanical and physical properties for a material to make it suitable for fabrication. Heat treatment is applied to steel to impart specific mechanical properties such as increased strength, toughness and wear resistance (Nagendra and Mittal, 2003). Heat treatment is also resorted to relieve internal stresses and to soften hard metals in order to improve machinability (Nagendra and Mittal, 2003).

Heat treatment of steel may be defined as series of operations involving the heating and cooling of steel in the solid state and in controlled atmosphere.

The theory of heat treatment is based on the changes that occur in the microstructure of steel at specific temperature. Steel is heat-treated for one of the following objectives (Asoke, 2005):

i. Softening heat treatments
ii. Hardening heat treatments

Hardening heat treatments can be studied based on the type of quenching used, the type of heating process used, and the source of heating. The various types of hardening are direct hardening, diffusion hardening and selective hardening.

Generally carbon adds hardness to the material which improves wearability. For carbon contents above 0.30%, the product may be direct-hardened. Carbon steel beneath this level typically require carburizing when heat treated in which carbon molecules are introduced so that a hardened “skin” is able to be developed on the surface or “case” (Huyett, 2004).

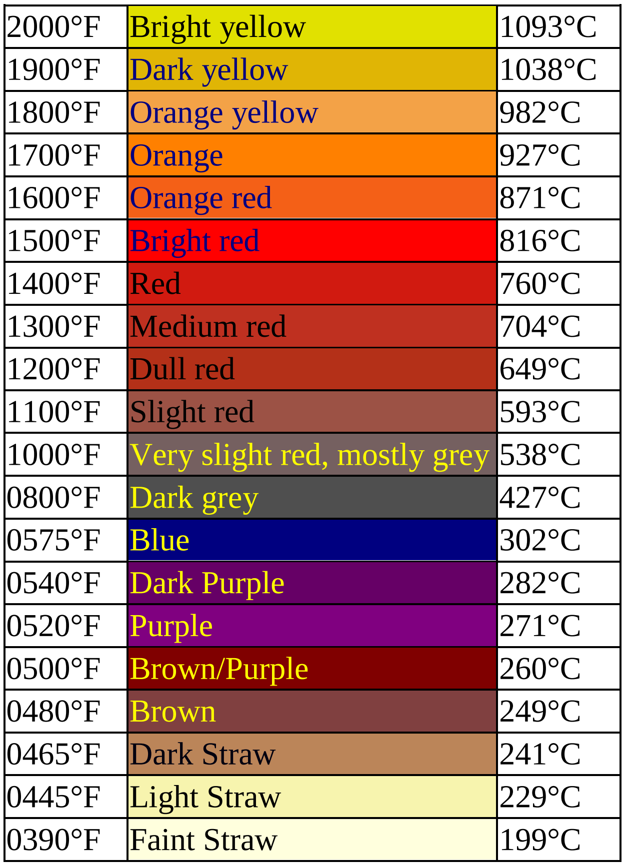
2.6.1. Direct Hardening

Carbon steel is hardened by heating the metal above the critical temperature and then rapidly cooling it by immersing it in a quenching medium. This treatment will change the crystal structure of the metal therefore inducing hardness in the metal. The change in structure depends on the carbon content or the alloy composition of the steel.

To obtain maximum hardness, the temperature of the steel should be raised to the upper critical point. Steel that has been heated to its upper critical point will harden completely if rapidly quenched (Asoke, 2005). At authentic level which is called as critical point, martensite is formed (Asoke, 2005). Hardening of steel requires a change in structure from the body-centered cubic structure that commonly exist at room temperature to face-centered cubic structure feasible in the austenitic region (Asoke, 2005). If steel is heated and suddenly quenched, very hard and brittle structure with increased hardness is formed (Asoke, 2005).

2.6.2 Steel Color versus Temperature

Figure 2.1 shows steel colors at various different temperatures ranging from 199°C to 1093°C.



2000°F	Bright yellow	1093°C
1900°F	Dark yellow	1038°C
1800°F	Orange yellow	982°C
1700°F	Orange	927°C
1600°F	Orange red	871°C
1500°F	Bright red	816°C
1400°F	Red	760°C
1300°F	Medium red	704°C
1200°F	Dull red	649°C
1100°F	Slight red	593°C
1000°F	Very slight red, mostly grey	538°C
0800°F	Dark grey	427°C
0575°F	Blue	302°C
0540°F	Dark Purple	282°C
0520°F	Purple	271°C
0500°F	Brown/Purple	260°C
0480°F	Brown	249°C
0465°F	Dark Straw	241°C
0445°F	Light Straw	229°C
0390°F	Faint Straw	199°C

Figure 2.1: Steel color versus temperature

Source: Berglund (2006)

Steel exhibits different colors depending on temperature. Temperatures above 800 °F (427 °C) produce incandescent colors; the atoms in the steel are so energized by heat that they give off photons. Temperatures below 800 °F (427 °C) produce oxidation colors. As the steel is heated, an oxide layer forms on the surface; its thickness (and thus the interference color as light is reflected) is a function of temperature. These colors may be used in tempering tool steel.

2.7 IRON-CARBON (Fe-C) EQUILIBRIUM

The binary iron-carbon system is the basis of all ferrous engineering materials or alloys of iron-steel and iron. When 2.0 % or less of carbon is alloyed with molten iron, steel is formed on solidification of the mixture while iron-carbon alloys containing carbon over 2 % to 6.7 % forms cast iron (Nagendra and Mittal, 2003). Beyond 6.7 % carbon, the iron-carbon compound formed is not a metal and is of no commercial importance (Nagendra and Mittal, 2003). The iron-carbon equilibrium diagram in Figure 2.2 is a map showing the ranges of alloy compositions, temperatures within which various phases are stable and the boundaries at which phase changes occur.

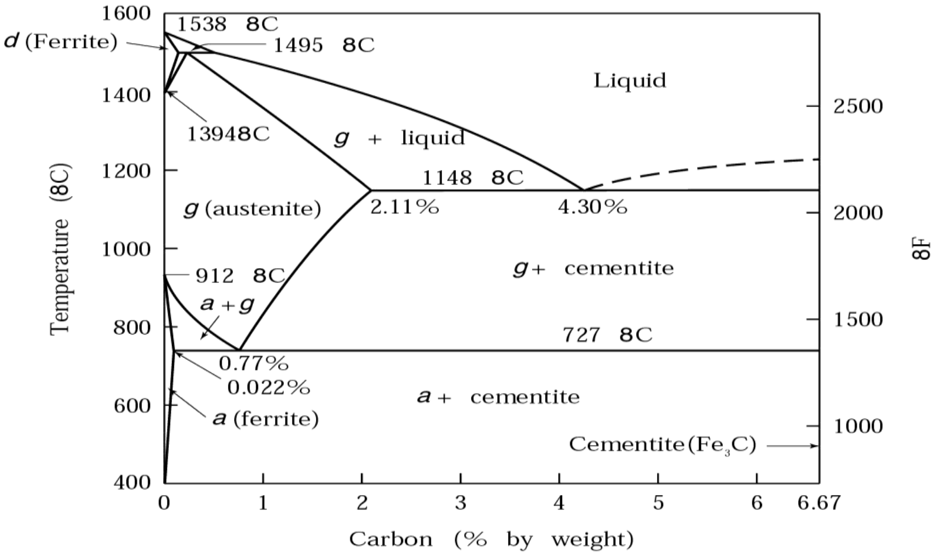


Figure 2.2: The iron-carbon phase diagram

Source: Smith and Hashemi (2006)

2.8 COOLING OF PLAIN CARBON STEEL

By changing the manner in which carbon steels are heated and cooled, different combinations of mechanical properties for steels can be obtained. At ordinary temperatures, the carbon in steel exists in the form of iron carbide scattered throughout the iron mixture known as ferrite (Asoke, 2005). The number, size and distribution of these ferrite particles determine the hardness of the steel (Asoke, 2005).

2.8.1 Formation of Fe-C by Rapid Quenching

If a sample of plain-carbon steel in austenitic conditions are rapidly cooled to room temperature by quenching it in water, its structure will be changed from austenite to martensite (Smith and Hashemi, 2006). Martensite in plain carbon steel is a metastable phase consisting of a supersaturated interstitial solid solution of carbon in body-centered cubic iron or body-centered tetragonal iron (Smith and Hashemi, 2006). According to Smith and Hashemi, the temperature upon cooling, at which the austenite-to-martensite transformation starts is called the martensite start, M_s, temperature, and the temperature at which the transformation finishes is called martensite finish, M_f, temperature. As the weight percent carbon increases, the M_s temperature for Fe-C alloys decreases.

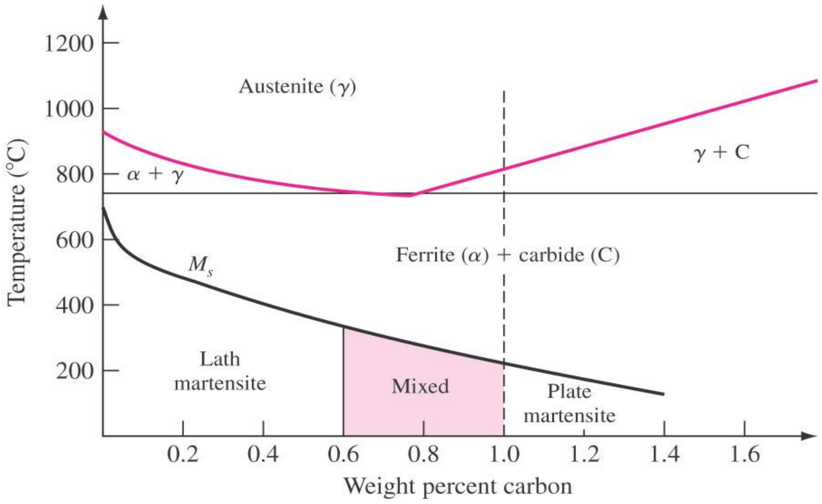


Figure 2.3: Effect of carbon content on the martensite-transformation start temperature for iron-carbon alloys

Source: Smith and Hashemi (2006)

2.8.2 Continuous-Cooling Transformation Diagram for Eutectoid Plain-Carbon Steel

In industrial heat-treating operations, most steels are not isothermally transformed at a temperature above the martensite start temperature but are continuously cooled from the austenitic temperature to room temperature (Smith and Hashemi, 2006). In continuously cooling plain-carbon steel, the transformation from austenite to pearlite occurs over a range of temperatures rather than at a single isothermal temperature (Smith and Hashemi, 2006). Figure 2.4 shows a continuous-cooling transformation (CCT) diagram for eutectoid plain-carbon steel.

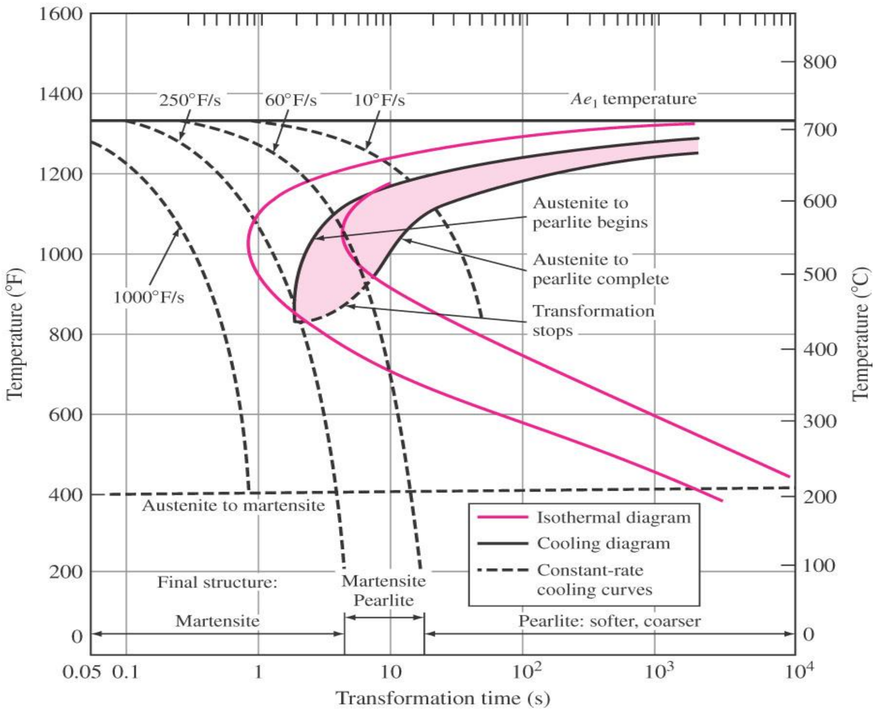


Figure 2.4: Continuous-cooling diagram for a plain-carbon eutectoid steel

Source: Smith and Hashemi (2006)

Figure 2.5 shows different rates of cooling for thin samples of eutectoid plain carbon steels cooled continuously from the austenitic region to room temperature. Cooling curve A represent very slow cooling, obtained by shutting off the power of an electric furnace and allowing the steel to cool as the furnace cools and the microstructure in this case would be coarse pearlite (Smith and Hashemi, 2006). Cooling curve B represents more rapid cooling and it can be obtained by removing an austenitized steel from a furnace and allowing the steel to cool in still air (Smith and Hashem, 2006). Therefore a fine pearlite microstructure will be formed. Cooling curve C starts with the formation of pearlite, but there is insufficient time to complete the austenite to pearlite transformation so the remaining austenite that does not form to pearlite at the upper temperature will transform to martensite at lower temperature starting at about 220 degree Celcius (Smith and Hashemi, 2006).

This type of transformation is called split transformation. The microstructure thus will consist a mixture of pearlite and martensite (Smith and Hashemi, 2006). Cooling at a rate faster than curve E which is called the critical cooling rate will cause a fully hardened martensite to be produced (Smith and Hashemi, 2006). Figure 2.5 shows different rates of cooling for thin samples of eutectoid plain carbon steels cooled continuously from the austenitic region to room temperature.

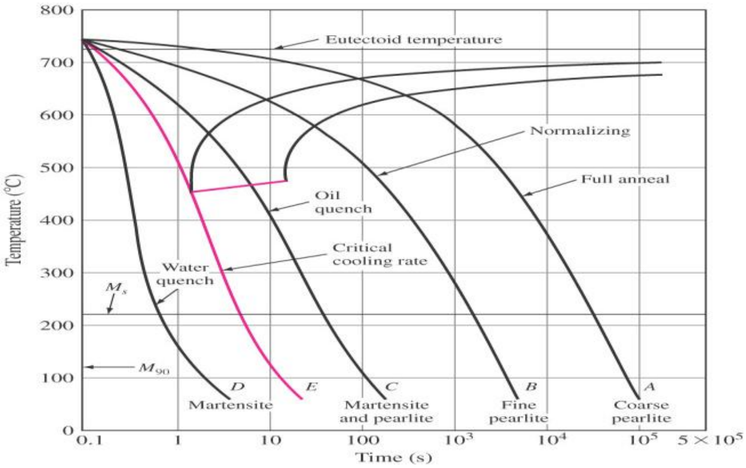


Figure 2.5: Variation in microstructure of eutectoid plain-carbon steel by continuously cooling at different rates

Source: Smith and Hashemi (2006)

2.9 QUENCHING MEDIUM

When hot steel is quenched, most of the cooling happens at the surface, resulting in the hardening of the surface. Cooling then propagates towards the core of the material. Table 2.3 shows description of different types of quenching media used.

Table 2.3: Types of quenching media and description

Quenching media	**Description**
Water	Water is a good rapid quenching medium. However water is corrosive for steel and the rapid cooling can sometimes cause distortion or cracking of steel.
Salt water	Salt water is a better rapid quench medium than water because the bubbles are broken easily and they allow for rapid cooling of the steel object. However, salt water is even more corrosive than plain water and must be rinsed off immediately.
Oil	Oil is used when a slower cooling rate is required because oil has a high boiling point, martensite formation is slow and this reduces the likehood of cracking.
Polymer quench	This produces a cooling rate that is less than that of water but more than that of oil. The cooling rate can be altered by varying the components in the quench mixture. Polymer quenches can produce far more predictable results and reduced corrosion as compared to water quenches.

Source: Timings (1998)

Oil is used as quenching medium as it result in even cooling that imparts good hardness and toughness to material (Meyers and Slattery, 2001). All types of oil are used but mineral oil is the most common because of its low cost and the fact that does not have objectionable odour. The temperature of the oil should ideally be about 125 ^{o}F (Meyers and Slattery, 2001).

2.10 MACHINABILITY

Machinability of a material can be defined as the property of the material which governs the ease or difficulty with which it can be machined under given set of conditions. Machinability criteria depend upon many factors such as the machine tool employed, cutting tool characteristics, work material and cutting conditions. The general criteria adopted for evaluating machinability are tool life or tool wear rate, the cutting force or surface finish generated. Other parameters that need consideration are torque and thrust during machining, penetration rate, and ease of chip removal and temperature of cutting tool. However for practical considerations, the measures most adopted are restricted to tool life or tool wear rate, cutting force and surface finish.
Many variables such as the choice of the machine, the choice of cutting tool, cutting conditions and material of workpiece have a marked influence on the machinability. The higher the carbon content, the more difficult carbon steel is to be machined (Huyett, 2004).

2.10.1 Lathes and Lathe Operations

A lathe removes the material by rotating the workpiece against a single point cutting tool (Bawa, 2004). Lathes are classified in many ways with respect to size, design, method of drive and purpose.

Operations performed by a lathe machine are turning, facing, drilling, reaming, milling, grinding, boring, counter boring, knurling, threading, spring winding, spinning and roll forming (Bawa, 2004).

Turning is the process of rotating or turning a workpiece against a cutting tool to impart a new shape (Meyers and Slattery, 2001). Machines performing this operation may bear different names (engine lathe, chucker, automatic screw machine, turret lathe, turning centers) but all are lathes (Meyers and Slattery, 2001). Turning involves various processes of removal of material from the outer surface of a workpiece to obtain finished surfaces, when the job rotates against a single point cutting tool. The surfaces may be of uniform diameter, stepped, tapered or contoured (Bawa, 2004).

When turned, low carbon steels produce long chips, which will form built-up edge on an indexable insert if a chip breaker does not create a sufficient shear angle to curl the chip away from the insert rake face (Isakov, 2007). Low cutting speed is another cause of built-up edge which acts as an extension of the cutting tool, changing part dimensions and imparting rough surface finishes (Isakov, 2007). The appropriate cutting speed depends on depth of cut, feed rate, cutting tool material and hardness of the workpiece (Isakov, 2007). Low carbon steels are subjected to slightly different cutting speeds and therefore are divided in two groups (Isakov, 2007).

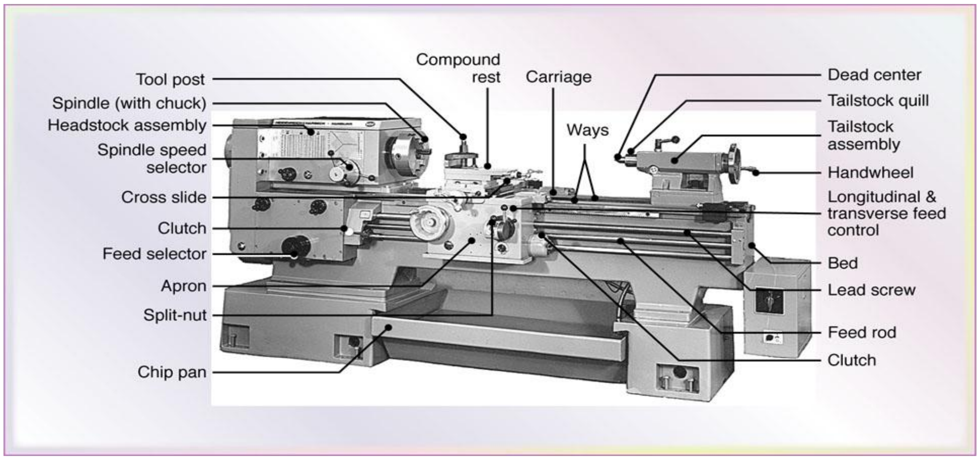


Figure 2.6: General view of a typical lathe showing various components

Source: Courtesy of Heidenreich & Harbeck

2.10.2 Cutting Speeds

The cutting speed or rate is the surface speed at which the workpiece passes the cutter. It is expressed in m/min. The cutting speed is constant when the spindle speed and part diameter remains the same (Asoke, 2005). Mathematically,

$$v = \frac{\pi d N}{1000} \tag{2.2}$$

Where v is the cutting speed in m/min, D=diameter of the workpiece in mm, N=number of revolutions per minute.

2.10.3 Feed

Feed refers to the amount of tool advancement per revolution of the job parallel to the surface of the job to be machined (Bawa, 2004). The feed of a tool depends upon many factors such as depth of cut, surface finished required, characteristics of the tool and workpiece and the rigidity of the machine tool (Bawa, 2004).

$$\text{Feed rate} = \text{Feed per tooth} \times \text{Number of teeth} \times \text{RPM} \tag{2.3}$$

2.10.4 Depth of Cut

The depth of cut d is the perpendicular distance measured from the machined surface to the uncut surface of the workpiece. For turning operations, the depth of cut is expressed as (Nagendra and Mittal, 2003):

$$\text{Depth of cut} = \frac{D_1 - D_2}{2}\ \text{mm} \tag{2.4}$$

Where D_1 is the original diameter of workpiece and D_2 is the final diameter of workpiece in mm. In turning operation if the depth of cut is 1 mm, then the diameter will be reduced by 2 mm.

2.10.5 Material Removal Rate

The material removal rate is the volume of material removed per unit time (Nagendra and Mittal, 2003). Volume of material removed is a function of speed, feed and depth of cut. Higher the values of these more will be the material removal rate.

If *D* represents the original diameter of the workpiece in mm, *d* represents the depth of cut in mm, f represents the feed in mm/rev, then material removed per revolution is the volume of chip whose length is πD and whose cross section area is *d* x *f*. The material removal rate formula in mm^3/min is (Nagendra and Mittal, 2003):

$$MRR = \pi \times D \times d \times f \times N \quad (2.5)$$

2.10.6 Selection of Cutting Tool Materials

Cutting tool materials must have the following properties:

i. Sufficient strength to resist the cutting forces.
ii. Sufficient hardness to resist wear and give an adequate life between regrinds.
iii. The ability to retain its hardness at the high temperature generated at the tool point when cutting.

2.11 CONCLUSION

Knowledge on material such as carbon steels are important in order to be able to use them in ways that would ease life of society. Since low carbon steel has wide applications therefore it is very important to study on how to improve its mechanical properties through various methodologies. Besides that, it is also important to study the effect of machinability parameters on the surface finish of carbon steels.

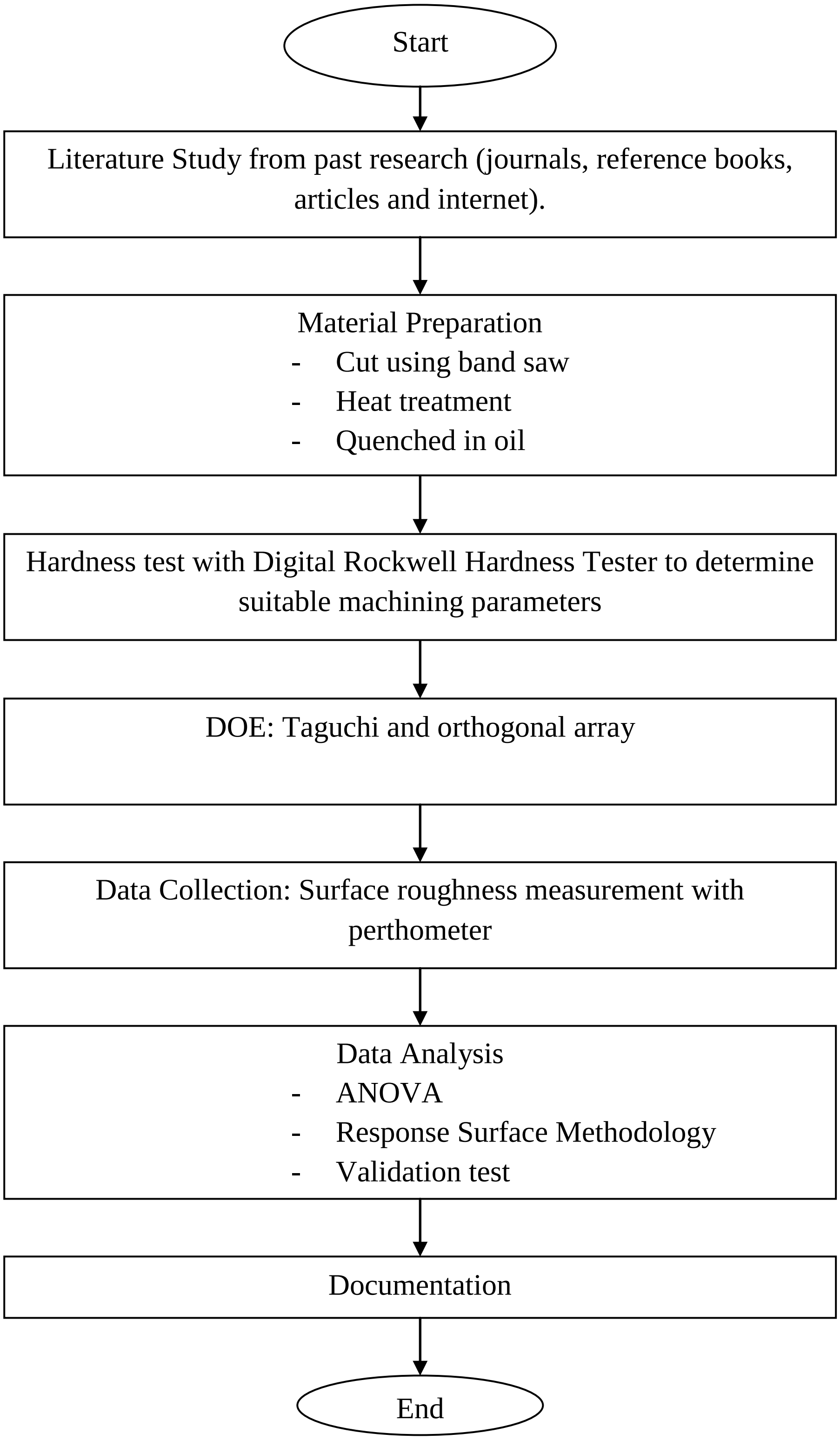
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the method and experimental procedures conducted throughout the project research will be discussed. The methodology conducted throughout the entire project was summarized and illustrated in a flow chart for better understanding on the flow of the entire project research. A systematic plan is very important before any project begin. First and foremost was to identify problem arising which lead to the research of this project, set objectives and scopes of study and ensure that the research carried out is significant to the study. Next, is the literature study and research. Related useful information was gathered from past research such as journals, reference books, articles and the internet. Next, was material preparation which includes heat treating and quenching of mild steel in oil. The hardness of quenched mild steel was then tested with Digital Rockwell Hardness Tester to determine the suitable machining parameter for turning operation. Subsequently, Taguchi and orthogonal array design of experiment was used to determine the number of experimental runs. Finally, data obtained from experimental runs were analyzed using statistical software, Minitab to determine the significant parameter affecting surface roughness. Predictions of surface roughness were also made with Response Surface Methodology (RSM) first- and second-order model. The percentage deviation between experimental and predicted surface roughness were observed and compared. Effect of cutting speed and depth of cut on surface roughness were discussed and conclusions were made.

3.2 FLOW CHART



3.3 MATERIAL PREPARATION

Mild steel was decided and ordered from manufacturer. The chemical composition particularly the percentage of carbon in the mild steel was checked using mass spectrometer. The long mild steel bar was then cut using band saw machine into three 40 mm in diameter and 150 mm in length cylindrical bar. Figure 3.1 presents an illustration of band saw machine used and Figure 3.2 shows cutting process using band saw machine.

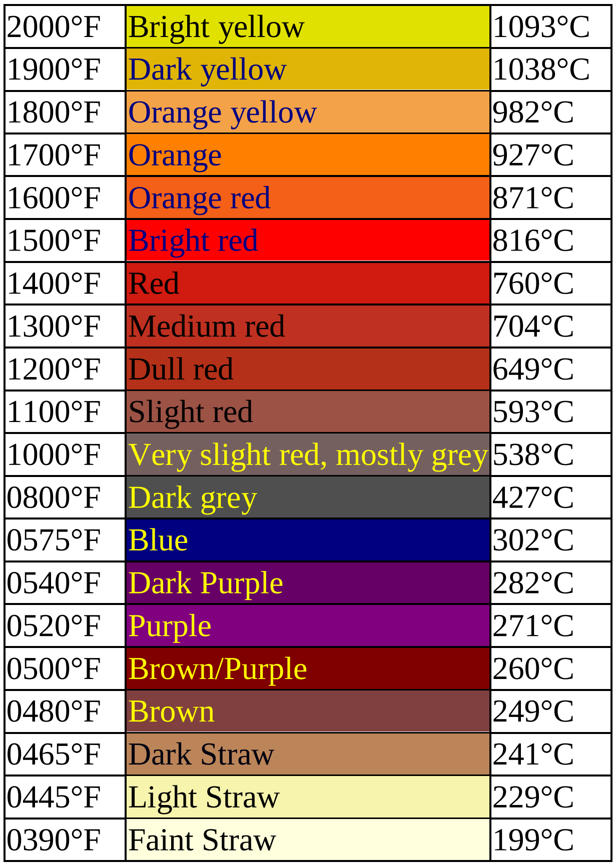
Figure 3.1: Band Saw Machine

Figure 3.2: Cutting using band saw machine

3.3.1 Heat Treatment

Mild steel was heated to austenitic temperature using an appropriate heat source (heat from welding machine). The steel was heated until it became orange red or orange which indicate austenitic temperature (above 900 ^{o}C). The color of the steel can be used as indicator which indicates the temperature of steel. This is because steel exhibits different colors depending on temperature. The color of steel temperature versus temperature is shown in Table 3.1.

Table 3.1: Steel color versus temperature



2000°F	Bright yellow	1093°C
1900°F	Dark yellow	1038°C
1800°F	Orange yellow	982°C
1700°F	Orange	927°C
1600°F	Orange red	871°C
1500°F	Bright red	816°C
1400°F	Red	760°C
1300°F	Medium red	704°C
1200°F	Dull red	649°C
1100°F	Slight red	593°C
1000°F	Very slight red, mostly grey	538°C
0800°F	Dark grey	427°C
0575°F	Blue	302°C
0540°F	Dark Purple	282°C
0520°F	Purple	271°C
0500°F	Brown/Purple	260°C
0480°F	Brown	249°C
0465°F	Dark Straw	241°C
0445°F	Light Straw	229°C
0390°F	Faint Straw	199°C

Source: Berglund (2006)

Figure 3.3 presents an illustration of heating mild steel with welding heat source.

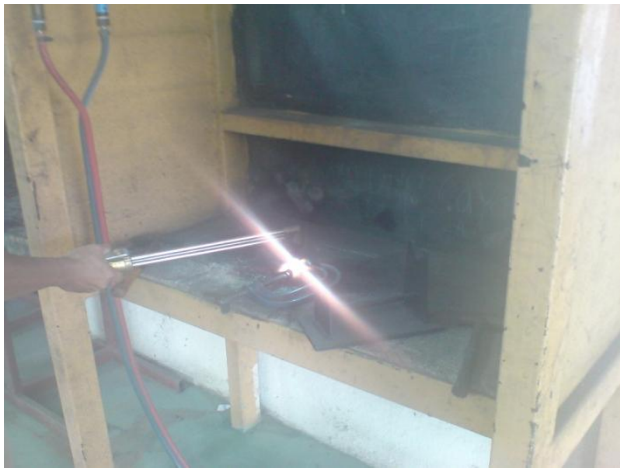


Figure 3.3: Heating mild steel with welding heat source

3.3.2 Oil-Quenching

Quenching refers to the process of rapidly cooling metal parts from austenizing or solution treating temperature, typically from within the range of 815 ^{o}C to 870 ^{o}C (1500 to 1600 ^{o}F) for steel. The mild steel was then removed from the heat source and immediately quenched in oil. Duckhams motor oil was used as a quenching medium to quench the heat treated mild steel. The red-hot steel was plunged vertically into the oil to avoid warping. The steel was then held in the oil until the oil stopped bubbling. The steel is left in the oil for approximately 1 hour. As soon as the steel is cool enough to be handled, it was wiped off and test for its hardness with Rockwell hardness testing machine. Figure 3.4 presents an illustration of heat treated mild steel quenched in motor oil and Figure 3.5 shows an illustration of the quenched mild steel which was held until the oil stop bubbling. Figure 3.6 presents an illustration of oil-quenched mild steels.

Figure 3.4: Heat treated mild steel quenched in motor oil

Figure 3.5: The steel was held until oil stop bubbling

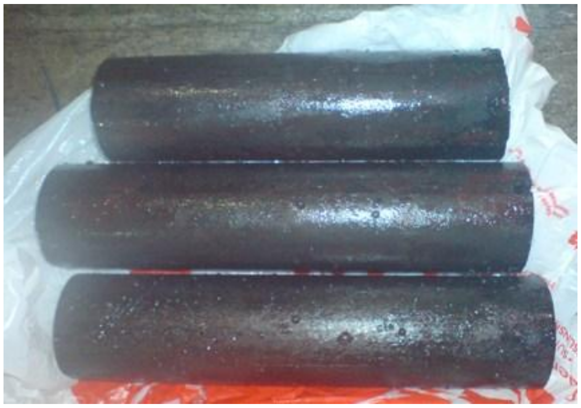


Figure 3.6: Oil-quenched mild steels

3.4 ROCKWELL HARDNESS TEST

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. The Rockwell hardness test is a hardness measurement based on the net increase in depth of impression as a load is applied. Hardness numbers has no units and are commonly given in term of scales. The higher the number in each of the scales means the harder the material. To test the hardness of mild steel, HRB scale and 1/16 in diameter steel sphere was used. The test procedures for Rockwell hardness test are as follows:

i. The sample of oil-quenched mild steel must be cleared well to remove any dust or oxidation layer as this may affect the accuracy of the reading.
ii. The machine is turned on.
iii. The sample is placed on the sample base.
iv. The wheel is rotated slowly in anti-clockwise direction until the sample get near to the penetrator.
v. Keep rotating until the screen on the machine gets filled by the black shadow and the machine generates a sound (beep).
vi. Wait until the value of hardness is shown on the screen.
vii. The wheel is then rotated in clock-wise direction to free the sample.

viii. The sample is tested again but in different position and the steps are repeated from iv. to vii. to get the second reading and third reading.

Figure 3.7 presents an illustration of Matsuzawa digital Rockwell hardness tester used.

Figure 3.7: Digital Rockwell hardness tester

3.5 MACHINING PARAMETERS

3.5.1 Constant Parameters

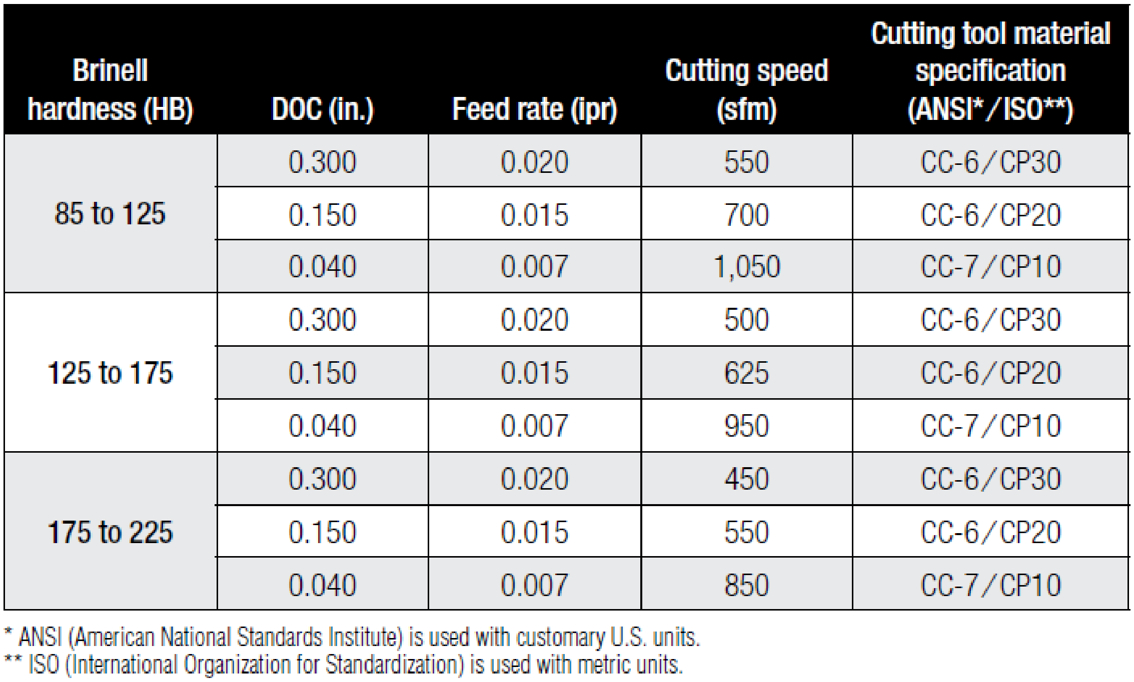
Cutting process involves various factors that would influence the surface finish of material. But in this study, the main parameters concerned were cutting speed and depth of cut. Hence, the cutting speed and depth of cut will be the variables while other parameters remained constant throughout the experiments. The suggested constant parameters are as shown:

i. Feed rate = 0.15 mm/rev
ii. Coolant = air
iii. Cutting tool = CVD coated carbide
iv. Workpiece diameter = 40 mm

3.5.2 Selection of Cutting Speed

Table 3.2 below shows the suggested machining parameters for mild steel based on Brinell Hardness Number (HB). After hardness of oil-quenched mild steel is determined, the appropriate cutting speed could be decided from Table 3.2.

Table 3.2: Parameters for AISI 1015, 1020, 1023, 1025 and 1026 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	550	CC-6/CP30
	0.150	0.015	700	CC-6/CP20
	0.040	0.007	1,050	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

* ANSI (American National Standards Institute) is used with customary U.S. units.
** ISO (International Organization for Standardization) is used with metric units.

Source: Isakov, E (2007)

3.5.3 Selection of RPM and Depth of Cut

Table 3.3 shows the RPM and depth of cut selection from low level to high level.

Table 3.3: RPM and depth of cut selection from low level to high level

Machining Parameters	**Low level**	**Medium Level**	**High Level**
Feed rate (mm/rev)	0.15	0.15	0.15
Cutting speed (m/min)	61.57	101.79	175.93
Spindle speed (RPM)	490	810	1 400
Depth of cut	0.1	0.3	0.5

The selection of cutting speed were done after the hardness of oil-quenched mild steel were determined from Rockwell hardness test and it was found that the hardness of oil-quenched mild steel falls in the range of 125 to 175 HB. Therefore, by referring to Table 3.2, the cutting speeds to be used were determined. Table 3.3 shows the machining parameters to be used for experiment ranging from low level to high level.

3.6 DESIGN OF EXPERIMENT: TAGUCHI AND ORTHOGONAL ARRAY

In this study, the experiments set up were based on Taguchi design of experiment and orthogonal array. Taguchi’s orthogonal arrays are highly fractional orthogonal designs which can be used to estimate main effects by using only a few experimental runs. Designs are also available to investigate main effects for certain mixed level experiments where the factors included do not have the same number of levels.

In this study, three machining parameters which are cutting speed, depth of cut and feed rate were involved. But the feed rate is kept constant throughout the experimental runs. The depth of cut and cutting speed were the factors involved. For a two factor, five level experiment, Taguchi had specified L15 ($3^1.5^1$) orthogonal array for experimentation. The response obtained from experimental runs were recorded and further analyzed. The factors and levels involved for the experimental set-up are as below:

i. 3 levels with 1 factor of spindle speed = $3^1 = 3$
ii. 5 levels with 1 factor of depth of cut = $5^1 = 5$
iii. Multiply all the parameters = 3 × 5 = 15 sets of experiments

Table 3.4 shows the orthogonal array design table which consist of the combination of spindle speed and depth of cut for different levels.

Table 3.4: Orthogonal array design table

No.	Machining Parameters	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
1	Spindle speed	RPM	490	810	1 400	_	_
2	Depth of cut	mm	0.1	0.2	0.3	0.4	0.5

3.7 LATHE MACHINING

To study effect of machining parameters on oil-quenched mild steel, conventional lathe machine is used. Three oil-quenched mild steel bars with the dimension of 150mm in length and 40mm in diameter will be used. 15 sets of experiment were conducted by varying the depth of cut and spindle speed.

Machining parameters other than depth of cut and spindle speed were kept constant throughout the 15 sets of experiment. Figure 3.8 presents an illustration of conventional lathe machine used in this study.

Figure 3.8: Conventional lathe machine

3.7.1 Selection of Cutting Tool Material

To select a suitable cutting tool, it must have sufficient strength to resist cutting forces, sufficient hardness to resist wear and give adequate life between regrinds. Besides that, cutting tool selected must have the ability to retain its hardness at the high temperature generated at the tool point when cutting. In this study, CVD coated carbide will be used as cutting tool throughout the machining process.

3.8 DATA ANALYSIS

3.8.1 Surface Roughness Measurement

Surface roughness test is performed after lathe machining process to determine effect of machining parameters on surface roughness.

In this study, three mild steel bars, each with varying depth of cut and spindle speed were analyzed using surface roughness tester, perthometer which is available at the FKM Metrology lab. The perthometer provides an average roughness, Ra which corresponds to the mean peak to valley height over the entire profile. The steps to use perthometer are as follows:

i. The perthometer is switched on by pressing START button for approximately 2 seconds.
ii. Sample is placed on the platform.
iii. "Measuring Station" view is selected by pressing M button.
iv. The pick-up (stylus) is positioned approximately in the centre.
v. Measurement is started by pressing START button.
vi. For each sample, the measurement were repeated three times to get more accurate and persistent value of surface roughness.

Figure 3.9 presents an illustration of surface roughness tester used in this study.

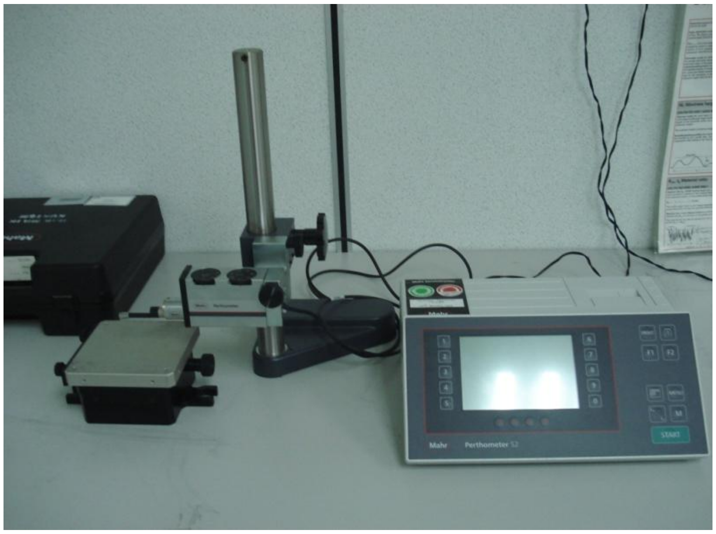


Figure 3.9: Surface roughness tester, perthometer

3.8.2 Prediction of Surface Roughness with Response Surface Methodology

Response Surface Methodology (RSM) is a collection of statistical and mathematical techniques useful for developing, improving and optimizing processes. The most extensive applications of RSM are in the industrial world, particularly in situations where several input variables potentially influence one performance measure of quality characteristic of the product or process. This performance measure is called the response. RSM is utilized to create an efficient analytical model for surface roughness in terms of cutting parameters. In this study, the surface roughness model in the turning of oil-quenched mild steel was developed in terms of spindle speed and depth of cut using response surface methodology. After conducting 15 sets of experiments, the surface roughness readings were used to find the parameters appearing in the postulated first- and second-order model. In order to calculate these parameters, the least square method is used with the aid of Minitab software. The percentage deviation between experimental and predicted surface roughness were observed and compared between first- and second-order model.

3.8.3 Analysis of Variance (ANOVA)

By using Minitab, analysis of variance (ANOVA) for first- and second-order equation were used to observe values of surface roughness in order to determine the significant parameter that influence the surface roughness of oil-quenched mild steel. Through the utilization of ANOVA, the significant parameters that influence surface roughness values could be identified.

3.8.4 Validation Test with Polynomial Trend Line Equation

Validation test is conducted to validate experimental result and evaluate the optimum cutting speed for oil-quenched mild steel by using polynomial trend line equation to find surface roughness value with respect to three different spindle speed which are 490 RPM, 810 RPM and 1400 RPM. After surface roughness value is determined by substituting depth of cut value (only one is chosen and will be used throughout the equation), the result of surface roughness obtained are compared for three different types of spindle speed. The same validation test were also carried out to evaluate the optimum depth of cut for oil-quenched mild steel.

3.9 DETERMINATION OF OIL-QUENCHED MILD STEEL CHEMICAL COMPOSITION

3.9.1 Grinding Process

Before the specimens were tested for its chemical composition, grinding process were carried out to planarize and reduce the damage created by band saw cutting. Figure 3.10 presents an illustration of grinding machine used to grind the oil-quenched mild steels.

Figure 3.10: Grinding Machine

3.9.2 Chemical Composition Determination with Bench Top Arc / Spark Spectrometer

The Bench Top Arc / Spark Spectrometer was used to determine the chemical composition of oil-quenched mild steel. This compact desktop can easily determine the chemical composition of oil-quenched mild steels. Figure 3.11 presents an illustration of bench top arc / spark spectrometer. Figure 3.12 and 3.13 present an illustration of specimen position during spark and after spark.

Figure 3.11: Bench Top Arc / Spark Spectrometer

Figure 3.12: Specimen position during spark

Figure 3.13: After spark on specimen

3.10 MACHINABILITY PARAMETERS AND FORMULAS

The formula for cutting speed is

$$v = \frac{\pi d N}{1000} \tag{3.1}$$

Where v is the cutting speed in m/min, D=diameter of the workpiece in mm, N=number of revolutions per minute.

The formula for calculating spindle speed is

$$N = \frac{1000v}{\pi D} \tag{3.2}$$

Where N is the spindle speed in revolutions per minute, v is the cutting speed in m/min and D is the diameter of workpiece in mm.

The formula for calculating feed rate is

$$\text{Feed rate} = \text{Feed per tooth} \times \text{Number of teeth} \times \text{RPM} \tag{3.3}$$

For turning operations, the depth of cut is expressed as

$$\text{Depth of cut} = \frac{D_1 - D_2}{2}\ \text{mm} \tag{3.4}$$

Where D_1 is the original diameter of workpiece and D_2 is the final diameter of workpiece in mm. In turning operation if the depth of cut is 1mm, then the diameter will be reduced by 2mm.

The material removal rate formula in mm^3/min is

$$MRR = \pi \times D \times d \times f \times N \tag{3.5}$$

Where D represents the original diameter of the workpiece in mm, d represents the depth of cut in mm, f represents the feed in mm/rev, material removed per revolution is the volume of chip whose length is πD and whose cross section area is d x f.

The surface roughness formula is

$$Ra = \frac{f^2}{8R} \tag{3.6}$$

Where R_a is the surface roughness, f is the feed rate and R is the tool nose radius.

3.11 EXPECTED RESULTS

According to Boothroyd, surface roughness for a turned component is expected to be higher at lower cutting speed. Value of surface roughness is also expected to increase when the depth of cut is increased (Boothroyd, 2006). Besides that, surface roughness will be higher when the feed rate increases (Boothroyd, 2006). Hence, it is expected that combination of low depth of cut in this experiment which is 0.1mm and high spindle speed which is 1400 RPM will produce better surface finish thus lower surface roughness value.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, results obtained from experiments conducted will be presented in the form of table as well as graphical representation to provide a clearer picture on overall research for better understanding. Predictions of surface roughness were done using Response Surface Methodology (RSM) of first- and second-order model. Besides that, results obtained were analyzed using Analysis of Variance (ANOVA) and validation test were also conducted. Validation test were carried out to validate experimental result and evaluate the optimum depth of cut and cutting speed from polynomial trend line equation. ANOVA were used to observe the significant parameter that influences the machinability of oil-quenched mild steel.

4.2 RESULTS FOR SURFACE ROUGHNESS VALUES WITH RESPECT TO VARIATION IN DEPTH OF CUT AND CUTTING SPEED

The table below shows the result of surface roughness values obtained by varying the cutting speed (RPM) and depth of cuts. 15 set of experiments were carried out using three different speed (RPM = 490, 810 and 1400) and five different depth of cut values (0.1mm-0.5mm).

Table 4.1: Result for surface roughness values obtained with respect to changes in depth of cut and cutting speed

		Factors	**Result**			
No. of experiment	**Depth of Cut (mm)**	**Spindle speed (RPM)**	**Surface roughness, R_a (μm)**			
			1	**2**	**3**	**average**
1	0.1	490	7.718	8.171	7.730	7.873
2	0.2	490	7.962	7.869	8.092	7.974
3	0.3	490	9.024	7.878	7.716	8.189
4	0.4	490	9.168	8.891	8.787	8.947
5	0.5	490	10.23	8.678	8.353	9.087
6	0.1	810	5.988	6.483	6.364	6.278
7	0.2	810	6.856	6.857	6.858	6.857
8	0.3	810	6.763	7.985	7.954	7.567
9	0.4	810	9.967	8.078	8.074	8.706
10	0.5	810	9.491	9.424	7.864	8.926

Table 4.1: Continued

	Factors		Result			
No. of experiment	**Depth of Cut (mm)**	**Spindle speed (RPM)**	**Surface roughness, R_a (µm)**			
			1	**2**	**3**	**average**
11	0.1	1400	4.594	4.674	4.658	4.642
12	0.2	1400	5.157	4.915	5.168	5.080
13	0.3	1400	5.276	5.192	5.210	5.226
14	0.4	1400	5.839	5.240	5.120	5.400
15	0.5	1400	6.429	6.645	6.187	6.420

4.3 EFFECT OF CUTTING SPEED ON OIL-QUENCHED MILD STEEL FROM GRAPHICAL ANALYSIS

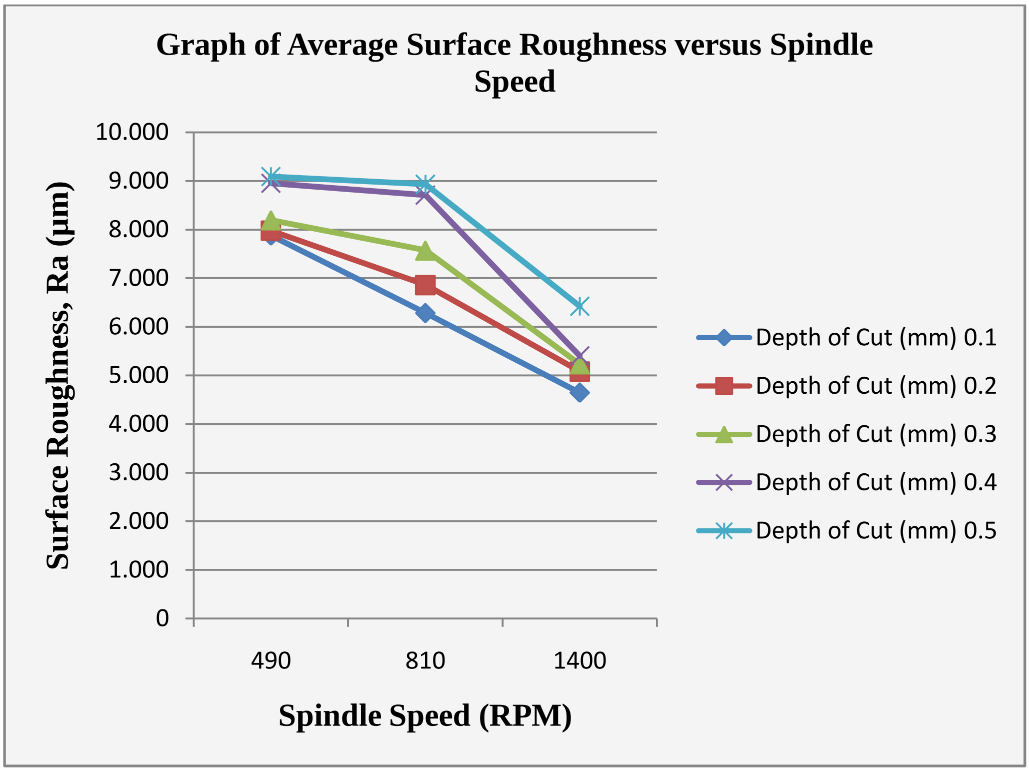


Figure 4.1: Average surface roughness vs. cutting speed with respect to various depth of cut values

Figure 4.1 presents graph of average surface roughness versus cutting speed with respect to various depth of cut values. From Figure 4.1 above, it shows that for a depth of cut of 0.1 mm, when the RPM used increased from 490 RPM, 810 RPM then to 1 400 RPM, the average surface roughness value had decreased significantly from 7.873 µm to 6.728 µm then to 4.642 µm. The same trends were observed for depth of cut of 0.2 mm, 0.3 mm, 0.4 mm and 0.5 mm with increasing RPM values. This shows that as the cutting speed increase, the average surface roughness value will decrease thus improved surface finish could be observed.

4.4 EFFECT OF DEPTH OF CUT ON OIL-QUENCHED MILD STEEL FROM GRAPHICAL ANALYSIS

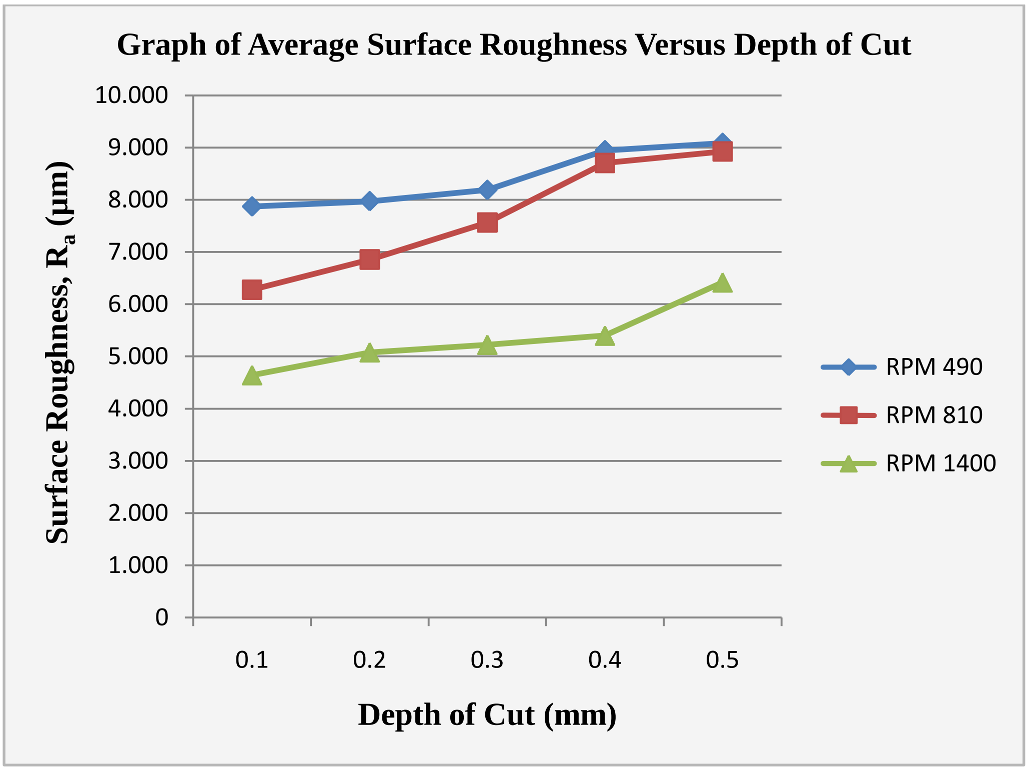


Figure 4.2: Average surface roughness vs. depth of cut with respect to various RPM values

Figure 4.2 presents graph of average surface roughness versus depth of cut with respect to various RPM values. From Figure 4.2 above, it shows that for a spindle speed of 490 RPM, when the depth of cut is increased from 0.1 mm to 0.5 mm, the average surface roughness value had increased significantly from 7.873 µm (depth of cut = 0.1 mm) to 9.087 µm (depth of cut = 0.5 mm). The same trend was observed for spindle speed of 810RPM with increasing depth of cut values. This proved that, as the depth of cut increased, the average surface roughness value was also increased. Thus, the surface finish was reduced when the depth of cut is increased.

4.5 PREDICTION OF SURFACE ROUGHNESS WITH RESPONSE SURFACE METHODOLOGY

The surface roughness model in the turning of mild steel was developed in terms of spindle speed and depth of cut using response surface methodology. After conducting 15 sets of experiments, the surface roughness readings were used to find the parameters appearing in the postulated first-order and second-order model. In order to calculate these parameters, the least square method is used with the aid of Minitab software. The linear model correlating the response and variables can be presented by the following expression:

$$y = C + m \times spindle\ speed + n \times depth\ of\ cut \tag{4.1}$$

where y is the response, C, m and n are the constants.
Equation 4.1 can also be expressed as:

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 \tag{4.2}$$

where y is the response (surface roughness), x_o = 1 (dummy variable), x_1=spindle speed, x_2=depth of cut, βo=C and β_1 and β_2 are the model parameters.
The second order model correlating the response and variables can be presented by the following expression:

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{11} x_1 x_2 \tag{4.3}$$

where y is the response (surface roughness), x_o = 1 (dummy variable), x_1=spindle speed, x_2=depth of cut, β_0=C and β_1 and β_2 are the model parameters.

4.5.1 Prediction of Surface Roughness with RSM First-Order Model

The first-order model for surface roughness was postulated based on Equation 4.4. The linear model correlating the response and variables can be represented by the following expression:

$$y = 8.79189 - 0.00343255x_1 + 4.80733x_2 \tag{4.4}$$

where x_1= spindle speed and x_2= depth of cut

Table 4.2 presents comparison between experimental and predicted R_a for first-order model.

Table 4.2: Comparison between experimental and predicted R_a for first-order model

RPM	**Depth of cut**	**Experimental R_a (µm)**	**Predicted R_a (µm)**	**% Deviation**
490	0.1	7.873	7.591	3.586
490	0.2	7.974	8.071	1.222
490	0.3	8.189	8.552	4.435
490	0.4	8.947	9.033	0.960
490	0.5	9.087	9.514	4.695
810	0.1	6.278	6.492	3.413
810	0.2	6.857	6.973	1.692
810	0.3	7.567	7.454	1.497
810	0.4	8.706	7.934	8.862
810	0.5	8.926	8.415	5.723
1400	0.1	4.642	4.467	3.769
1400	0.2	5.080	4.948	2.603
1400	0.3	5.226	5.429	3.875
1400	0.4	5.400	5.909	9.431
1400	0.5	6.420	6.390	0.467
			Average %Deviation = 3.749 %	

The percentage of deviation between the experimental R_a and predicted R_a were calculated and the average percentage deviation was obtained. The calculated average percentage deviation was 3.749 % using RSM first order model.

Figure 4.3 presents graph of normal probability plot where the response is surface roughness for first-order model.

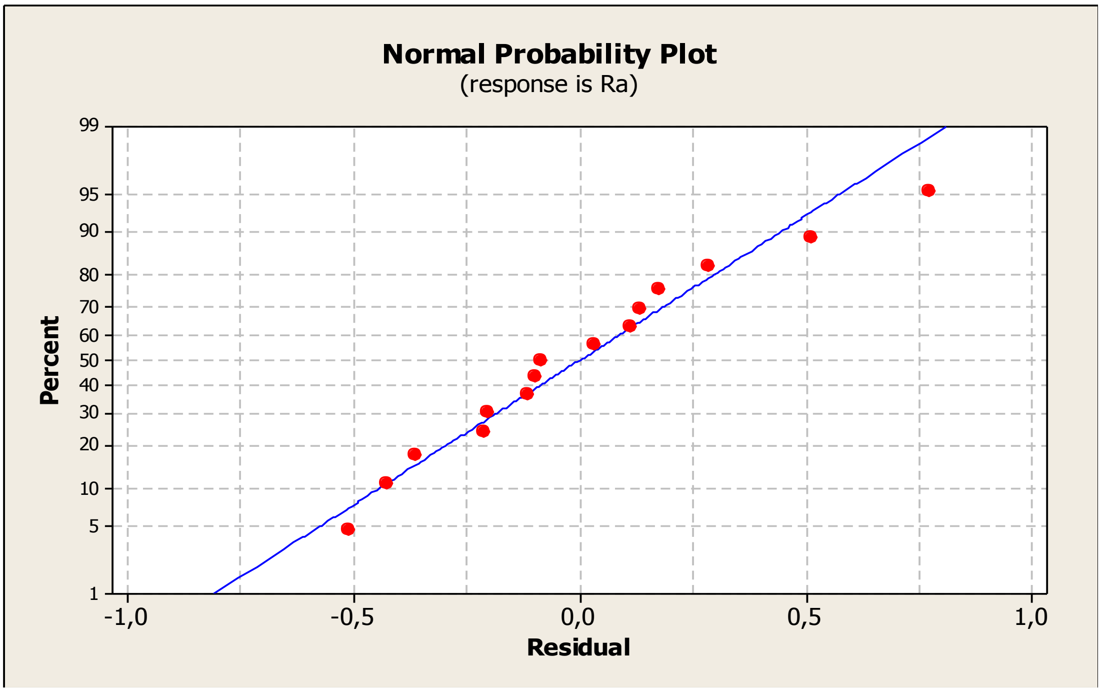


Figure 4.3: Normal probability plot for R_a data (first-order)

The normal probability plot of the residual for R_a data is shown in Figure 4.3. A check on the plot revealed that the residuals generally fall on a straight line except for few points implying that the errors are distributed normally. This implies that the model proposed is adequate and there is no reason to suspect any violation of the independence or constant variation assumption.

Figure 4.4 presents the contour plot of spindle speed-depth of cut plane of first-order model.

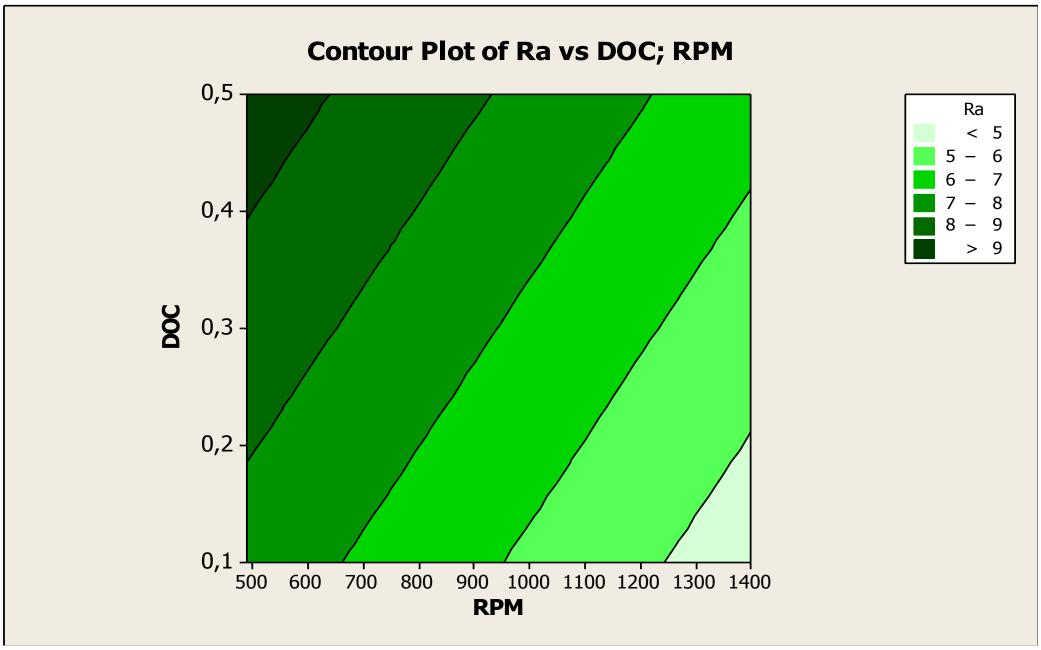


Figure 4.4: Contour plot of R_a versus depth of cut and RPM

From the observation, we can affirm that the R_a increases with the increase in depth of cut and decrease in spindle speed. Combination of low RPM and high depth of cut will produce rough surface. It is clearly shown that the relationship between the surface roughness and design variables.

4.5.2 Prediction of Surface Roughness with RSM Second-Order Model

The second-order model for surface roughness was postulated based on Equation 4.5. The full quadratic model correlating the response and variables can be represented by the following expression

$$y = 7.62534 + 2.63523 \times 10^{-7} x_1 + 2.84022 x_2 - 1.74250 \times 10^{-6} x_1^2 + 3.62857 x_2^2 - 2.33365 \times 10^{-4} x_1 x_2 \qquad (4.5)$$

where x_1 = spindle speed and x_2= depth of cut

Table 4.3 shows the comparison between the experimental and predicted Ra values using Response surface methodology second-order model.

Table 4.3: Comparison between experimental and predicted R_a for second order model

RPM	**Depth of cut**	**Experimental R_a (μm)**	**Predicted R_a (μm)**	**% Deviation**
490	0.1	7.873	7.506	4.662
490	0.2	7.974	7.887	1.086
490	0.3	8.189	8.341	1.861
490	0.4	8.947	8.868	0.883
490	0.5	9.087	9.467	4.184
810	0.1	6.278	6.774	7.896
810	0.2	6.857	7.148	4.239
810	0.3	7.567	7.594	0.360
810	0.4	8.706	8.113	6.807
810	0.5	8.926	8.705	2.475
1400	0.1	4.642	4.488	3.317
1400	0.2	5.080	4.848	4.562
1400	0.3	5.226	5.281	1.053
1400	0.4	5.400	5.786	7.155
1400	0.5	6.420	6.364	0.868

Average %Deviation = 3.427 %

The percentage of deviation between the experimental R_a and predicted R_a were calculated and the average percentage deviation was obtained. The calculated average percentage deviation was 3.427 % using RSM second order model. Hence, it can be deduced that prediction of surface roughness using second order model gives better accuracy in comparison with first order model.

Figure 4.5 presents graph of normal probability plot where the response is surface roughness for second-order model.

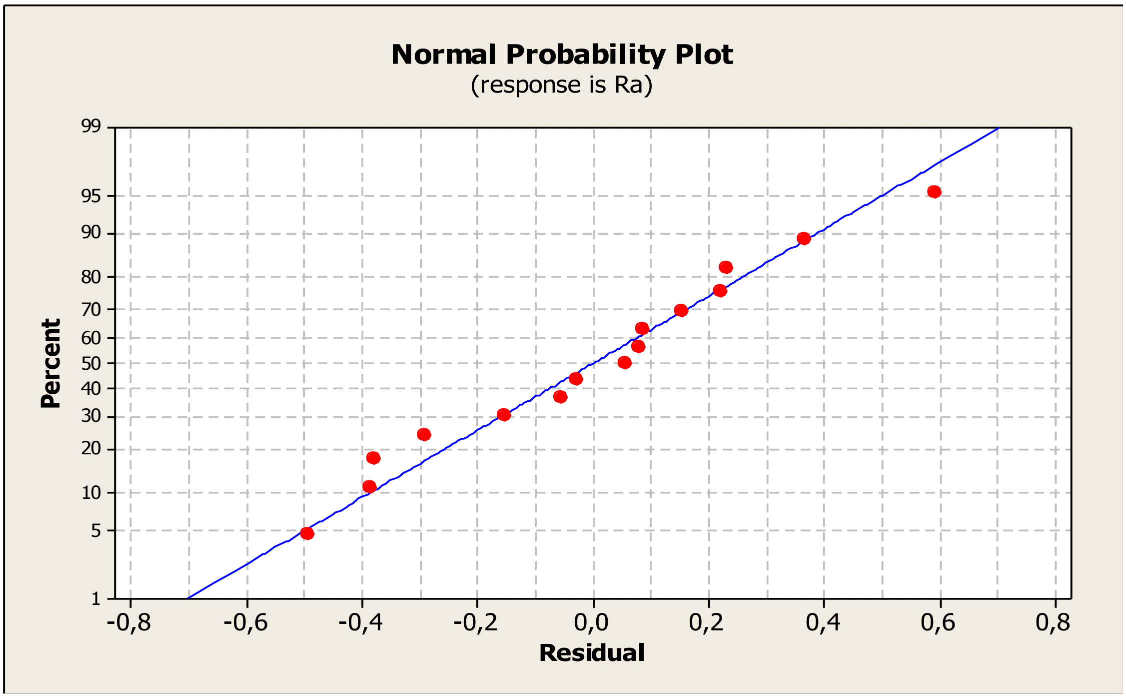


Figure 4.5: Normal probability plot for Ra data for second order model

The normal probability plot of the residual for R_a data is shown in Figure 4.5. A check on the plot revealed that the residuals generally fall on a straight line implying that the errors are distributed normally. This implies that the model proposed is adequate and there is no reason to suspect any violation of the independence or constant variation assumption.

Figure 4.6 shows the contour plot of spindle speed-depth of cut plane of second-order model.

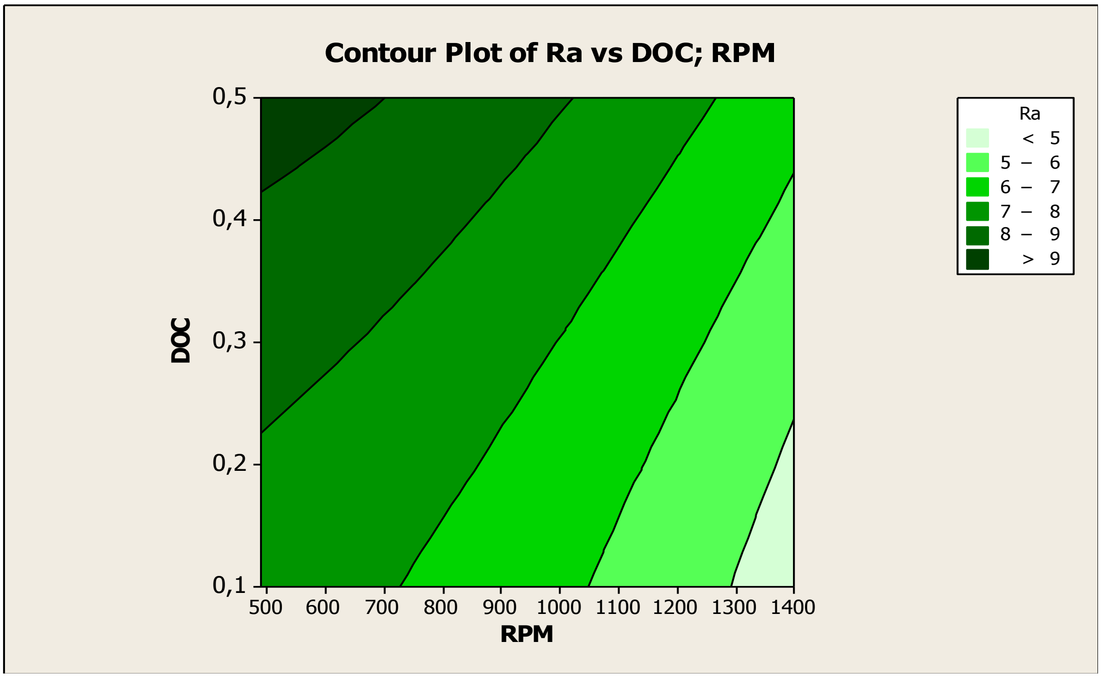


Figure 4.6: Contour plot of R_a versus depth of cut and RPM for second order model

From the observation, we can affirm that the R_a increases with the increase in depth of cut and decrease in spindle speed. Combination of low RPM and high depth of cut will produce rough surface. It is clearly shown that the relationship between the surface roughness and design variables.

4.5.3 Comparison between Experimental R_a and RSM Predicted R_a (First and Second-Order Model)

Figure 4.7 presents the comparison between experimental and predicted R_a values for first- and second-order model.

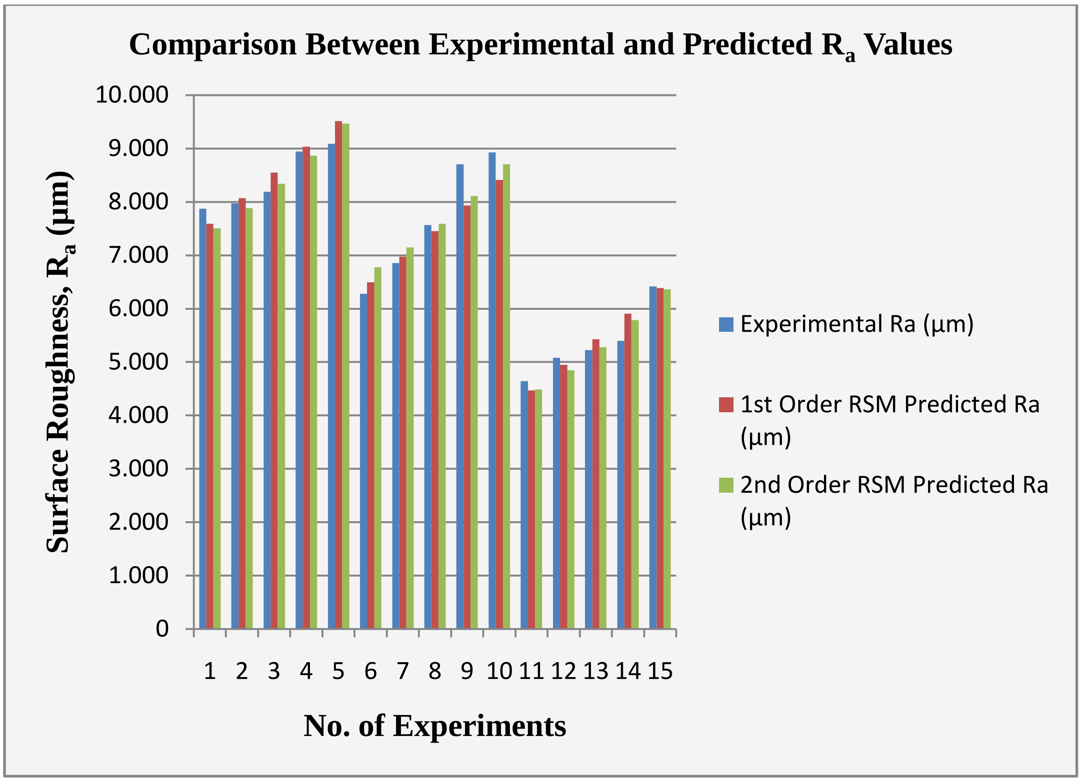


Figure 4.7: Comparison between experimental and predicted R_a values

As seen from Figure 4.7, the predicted surface roughness using the second order RSM model is closely match with the experimental results. The percentage average deviation for second-order model is 3.427 % in comparison with first-order model which exhibits higher percentage average deviation which is 3.749 %. Hence, it exhibits the better agreement as compared to those from the first-order RSM model.

4.6 ANALYSIS OF VARIANCE (ANOVA)

By using Minitab, analysis of variance (ANOVA) for first- and second-order equation were used to observe values of surface roughness in order to determine the significant parameter that influence the surface roughness of oil-quenched mild steel. Through the utilization of ANOVA, the significant parameters that influence surface roughness values could be identified. These are shown from the Table 4.4 to Table 4.7.

Table 4.4 shows the results obtained for analysis of variance for first-order equation.

Table 4.4: Analysis of variance for first-order equation

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	2	32.0414	32.0414	16.0207	113.88	0.000
Linear	2	32.0414	32.0414	16.0207	113.88	0.000
Residual Error	12	1.6882	1.6882	0.1407		
Total	14	33.7296				

Table 4.5 shows the estimated regression coefficients for R_a (first-order model).

Table 4.5: Estimated regression coefficients for R_a (first-order)

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	6.9903	0.09753	71.673	0.000
RPM	-1.5618	0.11691	-13.360	0.000
Depth of cut	0.9615	0.13696	7.020	0.000
R-Sq = 94.99%	R-Sq (pred) = 92.45%	R-Sq (adj) = 94.16%		

Table 4.6 shows the results generated for analysis of variance for second-order equation.

Table 4.6: Analysis of variance for second-order equation

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	5	32.4495	32.4495	6.4899	45.63	0.000
Linear	2	32.0414	30.2210	15.1105	106.24	0.000
Square	2	0.4058	0.4058	0.2029	1.43	0.290
Interaction	1	0.0023	0.0023	0.0023	0.02	0.901
Residual Error	9	1.2801	1.2801	0.1422		
Total	14	33.7296				

Table 4.7 shows the estimated regression coefficients for R_a (second-order model).

Table 4.7: Estimated regression coefficients for R_a (second-order)

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	7.17197	0.2222	32.273	0.000
RPM	-1.53020	0.1193	-12.831	0.000
DOC	0.95937	0.1387	6.917	0.000
RPM*RPM	-0.36074	0.2298	-1.570	0.151
DOC*DOC	0.14514	0.2328	0.624	0.548
RPM*DOC	-0.02124	0.1662	-0.128	0.901

The adequacy of the first- and second-order model was verified using the analysis of variance as shown in Table 4.4 and Table 4.6. At a level of confidence of 95 %, the models were checked for its adequacy. Generally, an increase in cutting speed and decrease in depth of cut caused better surface finish which mean lower surface roughness value. By examining the coefficient of both the cutting speed and depth of cut as shown in Table 4.5 and Table 4.7, both the cutting speed and depth of cut have dominant effect on the surface roughness.

After examining the experimental data, it can be seen that the contribution of cutting speed and depth of cut are significant. Also, owing to the P-value of interaction is 0.901 (>0.05), one can easily deduce that the interactions of distinct design variables are not significant.

Analysis of variance was also carried out using Microsoft Excel as it provides better accuracy in terms of P-value as compared with Minitab. The analysis of variance using Microsoft Excel is shown in Table 4.8.

Table 4.8: Analysis of variance using Microsoft Excel

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Depth of cut	21.10503	4	5.276258	17.78759	1.4E-07	2.689628
Spindle speed	76.52525	2	38.26263	128.9929	1.85E-15	3.31583
Interaction	3.693255	8	0.461657	1.556361	0.180073	2.266163
Within	8.898775	30	0.296626			
Total	110.2223	44				

From the Table 4.8, it can be seen that the P-value for spindle speed is the lowest (P = 1.85E-15) followed by P-value of depth of cut (P = 1.4E-07). Thus, it can be concluded that, spindle speed or cutting speed is the most significant parameter affecting surface roughness followed by depth of cut. The P-value for interaction is 0.180073 (>0.05) means the interaction of distinct variables are not significant.

4.7 VALIDATION WITH POLYNOMIAL TREND LINE EQUATION

4.7.1 Validation Test to Evaluate Optimum Cutting Speed

Validation test is conducted to validate experimental result and evaluate the optimum cutting speed for oil-quenched mild steel by using polynomial trend line equation to find surface roughness value with respect to three different spindle speed which are 490 RPM, 810 RPM and 1400 RPM. After surface roughness value is determined by substituting depth of cut value (only one is chosen and will be used throughout the equation), the result of surface roughness obtained are compared for three different types of spindle speed. Figure 4.8 shows the graph of average surface roughness versus depth of cut with respect to 490 RPM.

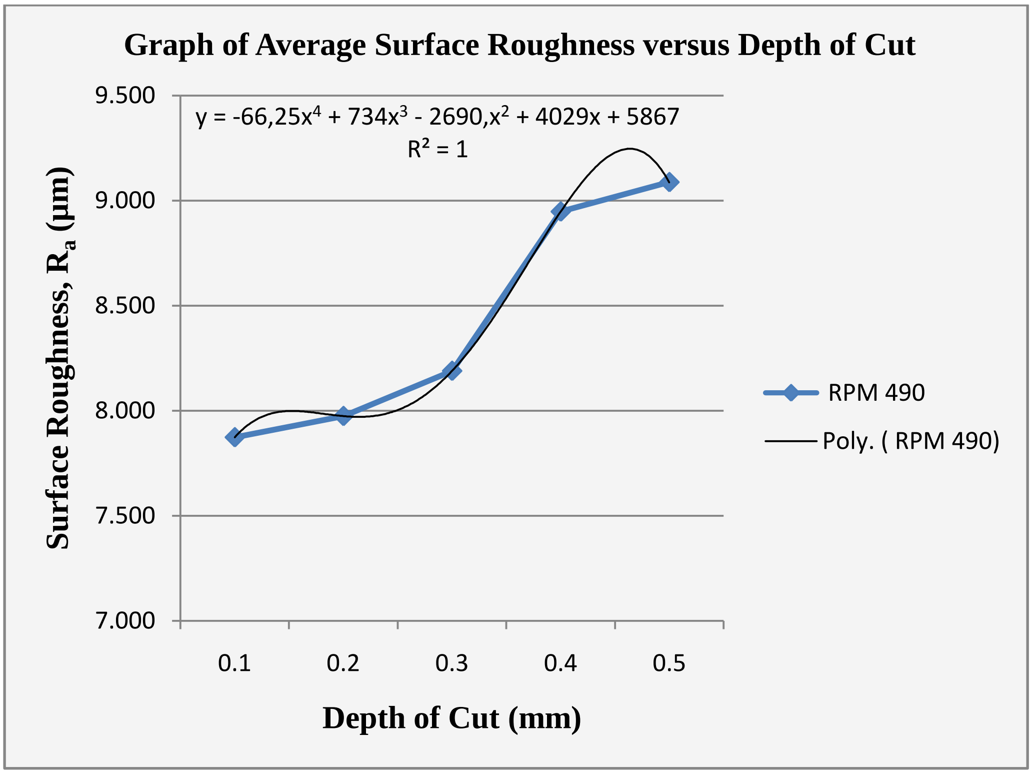


Figure 4.8: Average surface roughness vs. depth of cut with respect to 490 RPM

Validation test calculation from trend line equation:

Assumption: 0.1mm depth of cut will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -66.25x^4 + 734x^3 – 2690x^2 + 4029x + 5867$, $R^2 = 1$

$y = -66.25 (0.1)^4 + 734 (0.1)^3 – 2690 (0.1)^2 + 4029 (0.1) + 5867$

$y = 6243.7274$ µm

Figure 4.9 shows the graph of average surface roughness versus depth of cut with respect to 810 RPM.

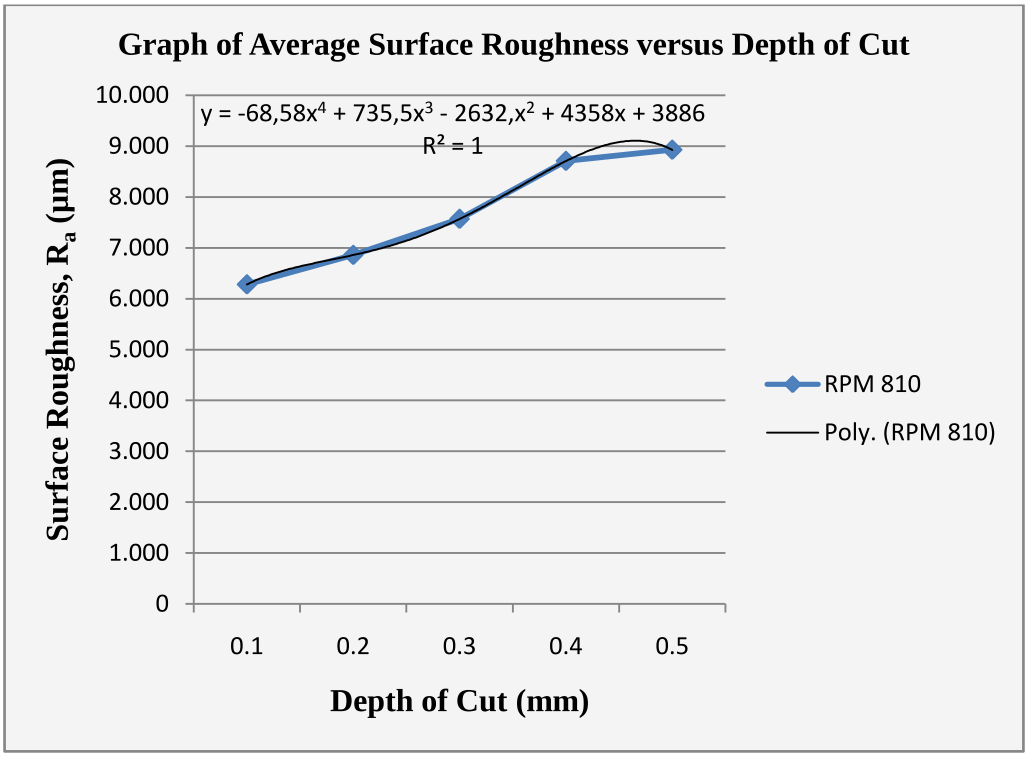


Figure 4.9: Average surface roughness vs. depth of cut with respect to 810 RPM

Validation test calculation from trend line equation:

Assumption: 0.1mm depth of cut will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -68.58x^4 + 735.5x^3 – 2632x^2 + 4358x + 3886$, R2 = 1

$y = -68.58 (0.1)^4 + 735.5 (0.1)^3 – 2632 (0.1)^2 + 4358 (0.1) + 3886$

$y = 4296.2086$ µm

Figure 4.10 shows the graph of average surface roughness versus depth of cut with respect to 1400 RPM.

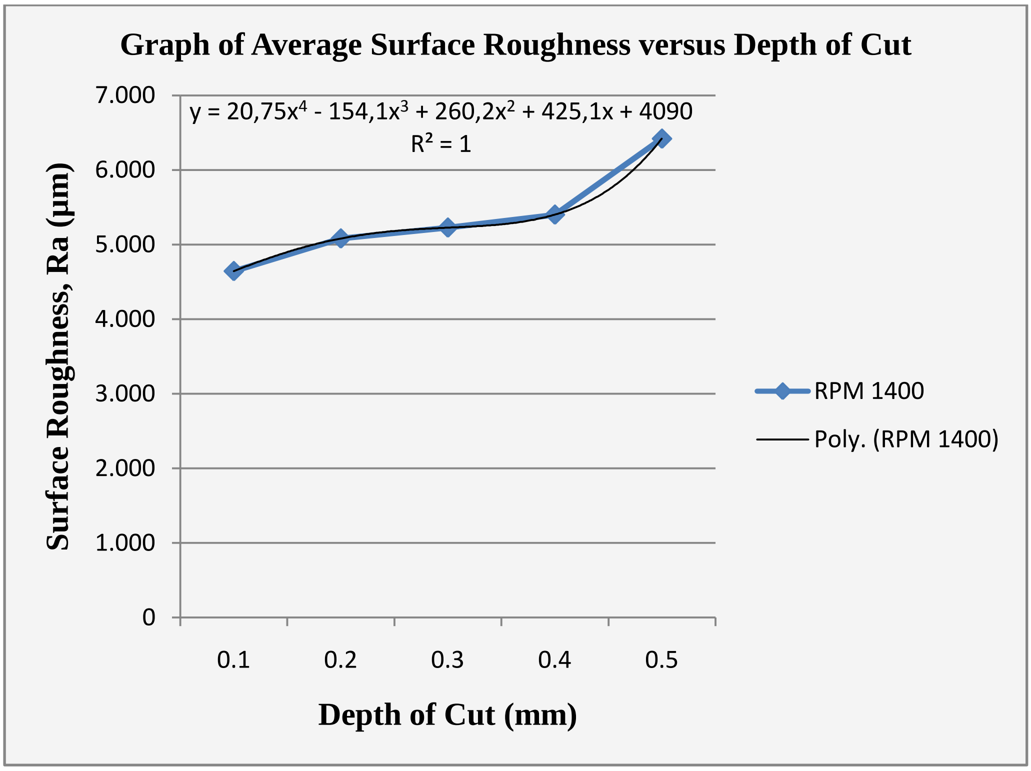


Figure 4.10: Average surface roughness vs. depth of cut with respect to 1400 RPM

Validation test calculation from trend line equation:

Assumption: 0.1mm depth of cut will be used as x value throughout the equation to find value of surface roughness (y value)

$y = 20.75x^4 – 154.1x^3 + 260.2x^2 + 425.1x + 4090, R^2 = 1$

$y = 20.75 (0.1)^4 – 154.1 (0.1)^3 + 260.2 (0.1)^2 + 425.1 (0.1) + 4090$

$y = 4134.96$ µm

Table 4.9 shows the result of validation test using trend line equations for surface roughness with respect to three different spindle speed values.

Table 4.9: Result of validation test using trend line equations for surface roughness with respect to three different spindle speed values

Spindle speed (RPM)	**Surface roughness, Ra (µm)**
490	6243.7274
810	4296.2086
1400	4134.96

From the Table 4.9, it can be observed that using higher spindle speed will give smaller surface roughness value. For example, it can be seen that using 1400RPM speed tend to give smallest surface roughness value (Ra = 4133.96 µm) in comparison with using 490RPM speed which give the highest surface roughness value (Ra = 6243.7274 µm) calculated from polynomial trend line equation assuming x value as 0.1. Hence, it can be concluded that 1400 RPM is the optimum spindle speed from the three spindle speed used as it gives the best surface finish to workpiece. The surface roughness value calculated from the polynomial trend line equation thus verified the experimental result that higher cutting speed will produce better surface finish.

4.7.2 Validation Test to Evaluate Optimum Depth of Cut

This validation test was carried out to validate experimental result and evaluate the optimum depth of cut by using trend line equation to find surface roughness value with respect to range of depth of cut from 0.1 mm to 0.5 mm. After surface roughness value is determined by substituting spindle speed value (only one is chosen and will be used throughout the equation), the result of surface roughness obtained are compared for five different values of depth cut.

Figure 4.11 shows the graph of average surface roughness versus spindle speed with respect to 0.1mm depth of cut.

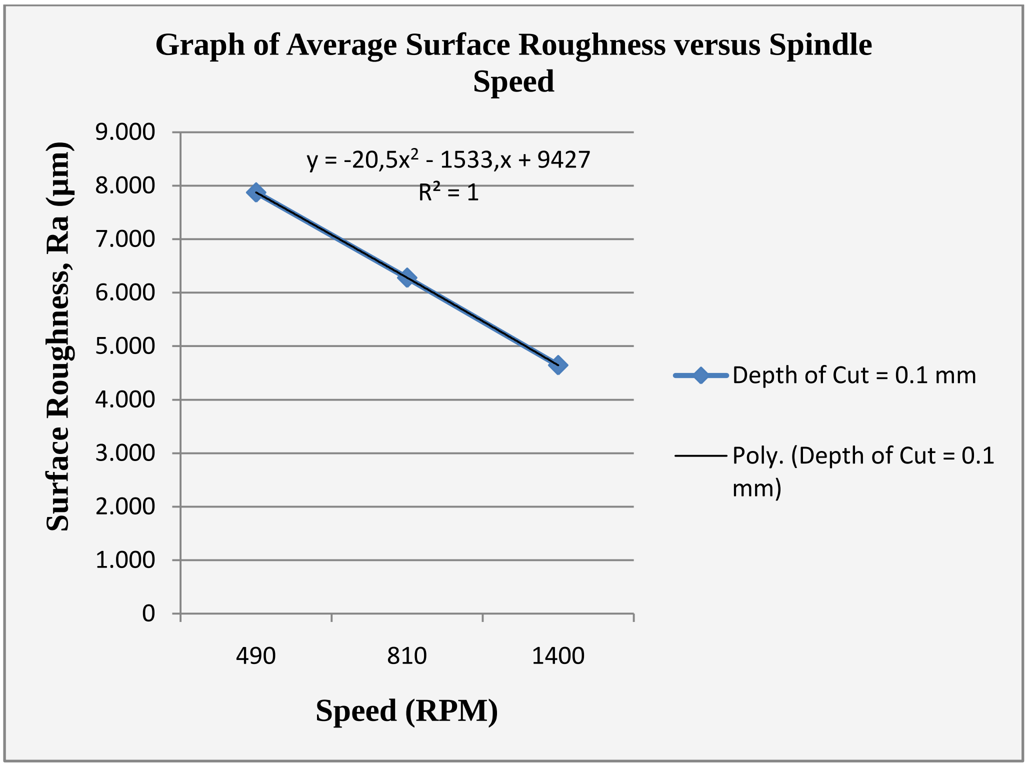


Figure 4.11: Average surface roughness vs. spindle speed (RPM) with respect to 0.1mm depth of cut

Validation test calculation from trend line equation:

Assumption: 490RPM will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -20.5x^2 – 1533x + 9427, R^2 = 1$

$y = -20.5 (490)^2 – 1533 (490) + 9427$

$y = -5.6638 \times 10^6$ µm

Figure 4.12 shows the graph of average surface roughness versus spindle speed with respect to 0.2mm depth of cut.

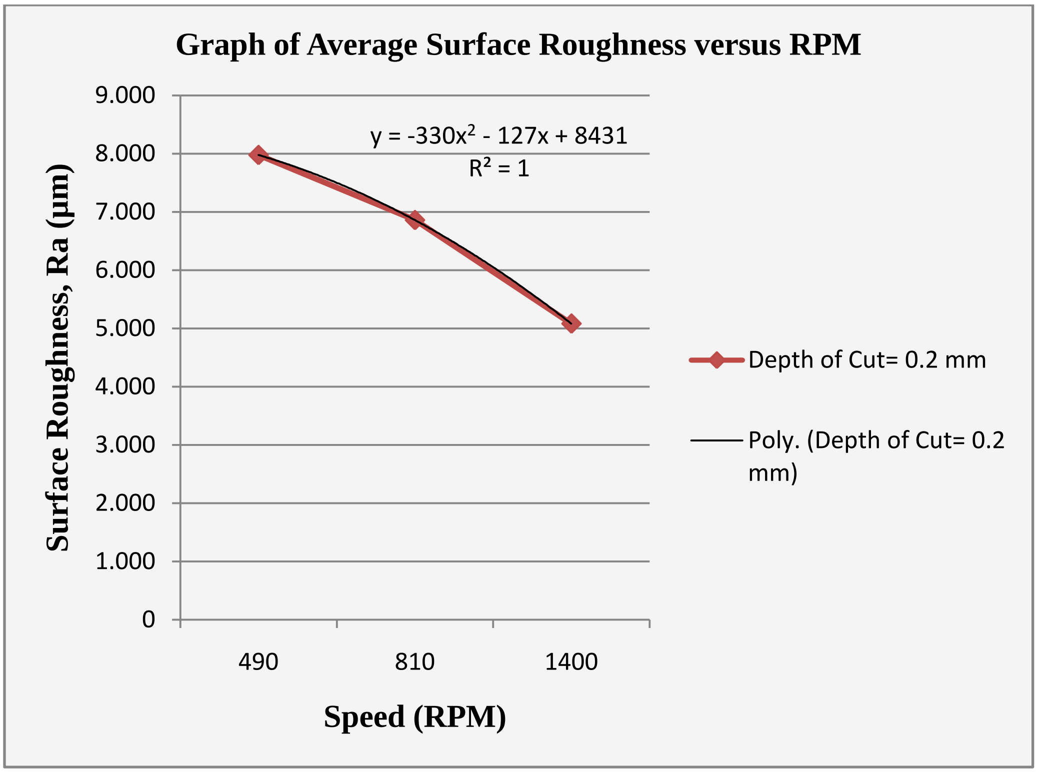


Figure 4.12: Average surface roughness vs. spindle speed (RPM) with respect to 0.2mm depth of cut

Validation test calculation from trend line equation:

Assumption: 490RPM will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -330x^2 - 127x + 8431,\ R^2 = 1$

$y = -330\,(490)^2 - 127\,(490) + 8431$

$y = -7.9287 \times 10^7$ µm

Figure 4.13 shows the graph of average surface roughness versus spindle speed with respect to 0.3mm depth of cut.

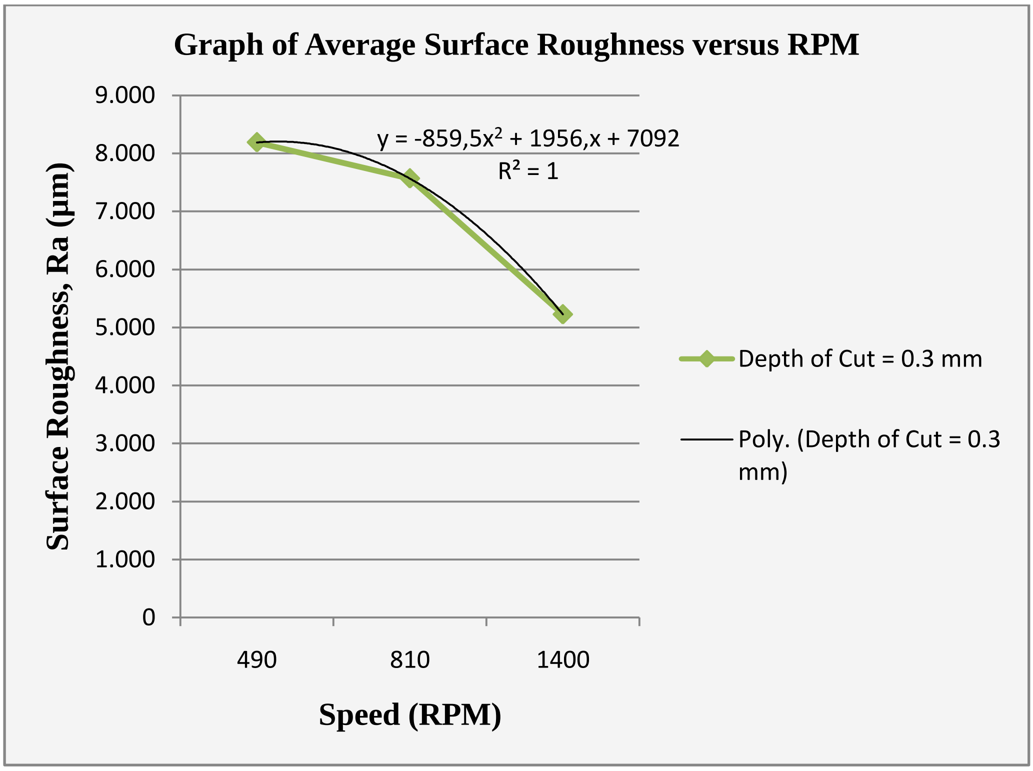


Figure 4.13: Average surface roughness vs. spindle speed (RPM) with respect to 0.3mm depth of cut

Validation test calculation from trend line equation:

Assumption: 490RPM will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -859.5x^2 – 1956x + 7092$, $R^2 = 1$

$y = -859.5 (490)^2 – 1956 (490) + 7092$

$y = -2.054 \times 10^8$ µm

Figure 4.14 shows the graph of average surface roughness versus spindle speed with respect to 0.4mm depth of cut.

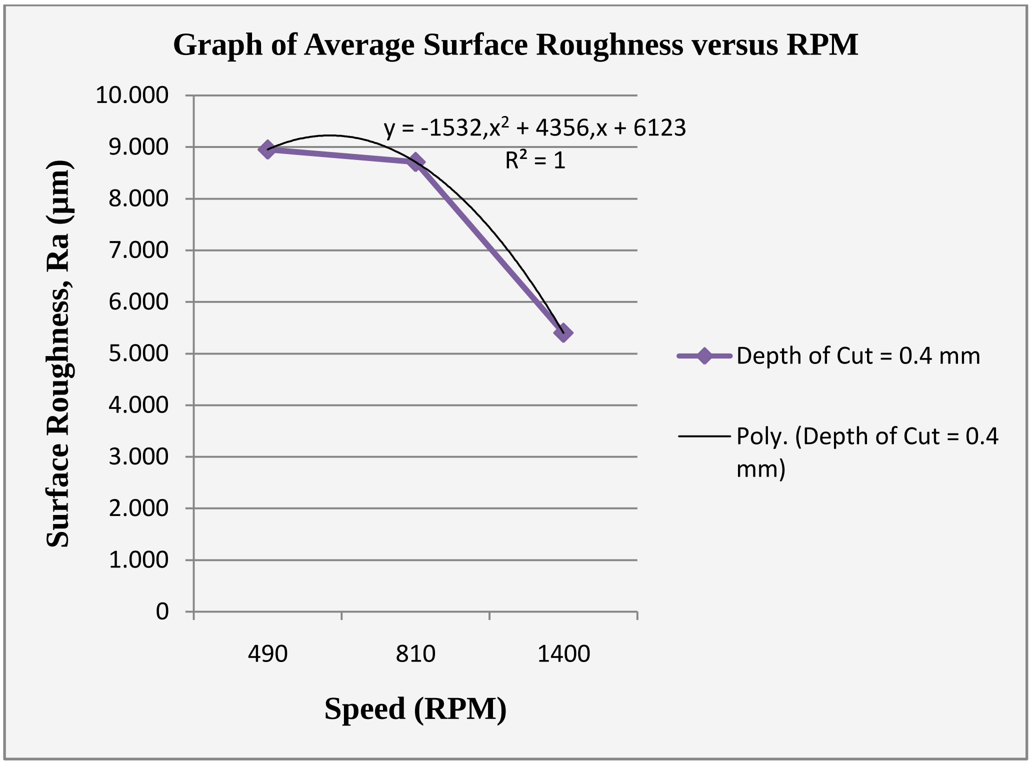


Figure 4.14: Average surface roughness vs. spindle speed (RPM) with respect to 0.4mm depth of cut

Validation test calculation from trend line equation:

Assumption: 490RPM will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -1532x^2 + 4356x + 6123, R^2 = 1$

$y = -1532 (490)^2 + 4356 (490) + 6123$

$y = -3.6569 \times 10^8$ µm

Figure 4.15 shows the graph of average surface roughness versus spindle speed with respect to 0.5mm depth of cut.

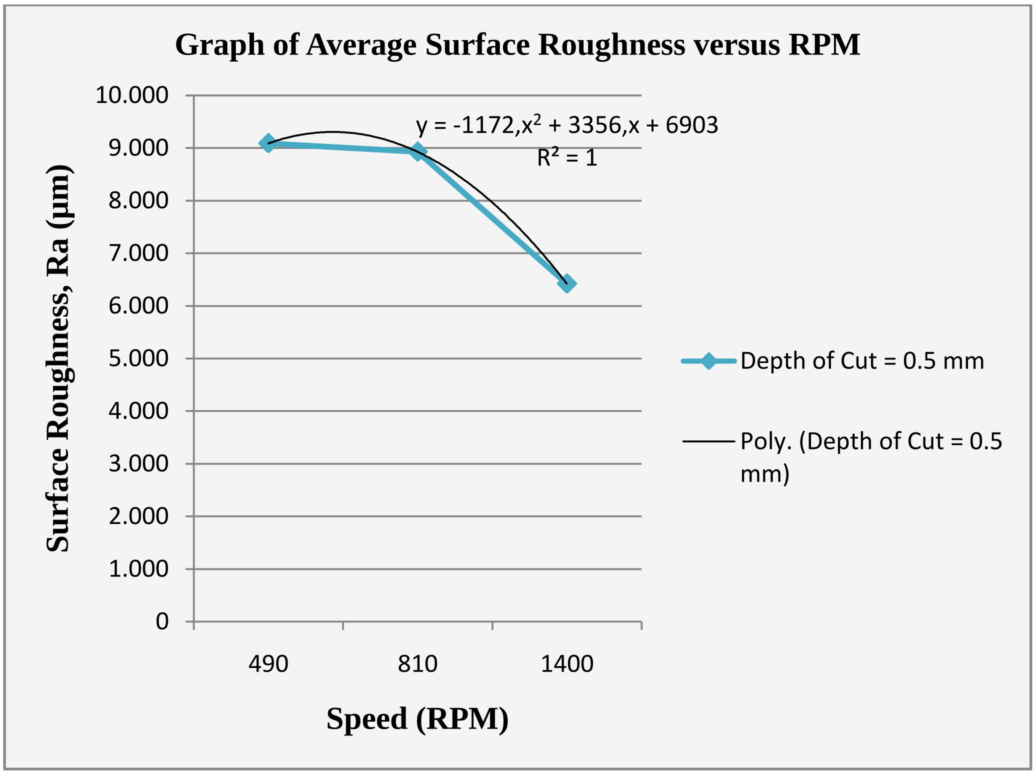


Figure 4.15: Average surface roughness vs. spindle speed with respect to 0.5mm depth of cut

Validation test calculation from trend line equation:

Assumption: 490RPM will be used as x value throughout the equation to find value of surface roughness (y value)

$y = -1172x^2 + 3356x + 6903, R^2 = 1$

$y = -1172\,(490)^2 + 3356\,(490) + 6903$

$y = -2.7975 \times 10^8$ µm

Table 4.10 shows result of validation test using trend line equations for surface roughness with respect to five different depth of cut values.

Table 4.10: Result of validation test using trend line equations for surface roughness with respect to five different depth of cut values

Depth of Cut (mm)	**Surface roughness, Ra (µm)**
0.1	-5.6638×10^{6} µm
0.2	-7.9287×10^{7} µm
0.3	-2.054×10^{8} µm
0.4	-3.6569×10^{8} µm
0.5	-2.7975×10^{8} µm

From the Table 4.10, it can be observed that higher depth of cut will produce higher surface roughness value. For example, we can see that using 0.1 mm depth of cut tend to give smallest surface roughness value. The trends were the same from depth of cut of 0.1 mm to 0.4 mm. But for depth of cut of 0.5 mm, the surface roughness calculated from the polynomial trend equation gave a lower surface roughness value than surface roughness for 0.4 mm depth of cut. This might be due to the irregularity of the surface of mild steel when it was heated and quenched in oil which then caused certain surface of the mild steel bar to be harder than the other. This will then affect the result of surface roughness value obtained. But overall, it can be concluded that higher depth of cut will lead to higher value of surface roughness. Thus, in order to produce better surface finish, lower depth of cut value should be used. Therefore, from the range of depth of cut from 0.1 mm to 0.5 mm, it can be concluded that 0.1 mm depth of cut produced the best surface finish. The surface roughness value calculated from the polynomial trend line equation thus verified the experimental result that decreasing depth of cut will produce better surface finish.

4.8 HARDNESS TEST USING ROCKWELL HARDNESS TESTER

A Rockwell Hardness tester was used to determine the hardness value of mild steel before and after it is quenched in oil. Results obtained are shown in Table 4.11. The values obtained which are in Rockwell B-scale (HRB) were converted to Brinell Hardness Number using Hardness Conversion Chart. Three readings were taken for each specimen and average value was calculated.

Table 4.11: Hardness values (HRB) of before and after oil-quenched mild steel

Condition	**HRB**			
	1	**2**	**3**	**Average**
Before Quenched	76.8	76.3	76.5	76.5
After Oil-Quenched	79.6	80.8	79.8	80.1

Table 4.12: Converted Hardness values (HB) of before and after oil-quenched steel

Condition	**HB**			
	1	**2**	**3**	**Average**
Before Quenched	138	136	137	137
After Oil-Quenched	145	149	146	147

Figure 4.16 shows chart of Brinell Hardness (HB) versus number of test for non-quenched and oil-quenched mild steel.

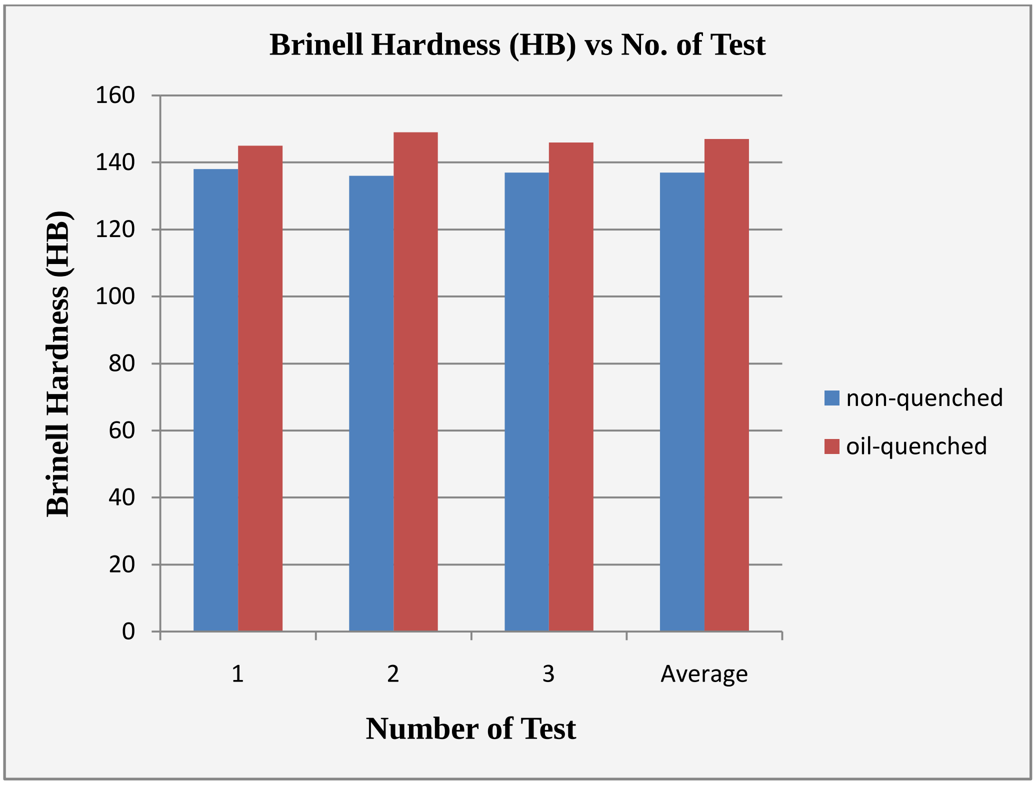


Figure 4.16: Chart of Brinell Hardness (HB) versus number of test for non-quenched and oil-quenched mild steel

Figure 4.16 shows the comparison in terms of hardness for both non-quenched and oil-quenched mild steel. From the chart, it was observed that mild steel which was quenched in oil gives higher hardness number in comparison with original mild steel which did not undergo any quenching process. From the average of the hardness, there is an increase from 137 HB for original mild steel to 147 HB for oil-quenched mild steel. Thus, there is an increase of approximately 7.3 % of hardness value after the mild steel was heat treated and quenched in oil. This shows that oil-quenching will increase the hardness of mild steel. This might be due to the changes in microstructure of mild steel when it was heated to austenitic temperature and rapidly quenched in oil. The use of oil as quenching medium gives slower cooling rate.

Thus, the structure is predicted to consist of ferrite, coarse and fine pearlite by referring to theoretical based on hardness obtained. Steels containing pearlitic microstructures will have greater strength and hardness. Usually when heat treated steel is quenched, most of the cooling happens at the surface only. This means, the changes in hardness will mostly happen at the surface of mild steel only.

4.9 CHEMICAL COMPOSITION ANALYSIS

The chemical composition of oil-quenched mild steel was analyzed using the Bench Top Arc / Spark Spectrometer. The analyzed chemical composition of oil-quenched mild steel is as shown in Table 4.13.

Table 4.13: Chemical composition of oil-quenched mild steel

Composition	**Wt (%)**
Fe	98.4
C	0.283
Si	0.182
Mn	0.571
P	0.100
S	0.154
Cr	0.0274
Mo	0.0050
Ni	0.0057
Al	0.0418
Co	0.0032
Cu	0.0495
Nb	0.0020
Ti	0.0041
V	0.0223
W	0.0150
Pb	0.0250
Sn	0.0020
B	0.0010
Ca	0.0009
Zr	0.0026
As	0.0050
Bi	0.0300

From the chemical composition analysis done, it can be concluded that the material is a low carbon steel with 0.28 % of carbon content.

4.10 RELATIONSHIP BETWEEN CUTTING SPEED AND DEPTH OF CUT ON SURFACE ROUGHNESS

4.10.1 Relationship between Cutting Speed and Surface Roughness

Generally, as cutting speed increases, the heat generated at the tool workpiece interface also increases. This will increase the temperature and reduced the adhesion characteristics thereby eliminating the formation of built-up edge (BUE). At low cutting speed, the formation of BUE might be significant. The BUE formed might act as a protective cap on the cutting edge thus preventing it from undergoing wear. However, the presence of BUE adversely affects the surface roughness. As proven from experimental result, when cutting was carried out at low RPM, the surface roughness values were higher compared with cutting at high RPM. This is because of the formation of relatively stable BUE at low RPM. The BUE formation of course will affect the surface quality of mild steel thus resulted in unacceptable surface finishes. An additional increase in cutting speed will result in a better surface finish. But when the cutting speed increases, tool life is reduced rapidly. Therefore, it is important to optimize the cutting speed so that a good surface quality could be obtained.

4.10.2 Relationship between Depth of Cut and Surface Roughness

As proven from experimental results, the average surface roughness increased with an increase in depth of cut. This is because the width of flank wear land increased rapidly with increasing depth of cut which cause the surface to become worse. Depth of cut for finished pass should be small because of tolerances and deformation. It is customary to increase the tool nose radius with increase in depth of cut. In finish cuts where the surface roughness is important, the tool nose radius should be limited to a maximum value of 1 mm in order to avoid chatter. Therefore, the depth of cut must be limited to avoid tool breakage.

The need to reduce depth of cut as a function of surface roughness is explained by the fact that as the depth of cut increases, the cutting force increased and therefore deformation of the workpiece and the tool occurs, the machine structure is stressed and deflects, chatter may appear and surface integrity increases. Therefore, to ensure that the produced workpiece will meet specifications, the depth of cut must be reduced. Lower depth of cut will produce better surface finish and is preferred as long as it does not increase manufacturing costs. Therefore, it is important to optimize the depth of cut used so that a better surface finish could be obtained at low manufacturing costs.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter summarizes all the main research points, observations and discussion resulting from the project for reference in the future research. Recommendations were suggested to further improve this project research in the future so that better outcome could be achieved.

5.2 CONCLUSION

The study on turning process on oil-quenched mild steel under low, medium and high level of cutting speed and depth of cut were performed and results obtained were analyzed. From Analysis of Variance (ANOVA), it was found that both cutting speed and depth of cut were the significant parameters affecting surface roughness of oil-quenched mild steel. But from ANOVA analysis with Microsoft Excel which provides better accuracy, it was found that cutting speed has greater influence on surface roughness.

The effect of depth of cut, it was observed that the surface roughness increase with increase in depth of cut. This is because the width of flank wear land increased rapidly with increasing depth of cut which cause the surface to become worse thus affecting the surface quality.

The effect of increasing cutting speed which produces better surface finish can be explained in terms of heat generated at the toll workpiece which then increase the temperature and reduce adhesion characteristics. The increase in temperature at high cutting speed will reduce the formation of built-up edge (BUE). Higher surface roughness is observed at low cutting speed because of the formation of relatively stable BUE at low cutting speed. Thus, in order to produce good surface finish, higher cutting speed should be used. But although high cutting speed will produce better surface finish but the tool life is reduced. Hence, it is important to optimize cutting speed in order to increase rate of production, prolong tool life, lower cost of maintenance for machine and reduce materials waste.

Surface plots between various process parameters were plotted in order to relate the parameters studied which is depth of cut and cutting speed. From results obtained, it can be concluded that combination of high cutting speed and low depth of cut values will produce lower average surface roughness values thus better surface finish is obtained.

It was also observed that there was an increase in the hardness of mild steel after it was heat treated and quenched in oil. The increase in hardness was approximately 7.3%.

5.3 RECOMMENDATIONS

Although this research met the objective, but there are still a lot which needs to be improved to make this project more significant to the study. Firstly, I would recommend future researchers to conduct more experimental runs and consider more machining parameters which could affect the surface roughness such as cutting speed, feed rate and depth of cut. The range of machining parameters selected should be made wider so that the accuracy of results obtained could be optimized. For example in my study only three different spindle speed were selected which is very limited.

If there are more speeds and depth of cut selected, it might be possible that a certain point the surface roughness of workpiece will become worse after that particular point. The cutting speed and depth of cut might not be always proportionate to the surface roughness if more selection of cutting speed and depth of cut are made. The RPM used is limited in my study due to the constraint of the lathe machine used in which the highest speed is only up to 1 400 RPM in comparison with other lathe machine which can use higher RPM. Thus, this limits the range of RPM which can be selected for my experimental study. I would suggest future researchers to use new model of lathe machine in which the RPM can be set digitally thus providing wider range of RPM selection.

I would also like to suggest future researchers to compare the surface roughness of mild steel before and after it is quenched. Due to lab constraint, I was not able to make comparison between the quenched and non-quenched mild steel. I would also suggest the importance of changing cutting tools if possible after each experimental runs to increase accuracy of results obtained.

Besides that, in the future, the researchers should also study the microstructure of the oil-quenched mild steel to analyze the types of microstructure formed.

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APPENDIX A1

Response Surface Regression: Ra versus RPM; DOC (First-Order)

The analysis was done using coded units.

Estimated Regression Coefficients for Ra

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	6.9903	0.09753	71.673	0.000
RPM	-1.5618	0.11691	-13.360	0.000
DOC	0.9615	0.13696	7.020	0.000

S = 0,375075   PRESS = 2,54675
R-Sq = 94,99% R-Sq(pred) = 92,45% R-Sq(adj) = 94,16%

Analysis of Variance for Ra

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	2	32.0414	32.0414	16.0207	113.88	0.000
Linear	2	32.0414	32.0414	16.0207	113.88	0.000
Residual Error	12	1.6882	1.6882	0.1407		
Total	14	33.7296				

Unusual Observations for Ra

```
Obs  Std   Order     Ra    Fit  SE Fit  Residual  St Resid
  9        9  8.706  7.934   0.121     0.772       2.17 R
```

R denotes an observation with a large standardized residual.

Estimated Regression Coefficients for Ra using data in uncoded units

Term	Coef
Constant	8.79189
RPM	-0.00343255
DOC	4.80733

Predicted Response for New Design Points Using Model for Ra

Point	**Fit**	**SE Fit**	**95% CI**	**95% PI**
1	7.59068	0.198075	(7.15911; 8.02225)	(6.66651; 8.5149)
2	8.07141	0.158636	(7.72577; 8.41705)	(7.18411; 8.9587)
3	8,.55214	0.143095	(8.24037; 8.86392)	(7.67747; 9.4268)
4	9.03288	0.158636	(8.68724; 9.37852)	(8.14557; 9.9202)
5	9.51361	0.198075	(9.08204; 9.94518)	(8.58944; 10.4378)
6	6.49226	0.169325	(6.12334; 6.86119)	(5.59563; 7.3889)
7	6.97300	0.120842	(6.70970; 7.23629)	(6.11441; 7.8316)
8	7.45373	0.099566	(7.23679; 7.67067)	(6.60821; 8.2993)
9	7.93446	0.120842	(7.67117; 8.19776)	(7.07588; 8.7930)
10	8.41520	0.169325	(8.04627; 8.78412)	(7.51856; 9.3118)
11	4.46706	0.211282	(4.00671; 4.92740)	(3.52910; 5.4050)
12	4.94779	0.174849	(4.56683; 5.32876)	(4.04614; 5.8494)
13	5.42853	0.160881	(5.07800; 5.77906)	(4.53930; 6.3177)
14	5.90926	0.174849	(5.52830; 6.29022)	(5.00761; 6.8109)
15	6.38999	0.211282	(5.92965; 6.85034)	(5.45204; 7.3279)

APPENDIX A2

Response Surface Regression: Ra versus RPM; DOC (Second-Order)

The analysis was done using coded units.

Estimated Regression Coefficients for Ra

Term	**Coef**	**SE Coef**	**T**	**P**
Constant	7.17197	0.2222	32.273	0.000
RPM	-1.53020	0.1193	-12.831	0.000
DOC	0.95937	0.1387	6.917	0.000
RPM*RPM	-0.36074	0.2298	-1.570	0.151
DOC*DOC	0.14514	0.2328	0.624	0.548
RPM*DOC	-0.02124	0.1662	-0.128	0.901

S = 0.377133   Pred. SS = 4.10417
R-Sq = 96.20% R-Sq(pred) = 87.83% R-Sq(adj) = 94.10%

Analysis of Variance for Ra

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	5	32,4495	32,4495	6,4899	45,63	0,000
Linear	2	32,0414	30,2210	15,1105	106,24	0,000
Square	2	0,4058	0,4058	0,2029	1,43	0,290
Interaction	1	0,0023	0,0023	0,0023	0,02	0,901
Residual Error	9	1,2801	1,2801	0,1422		
Total	14	33,7296				

Estimated Regression Coefficients for Ra using data in uncoded units

Term	**Coef**
Constant	7.61534
RPM	2.63623E-07
DOC	2.84022
RPM*RPM	-1.74250E-06
DOC*DOC	3.62857
RPM*DOC	-2.33365E-04

Predicted Response for New Design Points Using Model for Ra

Point	**Fit**	**SE Fit**	**95% CI**	**95% PI**
1	7.50597	0.288781	(6.85270; 8.1592)	(6.43145; 8.5805)
2	7.88741	0.205385	(7.42280; 8.3520)	(6.91597; 8.8589)
3	8.34143	0.204918	(7.87787; 8.8050)	(7.37049; 9.3124)
4	8.86802	0.205385	(8.40340; 9.3326)	(7.89657; 9.8395)
5	9.46717	0.288781	(8.81391; 10.1204)	(8.39265; 10.5417)
6	6.77370	0.249072	(6.21026; 7.3371)	(5.75130; 7.7961)
7	7.14768	0.191947	(6.71347; 7.5819)	(6.19040; 8.1050)
8	7.59423	0.204918	(7.13067; 8.0578)	(6.62329; 8.5652)
9	8.11335	0.191947	(7.67913; 8.5476)	(7.15607; 9.0706)
10	8.70504	0.249072	(8.14160; 9.2685)	(7.68264; 9.7274)
11	4.48804	0.307127	(3.79327; 5.1828)	(3.38779; 5.5883)
12	4.84825	0.211934	(4.36882; 5.3277)	(3.86963; 5.8269)
13	5.28103	0.204918	(4.81747; 5.7446)	(4.31009; 6.2520)
14	5.78638	0.211934	(5.30695; 6.2658)	(4.80776; 6.7650)
15	6.36430	0.307127	(5.66953; 7.0591)	(5.26405; 7.4645)

APPENDIX A3

Anova: Two-Factor With Replication

SUMMARY	RPM490	RPM810	RPM1400	Total
DOC1				
Count	3	3	3	9
Sum	23.619	18.835	13.926	56.38
Average	7.873	6.278333	4.642	6.264444
Variance	0.066639	0.06676	0.001792	1.991287
DOC2				
Count	3	3	3	9
Sum	23.923	20.571	15.24	59.734
Average	7.974333	6.857	5.08	6.637111
Variance	0.012546	1E-06	0.020449	1.606165
DOC3				
Count	3	3	3	9
Sum	24.618	22.702	15.678	62.998
Average	8.206	7.567333	5.226	6.999778
Variance	0.508404	0.485454	0.001956	2.095221
DOC4				
Count	3	3	3	9
Sum	26.846	26.119	16.199	69.164
Average	8.948667	8.706333	5.399667	7.684889
Variance	0.038784	1.191964	0.14836	3.293299
DOC5				
Count	3	3	3	9
Sum	27.261	26.779	19.261	73.301
Average	9.087	8.926333	6.420333	8.144556
Variance	1.006243	0.847536	0.052497	2.153689

Total			
Count	15	15	15
Sum	126.267	115.006	80.304
Average	8.4178	7.667067	5.3536
Variance	0.50494	1.497509	0.404484

ANOVA

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Sample	21.10503	4	5.276258	17.78759	1.4E-07	2.689628
Columns	76.52525	2	38.26263	128.9929	1.85E-15	3.31583
Interaction	3.693255	8	0.461657	1.556361	0.180073	2.266163
Within	8.898775	30	0.296626			
Total	110.2223	44				

APPENDIX B1

Gantt Chart / Project Schedule for FYP I

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1.0 TITLE VERIFICATION		■												
2.0 INTRODUCTION WRITING														
2.1 Setting Project Objectives			■	■										
2.2 Identify Project Scopes			■	■										
2.3 Identify Project Background			■	■										
2.4 Identify Problem Statement					■	■								
3.0 LITERATURE RESEARCH AND STUDY														
3.0 Gather informations from online journals							■	■						
3.2 Search relevant books from library							■	■						
3.3 Literature Writing							■	■						
4.0 METHODOLOGY														
4.1 Planning of Procedures									■	■				
4.2 Confirming Availability of Material									■					
4.3 Confirming Availability of Equipment									■					
5.0 PRESENTATION PREPARATION														
5.1 Slide Presentation											■	■		
5.2 Mock Presentation to Supervisor												■	■	
5.3 Obtain Approval for Presentation													■	
6.0 SUBMISSION OF DRAFT REPORT 1														■

APPENDIX B2

Gantt Chart / Project Schedule for FYP II

PSM 2 Activities	WK1	WK2	WK3	WK4	WK5	WK6	WK7	WK8	WK9	WK10	WK11	WK12	WK13	WK14
LITERATURE STUDY	■	■	■	■	■	■								
METHODOLOGY		■	■	■	■	■	■	■	■	■	■			
1. Specimen Preparation		■	■											
2. Microstructure Observation			■											
3. Lathe Machining				■	■	■	■	■	■					
4. Material Testing					■	■	■	■	■					
5. Data Collection and Analysis										■	■			
RESULT AND DISCUSSION										■	■	■		
FYP PRESENTATION 2													■	
REPORT SUBMISSION														■