PREDICTION OF SURFACE ROUGHNESS IN TURNING OPERATION OF LOW CARBON STEEL AISI 1018

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BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: PREDICTION OF SURFACE ROUGHNESS IN TURNING OPERATION OF LOW CARBON STEEL AISI 1018

SESI PENGAJIAN: 2009/2010

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PREDICTION OF SURFACE ROUGHNESS IN TURNING OPERATION OF LOW CARBON STEEL AISI 1018

FAKHRUR RAZI BIN BAHRIN

A report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2009

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "*Prediction of Surface Roughness in Turning Operation of Low Carbon Steel AISI 1018*" is written by *Fakhrur Razi Bin Bahrin (ID. No: ME06062).* We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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STUDENT’S DECLARATION

I declare that this thesis entitled *“Prediction of Surface Roughness in Turning Operation of Low Carbon Steel AISI 1018”* is the result of my own research except as cited in the references. The thesis has not been accepted for my degree and is not concurrently candidature of any other degree.

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To my Beloved Persons

HJH. RAHMAH BINTI ABDULLAH
HJ. BAHRIN BIN GIMAN
MALIANI BINTI MOHAMAD

ACKNOWLEDGEMENT

I would like to acknowledge and extend my heartfelt gratitude to my supervisor and co-supervisor, Mrs. SALWANI BINTI MOHD SALLEH and Mr. LEE GIOK CHUI, SMP, KMN, Lecturers of Faculty Mechanical Engineering for their continues support, helpful advices and valuable guidance throughout my thesis. This thesis could not have been done without them who not only served as my supervisors but also encouraged and guide me through the writing up thesis process by giving their best efforts. I also wish to express my sincere appreciate to the lecturers, technical staffs of Faculty Mechanical Engineering, Universiti Malaysia Pahang for their teaching and help during the period of the project.

I also wish to express sincere appreciation to all my friends for their advices to do the study. I benefited greatly from the comments and wisdom these reviewers generously shared with me.

Most importantly, I would like to thank to my family especially my parents, Tn. Hj. BAHRIN BIN GIMAN and Pn. Hjh. RAHMAH BINTI ABDULLAH, have guided me throughout my life. They have always sacrifices their time and continuous support me to achieve my dreams and goals. I would like to thank them for all support and encouragement they done for me. Besides that I also want to express my appreciation to all my family members for giving their ideas, supports, financial sponsors and helps throughout this project. I truly could not have done my thesis without them.

ABSTRACT

The present thesis discusses the development of the first order and second order models for predicting the roughness in turning operation of low carbon steel AISI 1018 using CVD coated carbide tips. The first order and second order equation was developed using the Response Surface Method (RSM). The cutting variables were the cutting speed, feed rate and depth of cut. The study found that the predictive models able to predict the longitudinal component of the surface roughness close to those readings recorded experimentally with a 95% confident interval. The two equations indicate that the feed rate was the most dominant cutting condition on the surface roughness, followed by the depth of cut and then by the cutting speed. The surface roughness increases with increasing the feed rate and depths of cut but decreases with increasing cutting speed. In addition, the second order model proves the existence of a very strong interaction of the feed rate with depth of cut.

ABSTRAK

Tesis ini membincangkan tentang pembikinan susunan model pertama dan kedua untuk menganggar kekasaran permukaan dalam proses melarik besi rendah carbon jenis AISI 1018 dengan menggunakan mata bucu jenis pemendapan wap secara kimia (CVD) bersadur karbaid. Persamaan susunan pertama dan kedua diterbitkan dengan menggunakan kaedah tndakbalas permukaan (RSM). Ciri-ciri pemotongan yang boleh diubah ialah halaju pemotongan, kadar pemotongan, dan kedalaman memotong. Kajian ini menunjukkan model yang dianggarkan, boleh dianggar pada komponen membujur kekasaran permukaan yang hampir kepada bacaan yang telah direkodkan dalam eksperimen dengan 95 peratus peringkat keyakinan. Kedua-dua persamaan menunjukkan bahawa kadar pemotongan ialah kondisi yang paling dominan pada kekasaran permukaan, diikuti oleh kedalaman pemotongan dan diikuti oleh halaju pemotongan. Kekasaran permukaan akan bertamabah apabila kadar pemotongan dan kedalaman pemotongan ditambahkan. Tetapi akan berkurang apabila halaju pemotongan ditambah. Untuk pengetahuan, susunan model yang kedua membuktikan kewujudan interaksi yang sangat kuat pada kadar pemotongan dengan kedalaman pemotongan.

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LIST OF SYMBOLS

d	Depth of Cut, mm
fr	Feed Rate, mm/rev
R_a	Surface Roughness, µm
R_t	Roughness Height
R_y	Roughness Component
V_c	Cutting Speed, m/min
x_0	Dummy Variable
x_1, x_2, and x_3	Cutting speed, feed rate and depth of cut substitute in surface roughness model.
y	Cutting power experimental value
$\hat{y}$	Cutting power predicted value
β_0, β_1, β_2, and β_3	Model parameter
ε	Experimental error

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AISI	American Iron Steel Institute
ANOVA	Analysis of Variance
BUE	Built Up Edge
CVD	Chemical Vapor Deposition
DOC	Depth of Cut
DOE	Design of Experiment
F	F-test ANOVA
FKM	Faculty of Mechanical Engineering
RSM	Response Surface Methodology

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter gives a short description of the project background including several approaches. It then introduces objectives, scopes, problem statement of this project on prediction of surface roughness in turning operation of low-carbon steel AISI 1018.

1.2 PROJECT BACKGROUND

Surface finish is an important factor in evaluating the quality of products. Surface roughness (R_a) is mostly used as an index to determine the surface finish in the machining process. Modeling techniques for the prediction of R_a can be classified into three groups which are experimental models, analytical models and Artificial Intelligence (Al)-based models (Benardos & Vosnaikos, 2003).

Surface roughness measurement presents an important task in many engineering applications (Whitehouse, 1997). Every surface has some form of texture that takes the form of peaks and valleys. These peaks and valleys vary in height and spacing and have properties inherent in the way the surface was produced or utilized. For this purpose, the response surface methodology RSM is utilized.

RSM is a group of mathematical and statistical techniques that are useful for modeling the relationship between the input parameters (cutting conditions) and the output variables (surface roughness) (Montgomer, 2001). RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. RSM has been extensively used in the prediction of responses such as tool life, surface roughness and cutting forces.

Start from design the experiments, create DOE by use RSM method in MINITAB software. After that, run the experiments use lathe machine and measure the surface roughness use perthometer. After get the experimental data, use RSM method to develop first and second order mathematical models to predict the surface roughness. Lastly, analysis the result and make the conclusion.

1.3 PROBLEM STATEMENT

Surface roughness has a major economic impact, as it is estimated that (in United States alone) the total cost of replacing worn parts and re machining cost to get the better surface finished (Kalpakjian, S. and Schmid, S., 2006). The factors that cause this problem are the operator workers didn’t use the right and suitable condition and parameters such as cutting speed, feed rate, and depth of cut during machining the work piece.

Thus, this research will give the solution to overcome this problem with modeling technique for the prediction of surface roughness by using response surface methodology (RSM) to develop prediction first and second mathematical model for surface roughness during turning low-carbon steel AISI 1018.

1.4 OBJECTIVES

i. To develop prediction first and second mathematical model for surface roughness using response surface methodology (RSM) when turning low-carbon steel AISI 1018.

ii. Investigate the relationship between cutting parameters (cutting speed, feed rate and depth of cut) with surface roughness of low carbon steel AISI 1018.

1.5 PROJECT SCOPES

In order to achieve the objectives of this project, the scopes are list as below:

i. Evaluate on the surface roughness by using the Mahrsurf XR 20 Perthometer S2 to measure the surface roughness of low-carbon steel AISI 1018 after machining using lathe machine.

ii. The constant parameters for the turning process are work pieces use is low-carbon steel AISI 1018, cold drawn, high temperature. Depth of cut, d (1.0, 1.5, 2.0) mm, tool material CVD Coated Carbide Tips, feed rate (fr = 0.20, 0.24, 0.28) mm/rev, and the range of cutting speed V_C = (400 to 600) m/min.

iii. Analysis the result (surface roughness) using response surface methodology (RSM) in MINITAB version 14 software.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Every work by using machining process that involves metal cutting process, the output of the product will result the surface roughness. Surface finish is an important factor in evaluating the quality of products. Surface roughness (R_a) is mostly used as an index to determine the surface finish in the machining process. Modeling techniques for the prediction of R_a can be classified into three groups which are experimental models, analytical models and Artificial Intelligence (Al)-based models (Benardos & Vosnaikos, 2003).

Surface roughness measurement presents an important task in many engineering applications. Every surface has some form of texture that takes the form of peaks and valleys. These peaks and valleys vary in height and spacing and have properties inherent in the way the surface was produced or utilized. The response surface methodology RSM was utilized for this experiment.

2.2 SURFACE STRUCTURE

Upon close examination of the surface of a piece of metal, it is found that it generally consists of several layers (Figure 2.1):

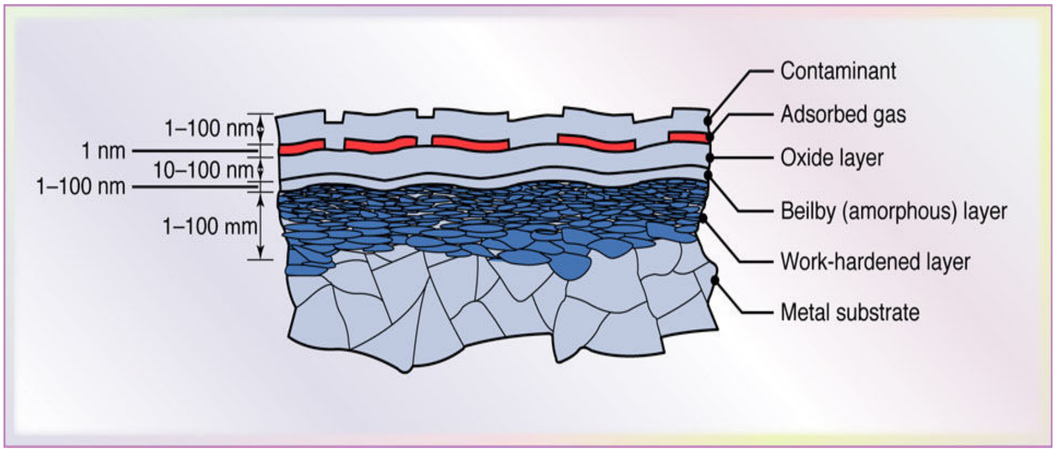


Figure 2.1: Schematic illustration of a cross-section of the surface structure of metals. The thickness of the individual layers depends on both processing conditions and processing environment.

Source: After E. Rabinowicz and B. Bhushan.

The bulk metal (also known as the metal *substrate)* has a structure that depends on the composition and processing history of the metal.

Above this bulk metal is a layer that usually has been deformed plastically and work hardener to a greater extent than the bulk during the manufacturing process. The depth and properties of the work-hardened layer (*surface structure*) depend on such factors as the processing method used and how much frictional sliding the surface undergoes (Kalpakjian, S. and Schmid, S., 2006).

Unless the metal is processed and kept in and inert (oxygen-free) environment or is a noble metal (such as gold or platinum), an *oxide layer* forms over the work-hardened layer. The oxide on a metal surface generally is much harder than the base metal, hence it is more abrasive. As a result, it has important effect on friction, wear, and lubrication.

Under normal environmental conditions, surface oxide layers generally are covered with *adsorbed* layers of gas and moisture (Kalpakjian, S. and Schmid, S., 2006).

Finally the outermost surface of the metal may be covered with *contaminants* such as dirt, dust, grease, lubricant residues, cleaning-compound residues, and pollutants from the environment (Kalpakjian, S. and Schmid, S., 2006).

It can be seen that surfaces have properties that generally are very different from those of the substrate material. The factors which pertain to the surface structures of the metals just describe also are factors in the surface structure of plastics and ceramics. The surface texture of these materials depends (as with metals) on the method of production.

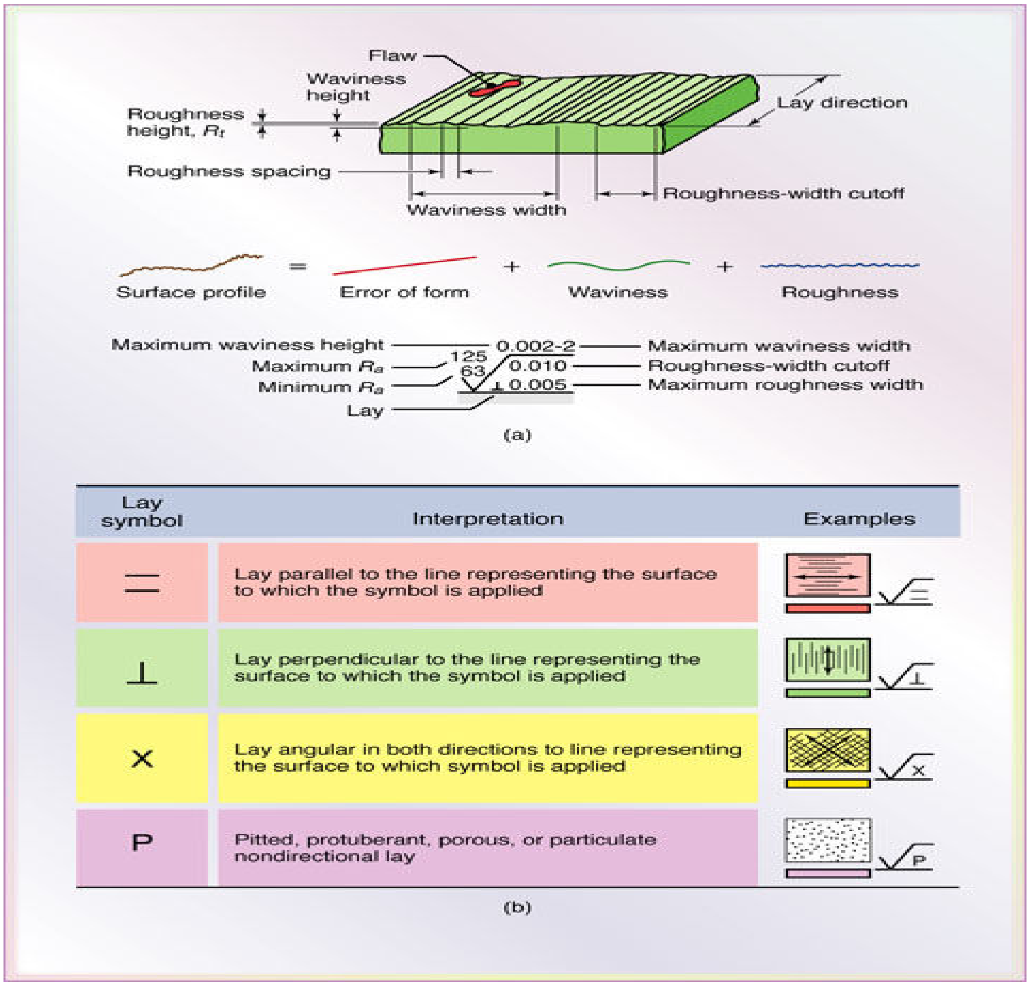
2.3 SURFACE INTEGRITY

Surface integrity describes not only the topological (geometric) feature of surface and their physical and chemical properties but their mechanical and metallurgical properties and characteristics as well. Surface integrity as in important consideration in manufacturing operations, because it influences such properties as fatigue strength, resistance to corrosion, and service life (Kalpakjian, S. and Schmid, S., 2006).

Several surface defects cause by and produced during component manufacturing can be responsible for inadequate surface integrity. These defects usually are caused by a combination of factors, such as defects in the original material, the method by which the surface is produced, and the lack proper control of the process parameters (which can result in excessive stresses, temperatures, or surface deformation).

2.4 SURFACE TEXTURE

Regardless of the method of production, all surfaces have their own characteristics, which collectively are referred to as surface texture. Although the description of surface texture as a geometrical property is complex, certain guidelines have been established for identifying surface texture in terms of well defined and measurable quantities (Figure 2.2).



Lay symbol	Interpretation	Examples
=	Lay parallel to the line representing the surface to which the symbol is applied	
⊥	Lay perpendicular to the line representing the surface to which the symbol is applied	
X	Lay angular in both directions to line representing the surface to which symbol is applied	
P	Pitted, protuberant, porous, or particulate nondirectional lay	

Figure 2.2: (a) Standard terminology and symbols used to describe surface finish. The quantities are given in μin. (b) Common surface lay symbols.

Source: Kalpakjian, S. and Schmid, S.

- **Flaws** or **defects** are random irregularities, such as scratches, cracks, holes, depressions, seams, tears, or inclusions.
- **Lay (directionality)** is the direction of the predominant surface pattern, usually visible to the naked eye.

- **Roughness** is defined as closely spaced, irregular deviation on a small scale; it is expressed in terms of its height, width, and distance along the surface.
- **Waviness** is a recurrent deviation from a flat surface; it is measured and described in term of the space between adjacent crest of the waves (*waviness width*) and height between the crests and valleys of the waves *(waviness height).*

2.5 SURFACE ROUGHNESS

Surface roughness is the measure if the finer surface irregularities in the surface texture. The final surface depends on the rotational speed of the cutter, velocity of traverse, feed rate and mechanical properties of work pieces being machined. Type and amounts of lubricant use at the point of cutting also influence the surface produce. A small change in any of the factor above can have a significant effect on the surface finish (Kalpakjian, S. and Schmid, S., 2006).

Surface roughness generally is described by two methods. The **arithmetic mean value (R_a)** is based on the schematic illustration of a rough surface, as shown in Figure 2.3. Where all ordinates a, b, c . . . , are absolute values and *n* is the number of readings. It is defined as

$$R_a = \frac{a+b+c+d+\dots}{n} \qquad (2.1)$$

$$R_q = \sqrt{\frac{a^2+b^2+c^2+d^2+\dots}{n}} \qquad (2.2)$$

The datum line AB in Figure 2.3 is located so that the sum of the areas above the line is equal to the sum of the areas below the line. The maximum roughness height (R_t) also can be used and is defined as the height from the deepest through to the highest peak. It indicates how much material has to be removed in order to obtain a smooth surface, such as by polishing.

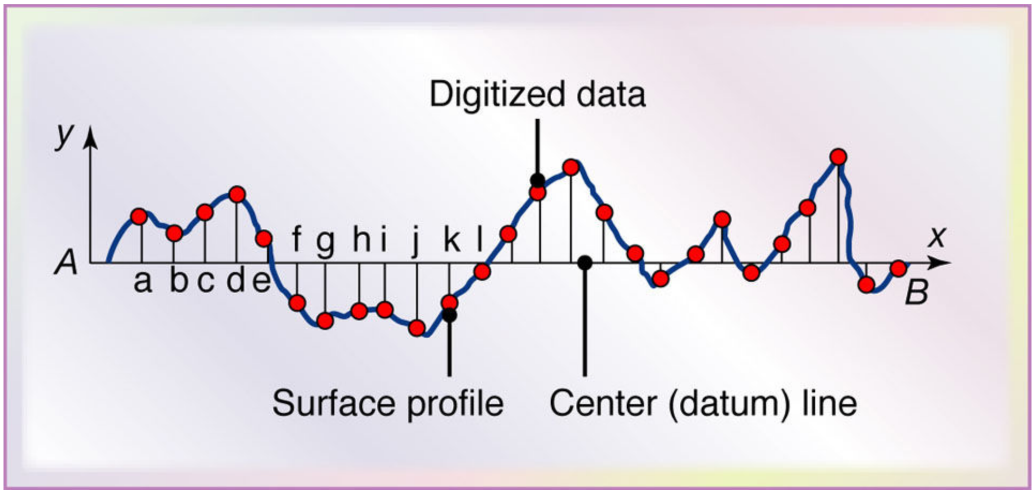


Figure 2.3: Coordinates used for surface-roughness measurement using equation (2.1) and (2.2).

Source: Kalpakjian, S. and Schmid, S.

According to Kalpakjian and Schmid, in general, a surface cannot be described by its R_a or R_q value alone, since these values are averages. Two surfaces may have the same roughness value but have actual topography which is very different. However the type of surface profile can be significant in term of friction, wear, and fatigue characteristics of a manufactured product. Consequently, it is important to analyze a surface in great detail, particularly for parts to be used in critical applications.

2.5.1 Symbols for Surface Roughness

Acceptable limits for surface roughness are specified on technical drawings by symbols, typically shown around the check mark in the lower portion of figure 2.2 (a), and the values of these limits are placed to the left of the check mark. The symbols and their meanings concerning the lay are given in Figure 2.2 (b).

Note that the symbol for the lay is placed at the lower right of the check mark. Symbols used to describe a surface specify only its roughness, waviness, and lay; they do not include flaws. Therefore, whenever necessary, a special note is included in technical drawings to describe the method which should be used to inspect for surface flaws (Kalpakjian, S. and Schmid, S., 2006).

2.5.2 Measuring Surface Roughness

Typically, instruments called surface profilometer are used to measure and record surface roughness. A profilometer has a diamond stylus that travel along straight line over the surface (Figure 2.4). The distance that the stylus travel is called the **cutoff**, this generally ranges from 0.08 to 25mm. A cutoff of 0.8mm is typical for most engineering applications (Kalpakjian, S. and Schmid, S., 2006). The rule of thumb is that the cutoff must be large enough to include 10 to 15 roughness irregularities, as well as all surface waviness.

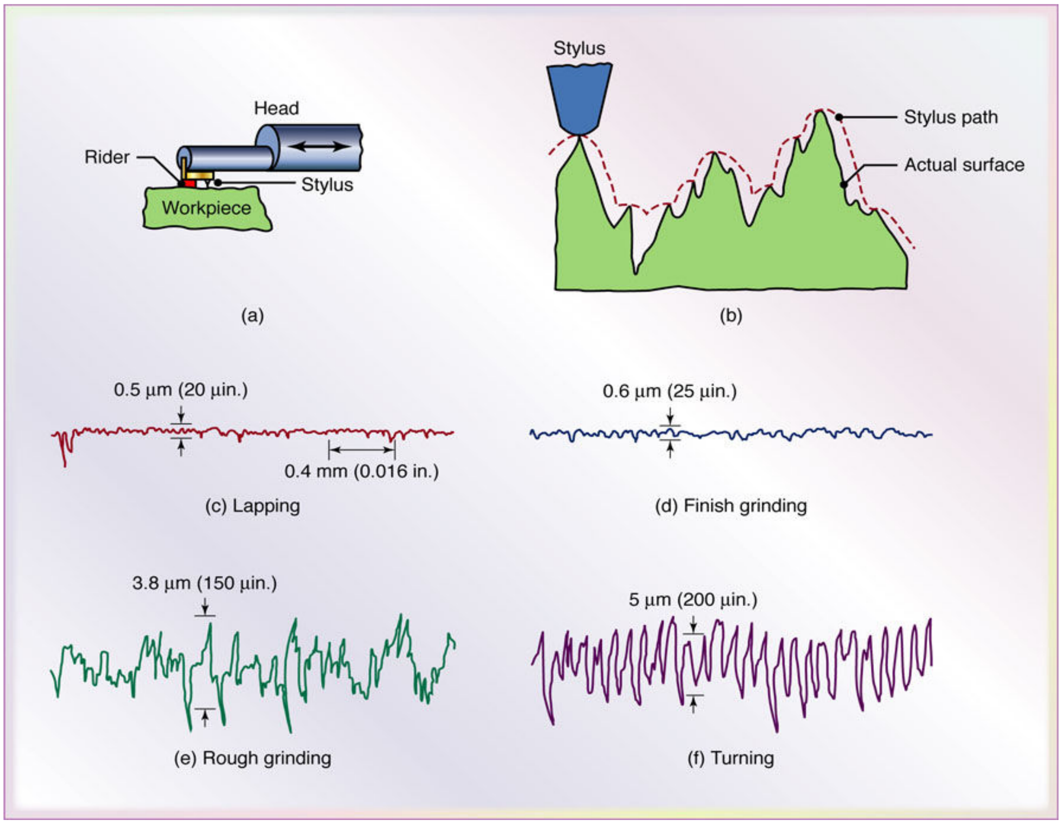


Figure 2.4: (a) Measuring surface roughness with a stylus. The rider supports the stylus and guards against damage. (b) Path of the stylus in surface-roughness measurements (broken line) compared to the actual roughness profile. Note that the profile of the stylus path is smoother than that of the actual surface. (c) Through (f) Typical surface profiles produced by various machining and surface-finishing processes. Note the difference between the vertical and horizontal scales.

Source: Kalpakjian, S. and Schmid, S.

In order to highlight the roughness, profilometer traces are recorded on exaggerated vertical scale (a few orders of magnitude larger than the horizontal scale; see Figure 2.4(c) through (f)); the magnitude of the scale is called **gain** on the recording instrument. Thus, the recorded profile is distorted significantly, and the surface appears to be much rougher than it actually is. The recording instrument compensates for any surface waviness; it indicates only roughness.

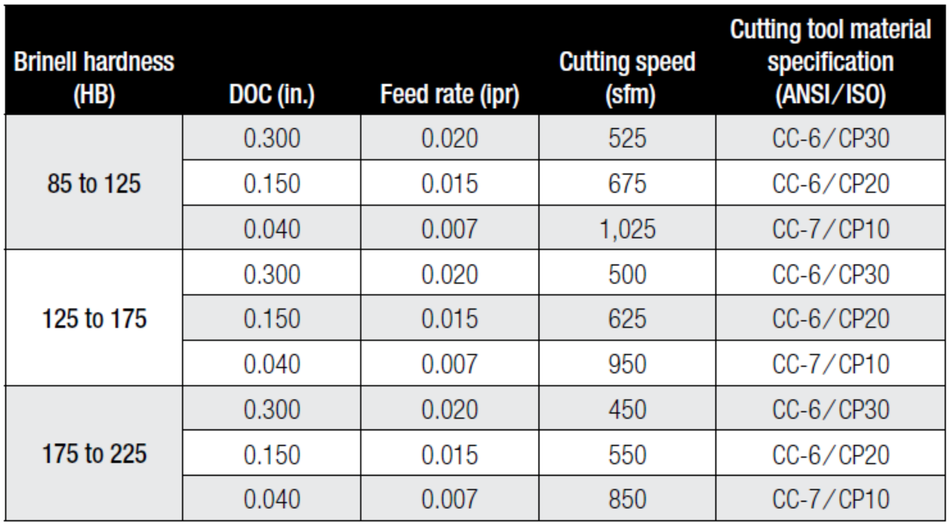
Because of the finite radius of the diamond stylus tip, the path of the stylus is different than the actual surface (note the path with the broken line in Figure 2.4(b)), and the measure roughness is lower. The most commonly used stylus-tip diameter is 10µm. the smaller the stylus diameter and the smoother the surface, the closer is the path of the stylus to the actual surface profile (Kalpakjian, S. and Schmid, S., 2006).

Surface roughness can be observed directly through on *optical* or *scanning electron microscope.* Stereoscopic photographs are useful particularly for three dimensional views of surfaces and also can be used to measure surface roughness.

2.6 MATERIAL

The material for evaluation of the surface roughness is low-carbon steel AISI 1018, cold drawn, high temperature. This metal consists of 0.06 to 0.28 percent carbons and 0.25 to 1.00 percent manganese. Low-carbon steels are limited to 0.040 percent phosphorus and 0.050 percent sulfur (Isakov, E. 2007).

Table 2.1: Parameters for low-carbon steels AISI 1016, 1017, 1018, 1019, 1021, and 1022 grades.



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

Source: Isakov, E. (2007)

Currently, there are 16 standard grades of low carbon steels (See Table 2.1). When turned, low-carbon steels produce long chips, which will form built-up edge on an index able insert if a chip breaker doesn't create a sufficient shear angle to curl the chip away from the insert's rake face. Low cutting speed is another cause of BUE, which acts as an extension of the cutting tool, changing part dimensions and imparting rough surface finishes. When that's the case, the cutting speed should be increased 15 to 20 percent or more until the surface finish improves (Isakov, E. 2007).

The appropriate cutting speed depends on the DOC, feed rate, cutting tool material and hardness of the work piece. Selecting the cutting speed is always a challenge. Usually, the DOC and feed rate are conservative parameters predetermined by whether it's a roughing, semi-finishing or finishing operation (Isakov, E. 2007).

2.7 TURNING PROCESS

According to Kalpakjian, S. and Schmid, S., one of the most basic machining processes is turning, meaning that the part is rotated while it is being machined. The starting material is generally a work piece that has been made by other process, such as casting, forging, extrusion, or powder metallurgy. Turning processes which typically are carried out on a *lathe* (Figure 2.6) or similar machine tools are outlined in Figure 2.5. These machines are very versatile and capable of producing a wide variety of shapes as outlined below:

- **Turning:** to produce straight, conical, curved or grooved work piece (Fig. 2.5 a through d), such as shafts, spindles and pin.

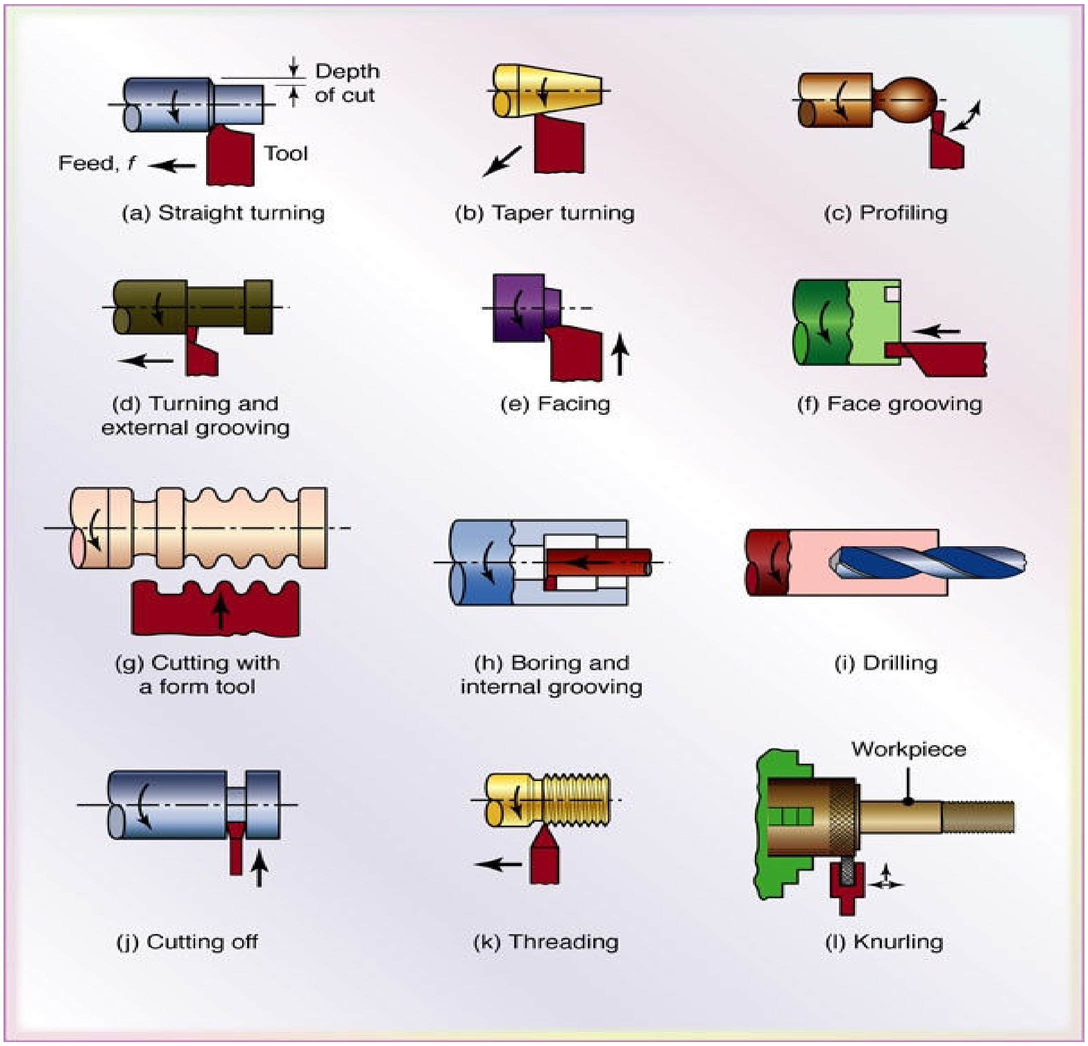


Figure 2.5: Miscellaneous cutting operations that can be performed on a lathe. Note that all parts are circular – a property known as axisymmetry.

Source: Kalpakjian, S. and Schmid, S.

- **Facing:** to produce a flat surface at the end of the part and perpendicular to its axis (Fig. 2.5 e), useful for parts that are assembled with other components. Face grooving produces grooves for application such as O-ring seats (Fig. 2.5 f).
- **Cutting with form tools:** (Fig. 2.5 g) to produce various axisymmetric shapes for functional or aesthetic purposes.

- **Boring:** to enlarge a hole or cylindrical cavity made by a previous process or to produce circular internal grooves (Fig. 2.5 h).
- **Drilling:** to produce a hole (Fig. 2.5 i), which may be followed by boring to improve it s dimensional accuracy and surface finish.
- **Parting:** also called cutting off, to cut a piece from the end of a part, as is done in the production of slugs or blanks for additional processing into discrete products (Fig. 2.5 j).
- **Threading:** to produce external or internal threads (Fig. 2.5 k).
- **Knurling:** to produce a regularly shaped roughness on cylindrical surfaces, as in making knobs (Fig. 2.5 l).

The cutting operation summarize typically are performed on a lathe (Figure 2.6) which is available in a variety of designs, sizes, capacities and computer-controlled feature.

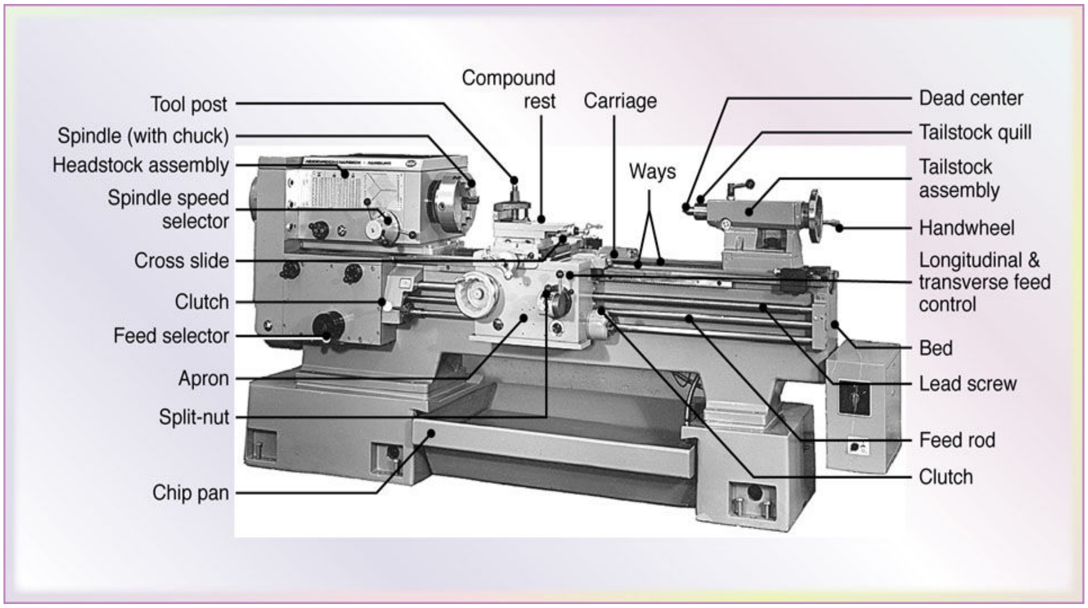


Figure 2.6: General view of a typical lathe, showing various components.

Source: Courtesy of Heidenreich & Harbeck.

The majority of turning operations involve the use of simple single-point cutting tools, with the geometry of a typical right-hand cutting tool shown in (Figure 2.7). As can be seen, such tools are described by a standardized nomenclature. Each group of work piece materials has an optimum set of tool angles, which have been developed largely through experience.

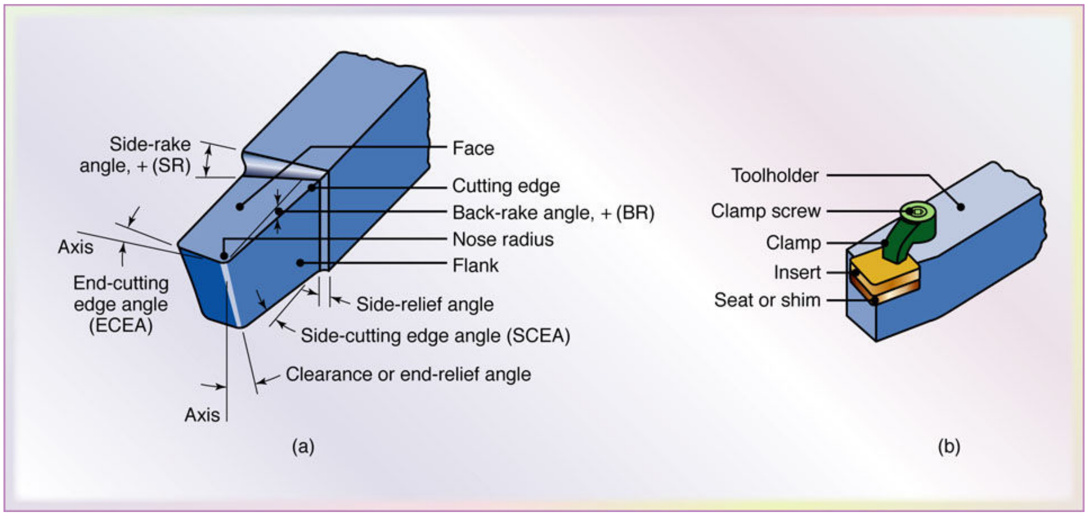


Figure 2.7: (a) Schematic illustration of right-hand cutting tool. Although these tools traditionally have been produced from solid tool-steel bars, they have been replaced largely with (b) inserts made of carbides and other materials of various shapes and sizes.

Source: Kalpakjian, S. and Schmid, S.

2.8 RESPONSE SURFACE METHODOLOGY (RSM)

Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response variable (output variable), which is influenced by several independent design variables (input variables). An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

Originally, RSM has been developed to model experimental responses and then migrated into the modeling of numerical experiments. The difference is in the type of error generated by the response. In physical experiments, inaccuracy can be due to measurement errors whereas in numerical experiments, errors may due to incomplete convergence of the iterative process, round-off errors and the discrete representation of continuous physical phenomena. In RSM, the errors are assumed to be random.

RSM is a methodology of constructing approximations of the system behavior using results of the response analyses calculated at a series of points in the design variable space. Optimization of RSM can be solved in the following three stages:

- Design of experiment.
- Building the response surface model.
- Solution of minimization/maximization problem according to the criterion selected.

RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously. RSM has been extensively used in the prediction of responses such as tool life, surface roughness and cutting forces (Kadirgama, K., Abou-El-Hossein, K. A. 2008).

Mead and Pike and Hill and Hunter reviewed the earliest work on Response Surface Method (RSM). In order to institute an adequate functional relationship between the surface roughness and the cutting parameters (speed, depth of cut and feeds), a large number of tests are required, requiring a separate set of tests for each and every combination of cutting tool and work piece material.

CHAPTER 3

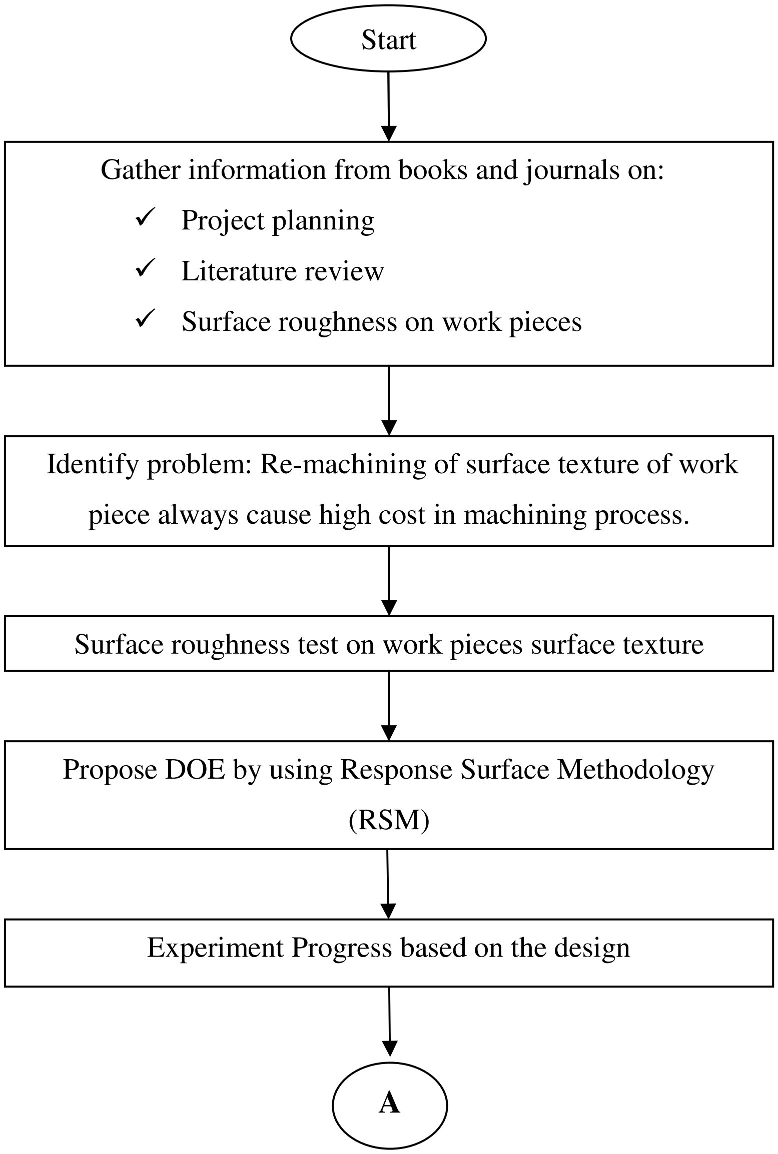
METHODOLOGY

3.1 INTRODUCTION

Chapter 3 discusses methodology of the project in general, with a specific focus on prediction of surface roughness in turning operation of low-carbon steel AISI 1018. The work is based on methodology flow chart. Chapter 3 presents current progress on research by surface roughness. Understanding prior and current research in this project provides method for the research contributions outlined in subsequent chapters.

3.2 METHODOLOGY FLOW CHART

Methodology flow chart is use as guidelines and the sequences to make this project go with a swing. As illustrated in Figure 3.1, firstly literature review was been study with the field that regards to this project. Then, the process begins with modeling and defines surface roughness. In this experiment, the constant range of cutting speed from 400m/min to 600m/min; the depth of cut and feed rate were kept constant too during the test period with values of 1, 1.5, 2mm, and 0.20, 0.24, 0.28mm/rev respectively.


Start
Gather information from books and journals on:
✓ Project planning
✓ Literature review
✓ Surface roughness on work pieces
Identify problem: Re-machining of surface texture of work piece always cause high cost in machining process.
Surface roughness test on work pieces surface texture
Propose DOE by using Response Surface Methodology (RSM)
Experiment Progress based on the design
A

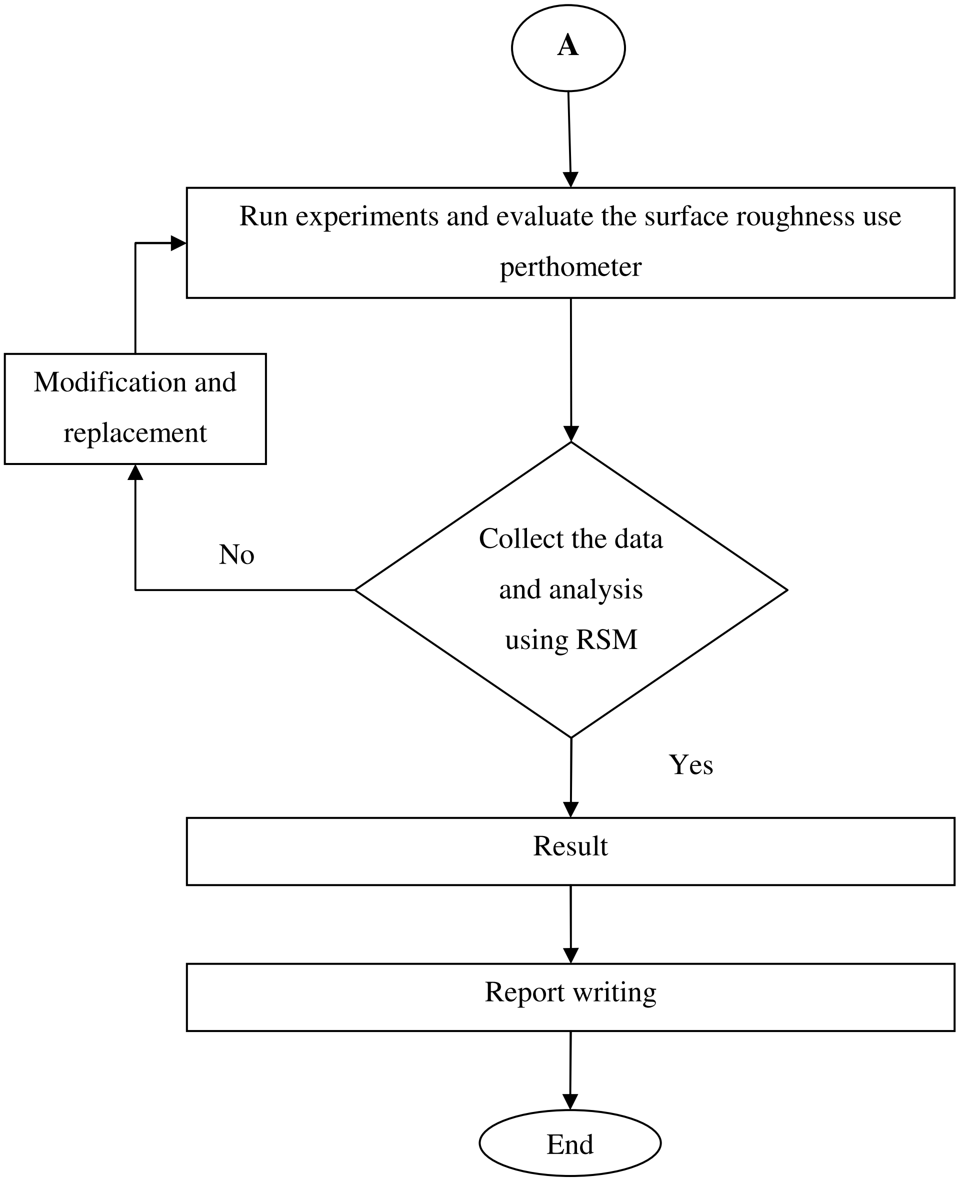


Figure 3.1: Methodology flow chart

3.3 METHODOLOGY

Methodology is a main part in any project or experimental where it specifically describes the methods and steps by steps to do the project. Methodologies also as guidance to the experimenter does the correct steps and ensure they are following the project flow as planed in the beginning. Methodology also can make the progress run smooth and clearly until we achieved the project objectives and get the result truly. Below is the flow of project procedures from above flow charts to achieve the project objectives.

3.3.1 Gather Information and Construct Literature Review

Finding all information related to the title from journals, books, and websites to give better understanding about this title and to construct the literature review. Understand about prediction concept is the main target in this project and the factors that affect the surface roughness of the metal. So, knowledge of knowing how to measure and analyze the surface roughness is very important to run this research.

3.3.2 Material and Cutting Tools Preparation

The material for this experiment is AISI 1018 Low-carbon steel, cold drawn, high temperature. The dimension of this material is 200mm x 50mm cylindrical bar (Figure 3.2).

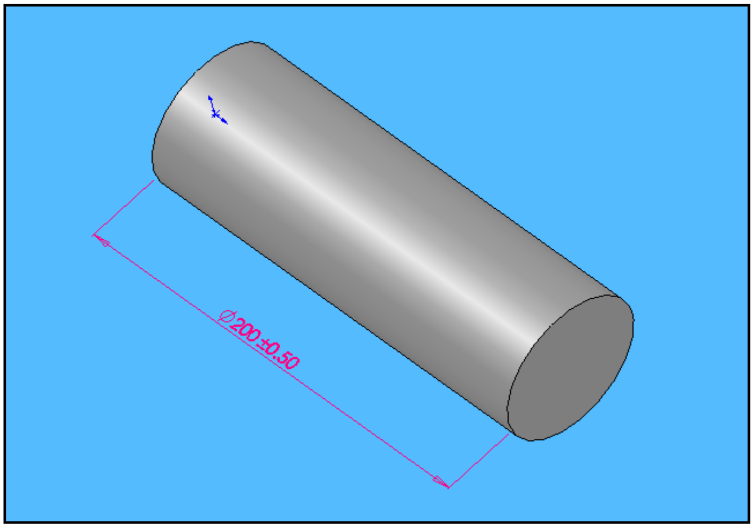


Figure 3.2: Low-carbon steel AISI 1018, 200mm x 50mm cylinder bar.

The cutting tool will be used in this research is insert carbide. The type of insert is CVD Coated Carbide Tips inserts.

Figure 3.3: Triangle shape CVD Coated Carbide Tips inserts for lathe machine.

Source: FKM laboratory.

The figure above (Figure 3.3) is the insert carbide used to run the experiments. The shape is triangle shape with the angle is 60º.

3.3.3 Propose DOE by Using Response Surface Methodology (RSM)

The experimentation for this work was based on RSM design of experiments (DOE). A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, RSM design was used to study the entire parameter space with a small number of experiments only. RSM saves cost and time on conducting metal cutting experiments by reducing the overall number of required tests. In addition, RSM helps describe and identify, with a great accuracy, the effect of the interactions of different independent variables on the response when they are varied simultaneously (C.R. Hicks. 1993; W.J. Hill and W.G. Hunter. 1966; R. Mead, D.J. Pike. 1975). In this study, three cutting parameter namely, cutting speed, depth of cut and feed rate were take part in this study.

To generate the table of experiments, select Response Surface as Design of Experiment, DOE and create Response Surface Design as shown in Figure 3.4 below.

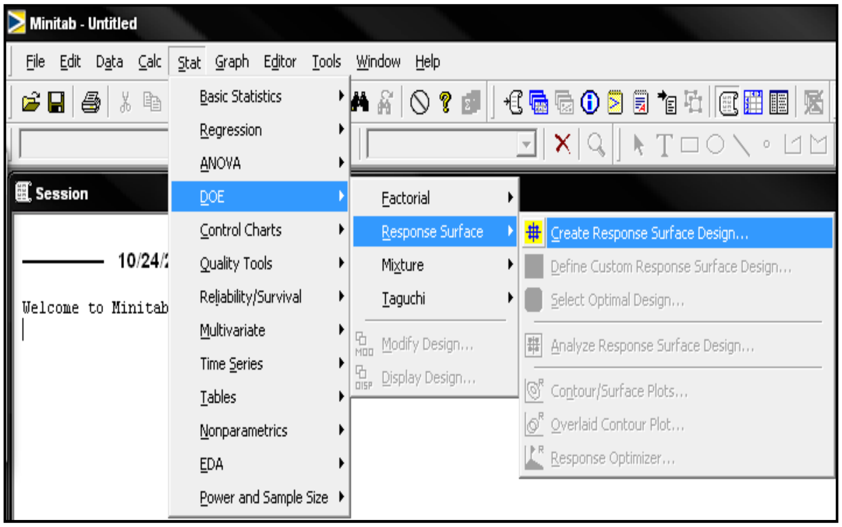
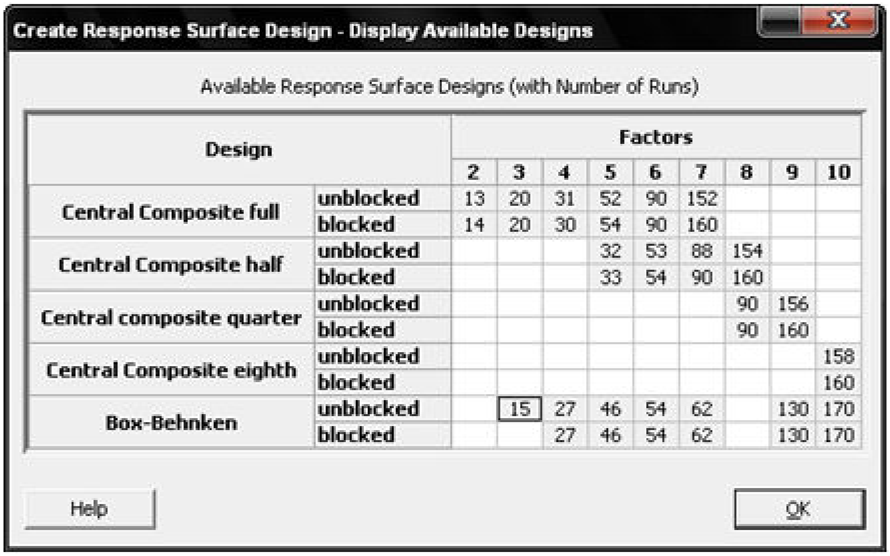


Figure 3.4: Method to generate Response Surface Design

Type of the design used is Box Behnken with 3 factors since the factors (parameters) are three which are cutting speed, feed rate and depth of cut. So, the estimation number of



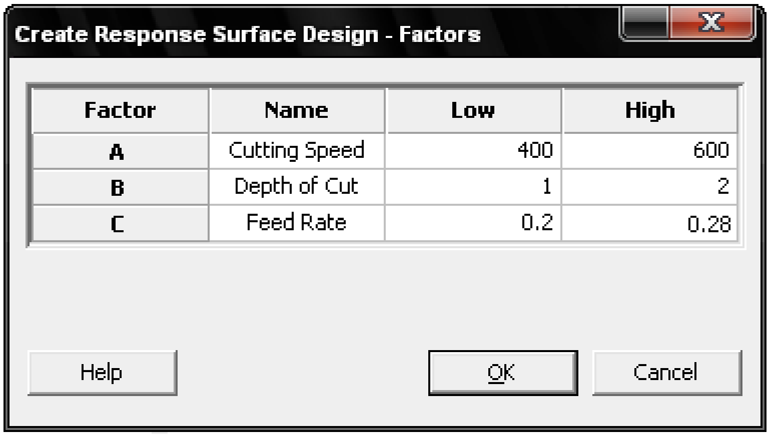
Available Response Surface Designs (with Number of Runs)

Design		Factors								
		2	3	4	5	6	7	8	9	10
Central Composite full	unblocked	13	20	31	52	90	152			
	blocked	14	20	30	54	90	160			
Central Composite half	unblocked				32	53	88	154		
	blocked				33	54	90	160		
Central composite quarter	unblocked							90	156	
	blocked							90	160	
Central Composite eighth	unblocked									158
	blocked									160
Box-Behnken	unblocked		15	27	46	54	62		130	170
	blocked			27	46	54	62		130	170

Figure 3.5: The estimation for 3 factors and unblocked Box-Behnken design is 15 experiments number.

the experiments are 15 experiments (Figure 3.5) for 3 factors and unblocked Box-Behnken design.

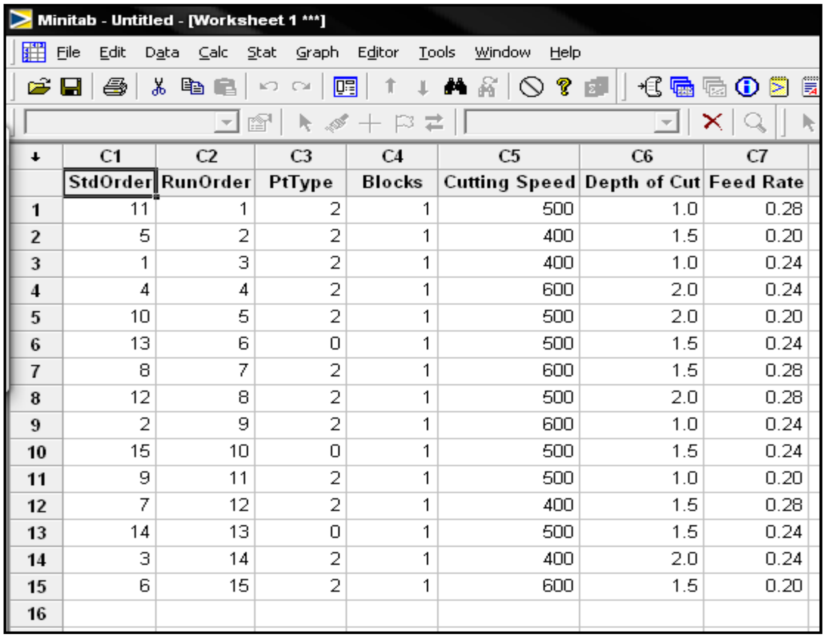
Declaration for all parameters limitation is the next step. Figure 3.6 below show the declaration of the limitation for all the three parameters.



Factor	Name	Low	High
A	Cutting Speed	400	600
B	Depth of Cut	1	2
C	Feed Rate	0.2	0.28

Figure 3.6: Declare the limitation for all parameters value.

As the result, the table of the experiment will come out (Figure 3.7) and used the table to run the experiments for this project.



↓	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	PtType	Blocks	Cutting Speed	Depth of Cut	Feed Rate
1	11	1	2	1	500	1.0	0.28
2	5	2	2	1	400	1.5	0.20
3	1	3	2	1	400	1.0	0.24
4	4	4	2	1	600	2.0	0.24
5	10	5	2	1	500	2.0	0.20
6	13	6	0	1	500	1.5	0.24
7	8	7	2	1	600	1.5	0.28
8	12	8	2	1	500	2.0	0.28
9	2	9	2	1	600	1.0	0.24
10	15	10	0	1	500	1.5	0.24
11	9	11	2	1	500	1.0	0.20
12	7	12	2	1	400	1.5	0.28
13	14	13	0	1	500	1.5	0.24
14	3	14	2	1	400	2.0	0.24
15	6	15	2	1	600	1.5	0.20
16							

Figure 3.7: Table of experiments generated for this project.

Table 3.1: Design of Experiment by RSM Method.

Experiments No.	Cutting Speed, V_C (m/min)	Depth of Cut (mm)	Feed Rate, *fr* (mm/rev)
1.	400	1.5	0.2
2.	400	1	0.24
3.	400	2	0.24
4.	400	1.5	0.28
5.	500	1	0.2
6.	500	1.5	0.24
7.	500	1	0.28
8.	500	1.5	0.24
9.	500	2	0.28
10.	500	1.5	0.24
11.	500	2	0.2
12.	600	1	0.24
13.	600	1.5	0.28
14.	600	2	0.24
15.	600	1.5	0.2

Table 3.2: Levels of independent variables

Factors	Coding of levels		
	-1	**0**	**1**
Cutting speed, V_C (m/min)	400	500	600
Feed Rate, f (mm/rev)	0.2	0.24	0.28
Depth of Cut (mm)	1	1.5	2

3.3.4 Machining Process

Start to make the machining processes which are cutting process by use lathe machine (Fig. 3.8) based on the table generated of RSM (Table 3.1) to get surface texture and measure the surface roughness value on the work piece texture by using perthometer. Handle the process with the values of cutting speeds, feed rates and depth of cut as in the table generated (Table 3.1).

Figure 3.8: Conventional lathe machine will be used.

Source: FKM laboratory

Experimental Setup

Machine: Conventional Lathe Machine
Cutting tools: CVD Coated Carbide Tips inserts (Figure 3.3).
Material: Low-Carbon steel AISI 1018 round bars (200mm X 50mm) Low-carbon steel.
Tools: Center drill, vernier caliper.

Machine: Mahrsurf XR 20 Perthometer S2
Material: Low-Carbon steel AISI 1018 round bars (200mm X 50mm) Low-carbon steel work piece.
Tools: Work piece clamp.

3.3.5 Analyze the Collected Data

After all the data and measured values recorded, start analyzes to get the result of first and second surface roughness prediction use RSM analysis.

3.3.6 Report Writing

After finishing analysis on the prediction of surface roughness, the result of analysis, data and calculation from the experiment will be compiling into a thesis.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter shows the validation and evaluation of development of first order and second order surface roughness models using Response Surface Methodology (RSM) to analysis surface roughness, R_a (µm) during the turning process.

4.2 MODEL FOR SURFACE ROUGHNESS

According to the response surface method, where the response variable is the surface roughness in this study, the relationship between the investigated three cutting conditions and the response can be represented by the following linear equation:

$$\ln R = A \ln V_C + B \ln f + C \ln d + E \tag{4.1}$$

where R is the surface roughness, $R_{a,}$ µm (response), A, B, C, and E are constants, while Vc, f, and d are cutting speed (m/min), feed rate (mm/rev), and depth of cut (mm) respectively. Equation 4.1 also can be written as follows:

$$y = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \ or$$
$$\hat{y} = y - \varepsilon = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \tag{4.2}$$

where y is the surface roughness experimental value and $\hat{y}$ is the predicted value, while x_0, x_1, x_2, x_3, and ε are dummy variable ($x_0 = 1$), cutting speed, feed rate, depth of cut and experimental error, respectively. β_0, β_1, β_2 and β_3 are the model parameters.

In most cases, the response surface variables demonstrate some curvature in most ranges of the cutting parameters. Therefore, it would be useful to consider also the second order model in this study. The second order model helps understand the second order effect of each factor separately and the two-way interaction amongst these factors combined. This model can be represented by the following equation:

$$\hat{y}'' = \beta_0 x_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x^2{}_1 + \beta_{22} x^2{}_2 + \beta_{33} x^2{}_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 \qquad (4.3)$$

4.3 DEVELOPMENT OF FIRST ORDER SURFACE ROUGHNESS MODEL

After conducting the 15 machining experiments, the surface roughness were measured by using perthometer to get the value of surface roughness for each condition parameter. The readings are used to find the parameters appearing in the postulated first

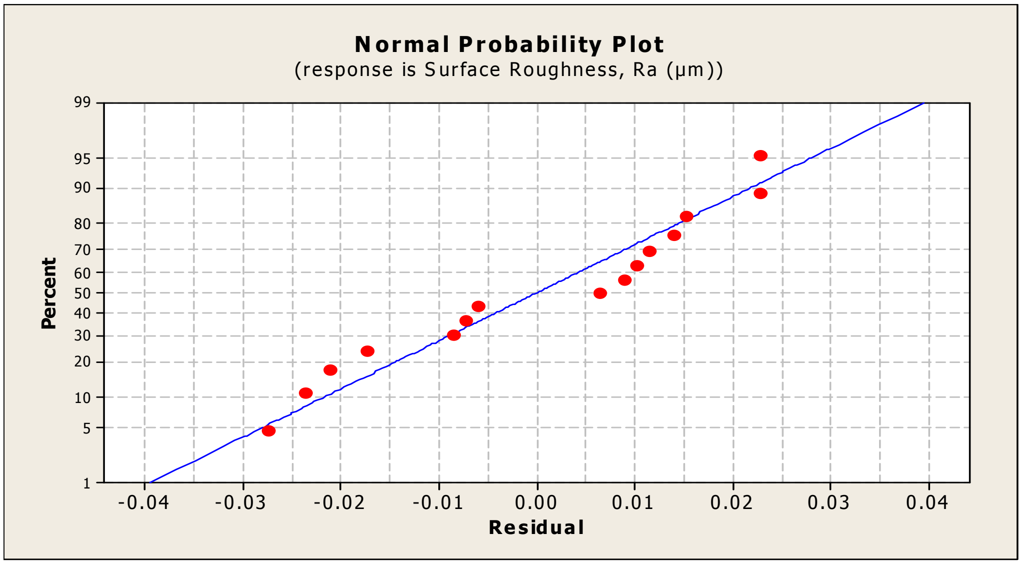


Figure 4.1: 1st order linear normal probability plot of residual.

order model (Equation 4.2). To do the calculation of these parameters, the method of least square is used with the aid of MINITAB software. Graph (Figure 4.1) above shows the normal probability plot of the residual generated from MINITAB based on first order linear equation. Table 4.1 below shows estimated regression coefficients for surface roughness, R_a (µm) using data in uncoded units.

Table 4.1 Estimated Regression Coefficients for surface roughness, R_a (µm) using data in uncoded units.

Term	**Coefficient**
Constant	2.23233
Cutting Speed, V_c (m/min)	$-5.875e^{-4}$
Depth of Cut, d (mm)	0.0025
Feed rate, fr (mm/rev)	0.6875

Next, the first order linear equation for predicting the surface roughness can be expressed as Equation 4.4 below.

$$\hat{y} = 2.23233 - 5.875e^{-4}x_1 + 0.0025x_2 + 0.6875x_3 \tag{4.4}$$

From this linear equation, one can easily notice that the response $\hat{y}$ (surface roughness) is affected significantly by the feed rate, followed by depth of cut and lastly, by the cutting speed.

Generally, the increase in the feed rate and depths of cut will cause the surface roughness to become larger. The proposed linear equation is valid only for cutting AISI 1018 with turning machine equipped with CVD Coated Carbide Tips inserts and within the cutting conditions ranges used in the experimentation. Table 4.2 below shows the surface roughness values received by experimentation and the values predicted by the first order model.

Table 4.2: Comparison between experiment results for surface roughness and predicted results generated by first order model

Experiments Number	**Cutting Speed, V_c (m/min)**	**Depth of Cut, d (mm)**	**Feed Rate, fr (mm/rev)**	**Experimental Results, R_a (µm)**	**Predicted Result, R_a (µm)**
1.	400	1	0.24	2.18	2.1648
2.	500	1	0.2	2.07	2.0785
3.	500	1	0.28	2.11	2.1335
4.	600	1	0.24	2.07	2.0473
5.	400	1.5	0.2	2.15	2.1385
6.	400	1.5	0.28	2.2	2.1935
7.	500	1.5	0.24	2.09	2.107
8.	500	1.5	0.24	2.1	2.1073
9.	500	1.5	0.24	2.08	2.1073
10.	600	1.5	0.28	2.09	2.0761
11.	600	1.5	0.2	2.03	2.0211
12.	400	2	0.24	2.19	2.1673
13.	500	2	0.28	2.13	2.136
14.	500	2	0.2	2.06	2.0811
15.	600	2	0.24	2.06	2.0498

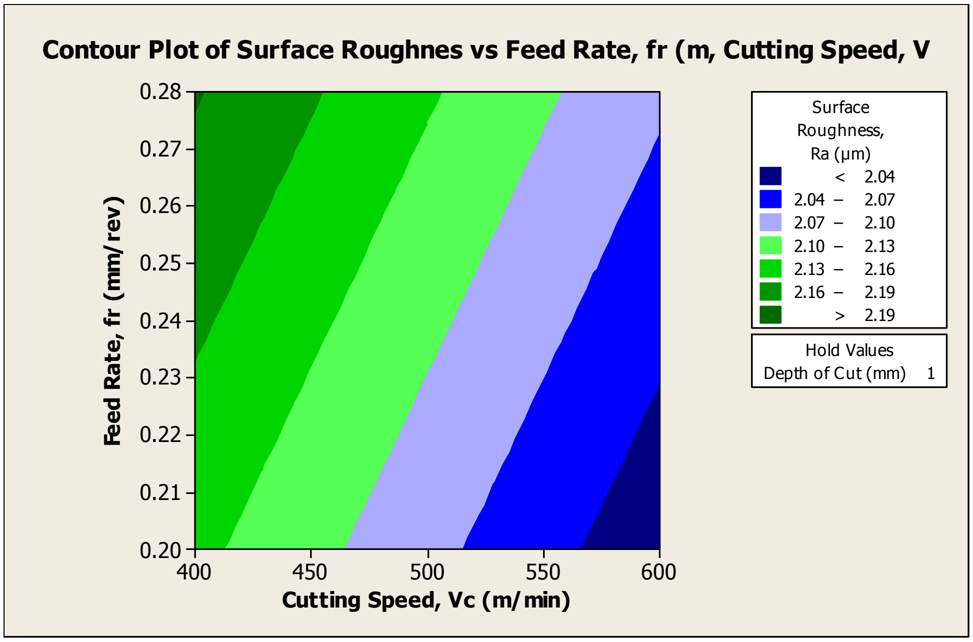
It is clear that the predicted values are very close to the experimental readings. This indicates that the obtained linear model is able to provide, to a great extent, accurate values of surface roughness.

The adequacy of the first order model was verified using the analysis of variance (ANOVA). At a level of confidence of 95%, the model was checked for its adequacy. The lack-of-fit F-value of 4.24 is not significant with relative to the pure error and this implies that the model could fit and it is adequate. There is about a chance of 20.5% that the lack-of-fit F-value could occur due to noise as shown in Table 4.3 below.

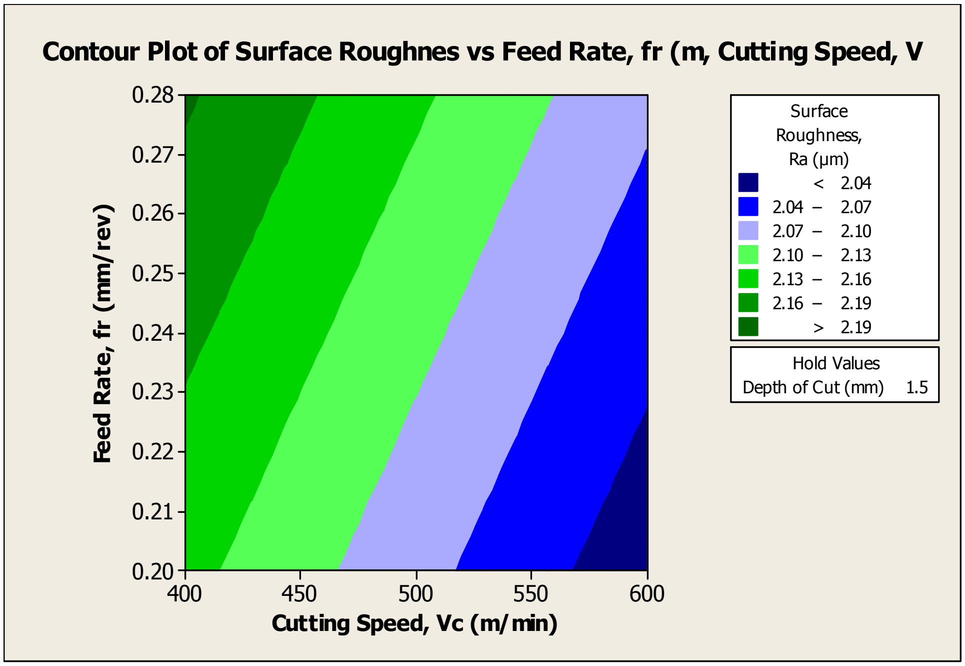
Table 4.3: Analysis of variance ANOVA for first order equation

Source of variation	**Degree of freedom (*d.f.*)**	**Sum of squares (*SS*)**	**Mean squares (*MS*)**	***F***	***P***
Zero order term	3	0.033675	0.011225	30.73	0.000
Residual error	11	0.004018	0.000365		
• Lack-of-fit	9	0.003818	0.000424	4.24	0.205
• Pure error	2	0.000200	0.000100		
Total	14	0.037693			

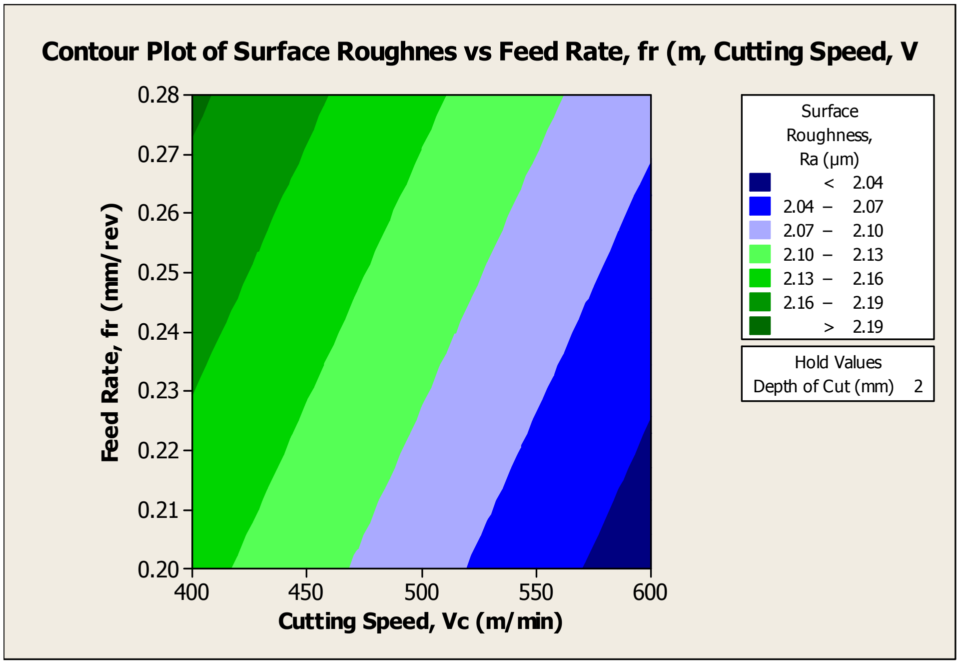
The developed linear model equation 4.4 was used to plot contours of the surface roughness at different values of the feed rate. Figure 4.2 below shows the surface roughness contours at three different combinations of the depth of cut (lowest "−1", middle "0", and highest values "+1"). It is clear that the increasing in feed rate and decrease the cutting speed will cause the surface roughness to increase dramatically. From Fig. 4.2(c) below, the surface roughness reaches its highest value when depth of cut and feed rate conditions at their maximum values and the cutting speed in lowest value. In this case the cutting speed is at its smallest value (400 m/min).



(a) Depth of cut = 1mm



(b) Depth of cut = 1.5mm



(c) Depth of cut = 2mm

Figure 4.2: Surface roughness contours in cutting speed–feed rate plane for different combinations of depth of cut plotted from first order model: (a) Depth of cut = 1mm (lowest values); (b) Depth of cut = 1.5mm (middle values); (c) Depth of cut = 2mm (highest values).

Source: MINITAB Ver. 14

4.4 DEVELOPMENT OF SECOND ORDER SURFACE ROUGHNESS MODEL

The second order equation was established to describe the effect of the three cutting conditions investigated in this study on the surface roughness. The model is obtained using the Box–Behnken design.

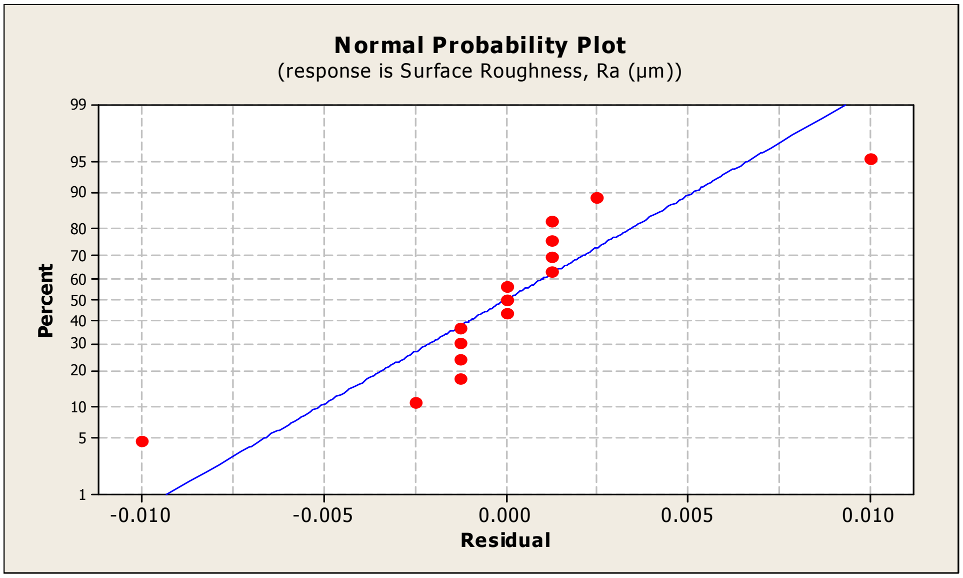


Figure 4.3: 2nd order full quadratic normal probability plot of residual.

Source MINITAB ver. 14

Graph above (Figure 4.3) shows the normal probability plot of the residual generated from MINITAB based on second order equation.

Table 4.4 below shows estimated regression coefficients for surface roughness, R_a (µm) using data in uncoded units.

Table 4.4 Estimated Regression Coefficients for Surface Roughness, R_a (µm) using data in uncoded units.

Term	**Coefficient**
Constant	3.055
Cutting Speed, V_c (m/min)	–0.0035875
Depth of Cut, *d* (mm)	–0.0975
Feed Rate, *fr* (mm/rev)	0.5625
Cutting Speed, V_c (m/min)*Cutting Speed, V_c (m/min)	$3e^{-6}$

Depth of Cut, *d* (mm)*Depth of Cut, *d* (mm)	−0.02
Feed Rate, *fr* (mm/rev)*Feed Rate, *fr* (mm/rev)	−1.5625
Cutting Speed, V_c (m/min)*Depth of Cut, *d* (mm)	$-1e^{-4}$
Cutting Speed, V_c (m/min)*Feed Rate, *fr* (mm/rev)	0.000625
Depth of Cut, *d* (mm)*Feed Rate, *fr* (mm/rev)	0.375

Next, the model is obtained using the Box–Behnken design and the equation (4.5) can be written as below:

$$\hat{y}'' = 3.055 - 0.0035875x_1 - 0.0975x_2 + 0.5625x_3 + 3e^{-6}x^2_1 - 0.02x^2_2 - 1.5625x^2_3 \\ -1e^{-4}x_1x_2 + 0.000625x_1x_3 - 0.375x_2x_3 \qquad (4.5)$$

The model shows that the surface roughness decreased when feed rate, depth of cut is reduced and increase the cutting speed. The surface roughness readings obtained experimentally and predicted values by this equation are shown in table (Table 4.5) below.

Table 4.5 Comparison between experimental results of surface roughness and predicted results generated by second order model.

Experiments Number	**Cutting Speed, V_c (m/min)**	**Depth of Cut, *d* (mm)**	**Feed Rate, *fr* (mm/rev)**	**Experimental Results, R_a (µm)**	**Predicted Result, R_a (µm)**
1.	400	1	0.24	2.18	2.1775
2.	500	1	0.2	2.07	2.0713
3.	500	1	0.28	2.11	2.1113
4.	600	1	0.24	2.07	2.07
5.	400	1.5	0.2	2.15	2.1513
6.	400	1.5	0.28	2.2	2.2013
7.	500	1.5	0.24	2.09	2.09
8.	500	1.5	0.24	2.1	2.09

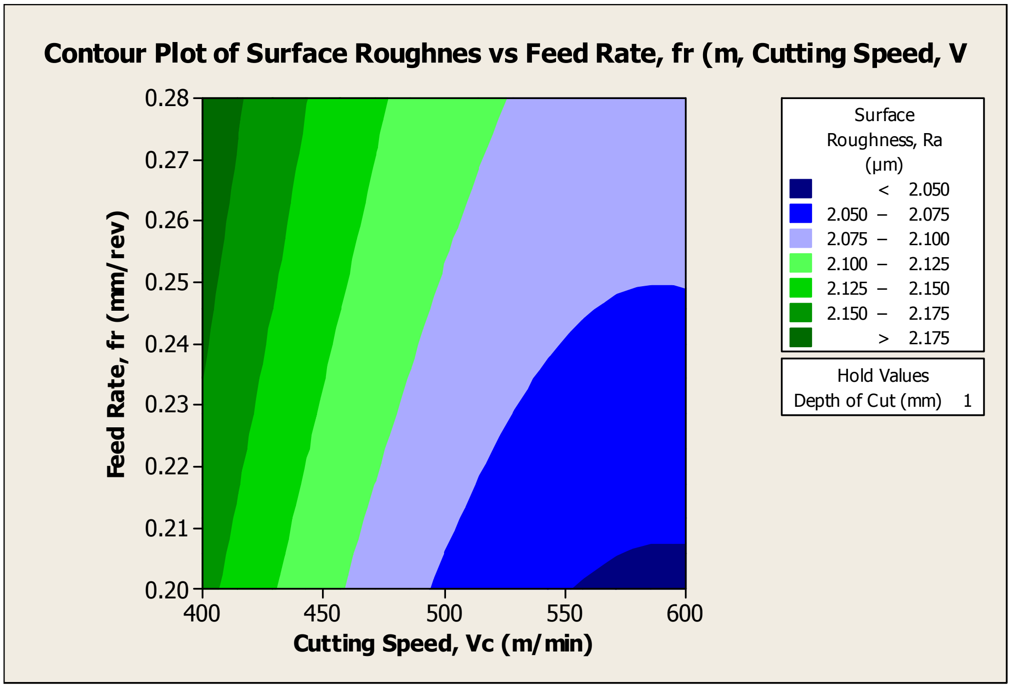
9.	500	1.5	0.24	2.08	2.09
10.	600	1.5	0.28	2.09	2.0888
11.	600	1.5	0.2	2.03	2.0288
12.	400	2	0.24	2.19	2.19
13.	500	2	0.28	2.13	2.1288
14.	500	2	0.2	2.06	2.0588
15.	600	2	0.24	2.06	2.0625

It can be concluded from the table that the equation can produce values close to those found experimentally. The analysis of variance shown in Table 4.6 below indicates that the model is adequate as the *P*-values of the lack-of-fit are not significant.

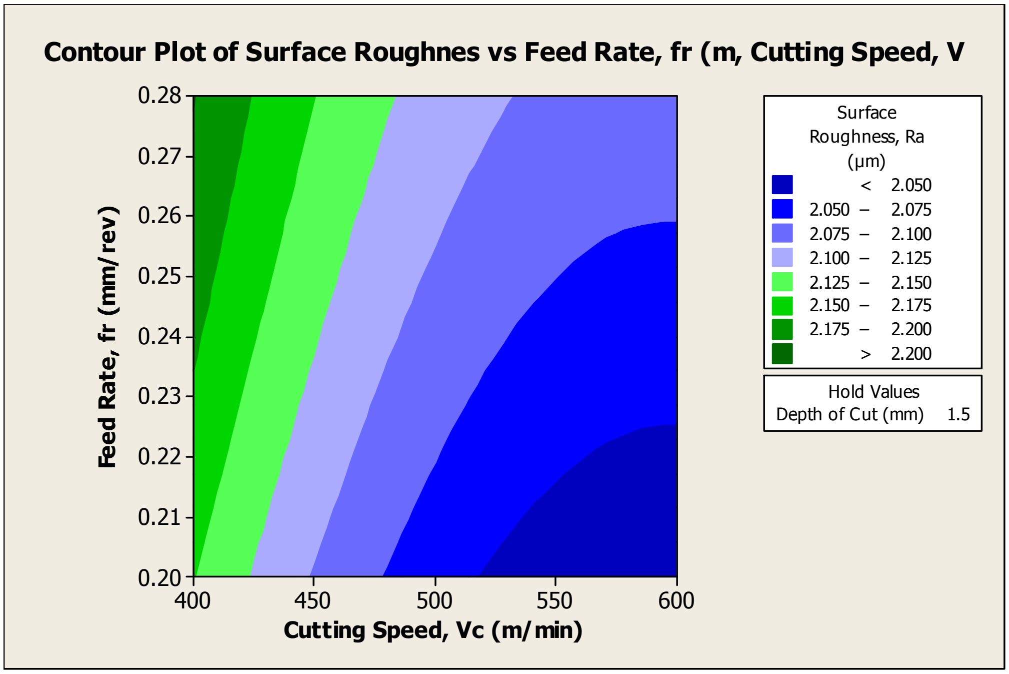
Table 4.6: Analysis of variance ANOVA for second order equation

Source of variation	**Degree of freedom (*d.f.*)**	**Sum of squares (*SS*)**	**Mean squares (*MS*)**	***F***	***P***
Regression	9	0.037468	0.004163	92.51	0.000
• 1st order term	3	0.033675	0.011225	249.44	0.000
• 2nd order term	3	0.003443	0.001148	25.51	0.002
• Interaction terms	3	0.000350	0.000117	2.59	0.165
Residual error	5	0.000225	0.000045		
• Lack-of-fit	3	0.000025	0.000008	0.08	0.963
• Pure error	2	0.000200	0.000100		
Total	14	0.037693			

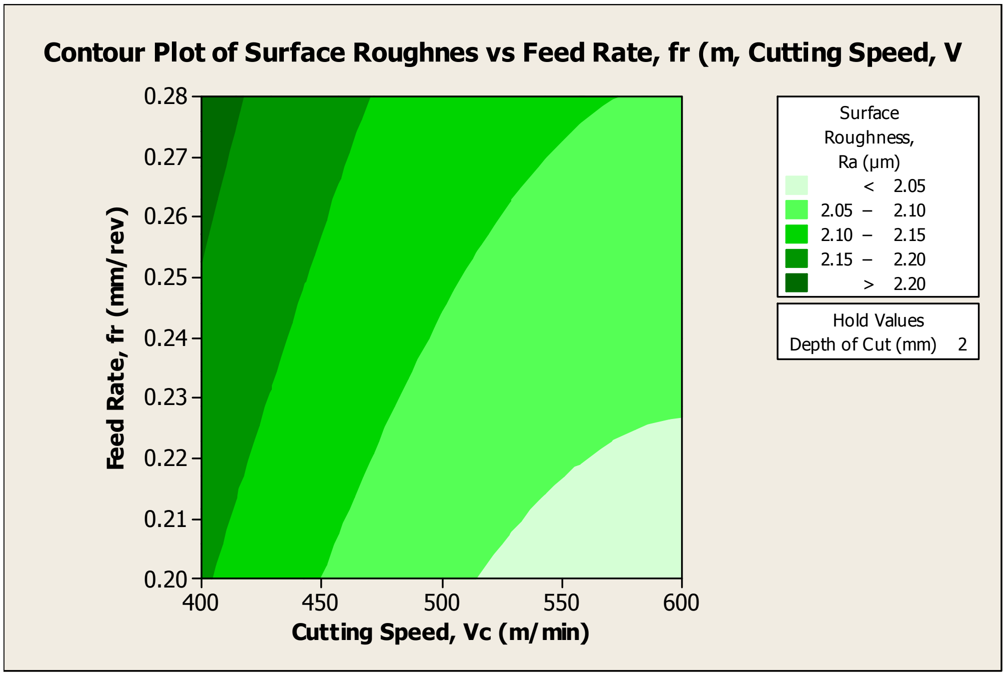
Figure 4.4 below shows the contour plots of the surface roughness in the cutting speed and feed rate plane of the lowest, middle and highest values of the depth of cut. As it was concluded before for the linear model, the surface roughness increase with increasing the feed rate, depth of cut and decreasing cutting speed. For the other factors, the surface roughness shows proportional relationship.



(a) Depth of cut = 1mm



(b) Depth of cut = 1.5mm



(c) Depth of cut = 2mm

Figure 4.4: Surface roughness contours in cutting speed–feed rate plane for different combinations of depth of cut plotted from second order model: (a) Depth of cut = 1mm (lowest values); (b) Depth of cut = 1.5mm (middle values); (c) Depth of cut = 2mm (highest values).

Source: MINITAB Ver. 14

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

Chapter 5 summarizes all the main research points of this dissertation. It concludes that all the important information and observation resulting from the project for the future research.

5.2 CONCLUSION

The studies on prediction of surface roughness on turning process on low-carbon steel AISI 1018, cold drawn, high temperature and with three factors (cutting speed, feed rate and depth of cut) were performed. Response surface methodology RSM has proved to be a successful technique that can be used to predict the longitudinal surface roughness R_y produced in turning of low-carbon steel AISI 1018 with CVD Coated Carbide Tips inserts. The first order and second order equation developed by RSM using Minitab are able to provide accurately predicted values of the surface roughness close to those values found in the experiments. The equations are checked for their adequacy with a confidence interval of 95%. The two equations indicate that the feed rate was the most dominant cutting condition on the surface roughness, followed by the depth of cut and then by the cutting speed. The surface roughness increases with increasing the feed rate and depths of cut but decreases with increasing cutting speed. But, in case of the output required is to get smooth surface roughness, the cutting condition for feed rate and depth of cut must be decrease and the cutting speed must be increase. In addition, the second order model proves the existence of a very strong interaction of the feed rate with depth of cut.

5.3 RECOMMENDATION

Another study that can be further performed on turning process could possibly be a work that studies the affects of different materials on the same types of cutters. Being able to use different materials in turning can be informative about the behaviors of the cutters and differences in ideal cutting parameters across different materials. Further research should always consider the need for flexibility for variation of parameters in a machining operation, which will make this type of research more adaptable to industry. Comparison which method gives more accurate mathematical model between neural networks (NN), taguchi method and response surface method (RSM) in term of surface roughness result in future study. Aluminum and composite materials can be candidates of material for the next study. Because of their different structures cutting parameters might have different effects on surface roughness. The geometries of the cutting tool will be included as planned factors in future study so as to design the cutter and to decide the optimum cutting conditions under the constraints of the maximum removal rate and the minimum surface roughness.

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APPENDIX A

Exp run	**Cutting Speed, V_c (m/min)**	**Depth of cut, d (mm)**	**Feed rate, fr (mm/rev)**	**Surface Roughness, R_a (µm)**
1.	400	1.5	0.2	2.15
2.	400	1	0.24	2.18
3.	400	2	0.24	2.19
4.	400	1.5	0.28	2.2
5.	500	1	0.2	2.07
6.	500	1.5	0.24	2.09
7.	500	1	0.28	2.11
8.	500	1.5	0.24	2.1
9.	500	2	0.28	2.13
10.	500	1.5	0.24	2.08
11.	500	2	0.2	2.06
12.	600	1	0.24	2.07
13.	600	1.5	0.28	2.09
14.	600	2	0.24	2.06
15.	600	1.5	0.2	2.03

Experiment data collection table

APPENDIX B

ANOVA result from Minitab for Linear.

```
The analysis was done using coded units.

Estimated Regression Coefficients for Surface Roughness, Ra (µm)

Term                           Coef   SE Coef        T      P
Constant                    2.10733  0.004935  427.024  0.000
Cutting Speed, Vc (m/min)  -0.05875  0.006757   -8.694  0.000
Depth of Cut (mm)           0.00125  0.006757    0.185  0.857
Feed Rate, fr (mm/rev)      0.02750  0.006757    4.070  0.002


S = 0.0191129  PRESS = 0.00751128
R-Sq = 89.34%  R-Sq(pred) = 80.07%  R-Sq(adj) = 86.43%


Analysis of Variance for Surface Roughness, Ra (µm)

Source          DF    Seq SS    Adj SS    Adj MS      F      P
Regression       3  0.033675  0.033675  0.011225  30.73  0.000
  Linear         3  0.033675  0.033675  0.011225  30.73  0.000
Residual Error  11  0.004018  0.004018  0.000365
  Lack-of-Fit    9  0.003818  0.003818  0.000424   4.24  0.205
  Pure Error     2  0.000200  0.000200  0.000100
Total           14  0.037693
```

```
   Estimated Regression Coefficients for Surface Roughness, Ra (µm) using data
in
        uncoded units

   Term                                Coef
   Constant                         2.23233
   Cutting Speed, Vc (m/min)  -5.87500E-04
   Depth of Cut (mm)             0.00250000
   Feed Rate, fr (mm/rev)          0.687500


   Predicted Response for New Design Points Using Model for Surface Roughness,
Ra
         (µm)

   Point      Fit     SE Fit         95% CI              95% PI
       1  2.13858  0.0107554  (2.11491, 2.16226)  (2.09031, 2.18685)
```

```
 2  2.16483  0.0107554  (2.14116, 2.18851)  (2.11656, 2.21310)
 3  2.16733  0.0107554  (2.14366, 2.19101)  (2.11906, 2.21560)
 4  2.19358  0.0107554  (2.16991, 2.21726)  (2.14531, 2.24185)
 5  2.07858  0.0107554  (2.05491, 2.10226)  (2.03031, 2.12685)
 6  2.10733  0.0049349  (2.09647, 2.11820)  (2.06389, 2.15078)
 7  2.13358  0.0107554  (2.10991, 2.15726)  (2.08531, 2.18185)
 8  2.10733  0.0049349  (2.09647, 2.11820)  (2.06389, 2.15078)
 9  2.13608  0.0107554  (2.11241, 2.15976)  (2.08781, 2.18435)
10  2.10733  0.0049349  (2.09647, 2.11820)  (2.06389, 2.15078)
11  2.08108  0.0107554  (2.05741, 2.10476)  (2.03281, 2.12935)
12  2.04733  0.0107554  (2.02366, 2.07101)  (1.99906, 2.09560)
13  2.07608  0.0107554  (2.05241, 2.09976)  (2.02781, 2.12435)
14  2.04983  0.0107554  (2.02616, 2.07351)  (2.00156, 2.09810)
15  2.02108  0.0107554  (1.99741, 2.04476)  (1.97281, 2.06935)
```

APPENDIX C

ANOVA result from Minitab for Full Quadratic.

```
The analysis was done using coded units.

Estimated Regression Coefficients for Surface Roughness, Ra (µm)

Term                                     Coef   SE Coef        T      P
Constant                              2.09000  0.003873  539.636  0.000
Cutting Speed, Vc (m/min)            -0.05875  0.002372  -24.771  0.000
Depth of Cut (mm)                     0.00125  0.002372    0.527  0.621
Feed Rate, fr (mm/rev)                0.02750  0.002372   11.595  0.000
Cutting Speed, Vc (m/min)*            0.03000  0.003491    8.593  0.000
  Cutting Speed, Vc (m/min)
Depth of Cut (mm)*Depth of Cut (mm)   0.00500  0.003491    1.432  0.212
Feed Rate, fr (mm/rev)*              -0.00250  0.003491   -0.716  0.506
  Feed Rate, fr (mm/rev)
Cutting Speed, Vc (m/min)*           -0.00500  0.003354   -1.491  0.196
  Depth of Cut (mm)
Cutting Speed, Vc (m/min)*            0.00250  0.003354    0.745  0.490
  Feed Rate, fr (mm/rev)
Depth of Cut (mm)*                    0.00750  0.003354    2.236  0.076
  Feed Rate, fr (mm/rev)


S = 0.00670820  PRESS = 0.00085
R-Sq = 99.40%   R-Sq(pred) = 97.74%  R-Sq(adj) = 98.33%


Analysis of Variance for Surface Roughness, Ra (µm)

Source          DF    Seq SS    Adj SS    Adj MS       F      P
Regression       9  0.037468  0.037468  0.004163   92.51  0.000
  Linear         3  0.033675  0.033675  0.011225  249.44  0.000
  Square         3  0.003443  0.003443  0.001148   25.51  0.002
  Interaction    3  0.000350  0.000350  0.000117    2.59  0.165
Residual Error   5  0.000225  0.000225  0.000045
  Lack-of-Fit    3  0.000025  0.000025  0.000008    0.08  0.963
  Pure Error     2  0.000200  0.000200  0.000100
Total           14  0.037693
```

```
Estimated Regression Coefficients for Surface Roughness, Ra (µm) using data
in
     uncoded units

Term                                          Coef
Constant                                   3.05500
Cutting Speed, Vc (m/min)              -0.00358750
Depth of Cut (mm)                       -0.0975000
Feed Rate, fr (mm/rev)                    0.562500
Cutting Speed, Vc (m/min)*             3.00000E-06
  Cutting Speed, Vc (m/min)
Depth of Cut (mm)*Depth of Cut (mm)      0.0200000
Feed Rate, fr (mm/rev)*                   -1.56250
  Feed Rate, fr (mm/rev)
Cutting Speed, Vc (m/min)*            -1.00000E-04
  Depth of Cut (mm)
Cutting Speed, Vc (m/min)*             0.000625000
  Feed Rate, fr (mm/rev)
Depth of Cut (mm)*                        0.375000
  Feed Rate, fr (mm/rev)


Predicted Response for New Design Points Using Model for Surface Roughness,
Ra
     (µm)

Point      Fit     SE Fit        95% CI              95% PI
    1  2.15125  0.0058095  (2.13632, 2.16618)  (2.12844, 2.17406)
    2  2.17750  0.0058095  (2.16257, 2.19243)  (2.15469, 2.20031)
    3  2.19000  0.0058095  (2.17507, 2.20493)  (2.16719, 2.21281)
    4  2.20125  0.0058095  (2.18632, 2.21618)  (2.17844, 2.22406)
    5  2.07125  0.0058095  (2.05632, 2.08618)  (2.04844, 2.09406)
    6  2.09000  0.0038730  (2.08004, 2.09996)  (2.07009, 2.10991)
    7  2.11125  0.0058095  (2.09632, 2.12618)  (2.08844, 2.13406)
    8  2.09000  0.0038730  (2.08004, 2.09996)  (2.07009, 2.10991)
    9  2.12875  0.0058095  (2.11382, 2.14368)  (2.10594, 2.15156)
   10  2.09000  0.0038730  (2.08004, 2.09996)  (2.07009, 2.10991)
   11  2.05875  0.0058095  (2.04382, 2.07368)  (2.03594, 2.08156)
   12  2.07000  0.0058095  (2.05507, 2.08493)  (2.04719, 2.09281)
   13  2.08875  0.0058095  (2.07382, 2.10368)  (2.06594, 2.11156)
   14  2.06250  0.0058095  (2.04757, 2.07743)  (2.03969, 2.08531)
   15  2.02875  0.0058095  (2.01382, 2.04368)  (2.00594, 2.05156)
```

APPENDIX D

Gantt Chart for Final Year Project 1

Name: Fakhrur Razi Bin Bahrin

Metrics No: ME06062

Supervisor: Pn. Salwani Binti Mohd Salleh

Tasks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Meetings with supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Defining project information	■	■												
Project planning	■	■												
Introduction		■	■	■	■									
Literature review				■	■	■	■	■	■	■	■	■		
Defining methodology								■	■	■	■			
Prepare report											■			
Submit logbook, report												■		
Presentation preparation													■	■

APPENDIX E

Gantt Chart For Final Year Project 2

Name: Fakhrur Razi Bin Bahrin

Metrics No: ME06062

Supervisor: Pn. Salwani Binti Mohd Salleh

Tasks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Literature review	■	■	■	■	■	■	■	■	■	■	■	■		
Prepare material and cutting tool		■	■											
Design the experiment (DOE) use RSM			■	■	■									
Conduct experiment by use lathe machine					■	■	■	■						
Measure the surface roughness						■	■	■						
Analyze collected data						■	■	■	■	■	■			
Completing final report												■	■	■
Presentation FYP 2 with panels													■	
Submit full report														■