A STUDY ON THE EFFECT OF MACHINING PARAMETERS, MACHINING CONDITIONS AND MATERIALS ON SURFACE ROUGHNESS IN TURNING PROCESS

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DECLARATION

I declare that this project report entitled "A Study on the Effect of Machining Parameters, Machining Conditions and Materials on Surface Roughness in Turning Process " is the result of my own work except as cited in the references

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Design and Innovation).

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DEDICATION

To my beloved mother and father

BON LIAN CHIN

LEE BON CHONG

ABSTRACT

Surface roughness is one of the criteria that can be used to decide the quality of products. Products with low surface roughness are more resistive to fatigue failure. Besides that, different materials have different level of machinability. Materials with good machinability can be easily cut and at the same time give good surface finish with low roughness. Hence, this study was carried out to investigate the effect of machining parameters of conventional lathe machine on quality of surface roughness on different materials and determine whether coolant and lubricant are effective to reduce surface roughness. This study started with literature reviews. Next, experiment was conducted under different conditions with different cutting parameters to obtain surfaces on aluminium alloy 6061 and carbon steel AISI 1060. All the obtained surfaces are measured by using surface roughness tester to detect their quality of surface finish in term of arithmetic average surface roughness (Ra). Justifications were made based on the obtained results. From the results obtained, it was found that it cannot be guaranteed to get low surface roughness at the highest spindle speed and the lowest feed rate. Optimization should be carried out in order to find out the most appropriate machining parameters to get low surface roughness. Spindle speed 1100 rpm and feed rate 0.094 mm/rev are suggested to be the candidates for optimization. Besides that, this study found that lubricant is the most effective condition in order to produce surface with low roughness. On top of that, it was discovered that machinability of aluminium alloy 6061 is better than machinability of carbon steel AISI 1060 because obtained surfaces of aluminium alloy 6061 showed lower surface roughness. This study is vital to be conducted as it provides crucial facts and information to help in fabrication industry especially turning process by using conventional lathe machine. The findings from this study are helpful for manufacturers to improve quality of products.

ABSTRAK

Kekasaran permukaan adalah salah satu kriteria yang boleh digunakan untuk menentukan kualiti produk. Produk dengan kekasaran permukaan rendah lebih merintang terhadap kegagalan keletihan. Selain itu, bahan-bahan yang berbeza mempunyai tahap yang berbeza atas kebolehan dimesin. Bahan-bahan yang mempunyai kebolehan dimesin tinggi adalah lebih mudah dipotong dan pada masa yang sama memberi kemasan permukaan yang baik dengan kekasaran rendah. Oleh itu, kajian ini dijalankan untuk mengkaji kesan parameter pemesinan mesin pelarik konvensional kepada kualiti kekasaran permukaan pada bahan yang berbeza dan menentukan sama ada penyejuk dan pelincir berkesan untuk mengurangkan kekasaran permukaan. Kajian ini bermula dengan ulasan kesusasteraan. Seterusnya, eksperimen telah dijalankan di bawah keadaan yang berbeza dengan parameter pemotongan yang berbeza untuk mendapatkan permukaan pada aloi aluminium 6061 dan keluli karbon AISI 1060. Semua permukaan yang diperolehi diukur dengan menggunakan kekasaran permukaan tester untuk mengesan kualiti kemasan permukaan dari segi aritmetik purata kekasaran permukaan (Ra). Justifikasi dibuat berdasarkan keputusan yang diperolehi. Dari keputusan yang diperolehi, didapati bahawa ia tidak boleh dijamin untuk mendapatkan kekasaran permukaan rendah pada kelajuan spindle tertinggi dan kadar suapan yang paling rendah. Pengoptimuman perlu dijalankan untuk mengetahui parameter pemesinan yang paling sesuai untuk mendapatkan kekasaran permukaan rendah. Kelajuan spindle 1100 rpm dan kadar suapan 0,094 mm / rev dicadangkan untuk menjadi calon untuk pengoptimuman. Selain itu, kajian ini mendapati bahawa pelincir adalah keadaan yang paling berkesan untuk menghasilkan permukaan dengan kekasaran rendah. Selain itu, kajian ini mendapati bahawa kebolehan dimesin daripada aloi aluminium 6061 adalah lebih baik daripada kebolehan dimesin keluli karbon AISI 1060 kerana permukaan yang diperolehi daripada aloi aluminium 6061 menunjukkan kekasaran permukaan yang lebih rendah. Kajian ini adalah penting untuk dijalankan kerana ia menyediakan fakta-fakta dan maklumat yang penting untuk membantu dalam industri proses fabrikasi terutamanya proses 'turning' dengan menggunakan mesin pelarik konvensional. Penemuan daripada kajian ini adalah berguna untuk pengeluar bagi meningkatkan kualiti produk.

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CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBEREVATIONS

Al 6061	Aluminium alloy 6061
AISI 1060	Carbon steel 1060
CC	Coolant condition
DC	Dry condition
DOC	Depth of Cut
LC	Lubricant condition
SOP	Standard Operating Procedures

LIST OF SYMBOL

Ra	=	Average surface roughness
$\sum$	=	Summation

CHAPTER 1

INTRODUCTION

1.1 Background

It is an actual fact that all the raw materials are exploited from natural resources. In the first place, the raw materials, such as ores, coals and logs, are extracted from the earth. As such, most of the raw materials are either too large or too tiny to be used. As the result, all these materials need to be further processed. Metals which are obtained from mining are normally made into slab, rod, bar as well as plate. Hence, machining process is needed in order to cut the metals into various desired shape.

Generally, machining process refers to the removal of material from a work piece in the form of chips. There are several types of machining process such as drilling, milling, turning, boring, reaming and so on. Most of the machining processes have low set-up cost compared to other manufacturing processes like moulding, forming and casting. The main concerns that need to be emphasised while machining is the machinability and surface finish of products.

Basically, machinability can be defined as the easiness to machine or cut a material. A material with good machinability normally provides good surface finish and at the same time it requires less power to get rid of the unwanted material. It is undeniable that every single of material has its particular compositions. Moreover, different materials have different arrangement of atoms. Consequently, all the materials are distinct in term of physical properties such as hardness, ductility, tensile strength as well as malleability. All these can influence the machinability of materials. In order to compare the machinability among materials, surface finish can be used as the measure. Surface finish can be observed to distinguish the machinability of materials. Materials which are difficult to be machined will give bad quality of surface finish. In contrast, materials which are easy to be cut or removed will produce good surface finish.

So what is surface finish refers to? Generally, surface finish also can be called as surface texture or surface topography. It refers to the nature of surface. The nature of surface is categorised into three characteristics which are lay, surface roughness and waviness. Firstly, lay can be defined as the direction or general way of the predominant surface pattern. It usually can be identified by production method used. Secondly, surface roughness refers to a measure which is used to determine the finely spaced surface irregularities. Lastly, waviness is the measure of surface irregularities with spacing greater than that of surface roughness. The reasons that lead to waviness are vibrations, deflection as well as warping during machining.

In facts, surface finish is no doubt an important criterion for machining products as rough and uneven surface will lead to friction. Consequently, the products are low resistive to wear and short life spans. In other words, rough surface is undesirable. Conversely, smooth surface ensures good quality of products. Thus, it is vital to find out the way to achieve low surface roughness of machining products.

Conventional lathe machine is the machine that is used in this study. The main function of this machine is to get rid unwanted material from a work piece in order to achieve desired shape. The work piece for the machine is usually in cylindrical shape. The working principle of the machine is that the cutting tool of the machine is fixed and not rotating while the work piece is rotating. In this study, the effect of machining parameters on surface roughness is investigated. This is achieved by using different values of spindle speed and feed rate to cut the selected materials and then observing the quality of surface in term of roughness. Besides that, the machining process is conducted under three conditions to determine whether coolant and lubricant bring any effect on surface roughness.

1.2 Problem Statement

Nowadays, machining is no doubt playing important role in manufacturing process due to rapid changing of industries. Machining is the process of removing material from work piece in order to achieve a desired shape for a particular use. One of the fundamental and utmost important requirements of machining is surface roughness. Surface roughness is an imperative parameter that needs to be concerned as it manipulates the performance and quality of machined components. The quality of surface can affect the fatigue life, in term of service duration, of the machined components. Machined component with poor surface quality produces fatigue failure easily in short period of time compared to those with good surface quality. Thus, surface finish directly acts as the key to decide the profitability as well as nature of machined parts. It plays a role as a trademark that may impact the execution of mechanical parts and the generation costs. Due to vision limitation of human, the surfaces of products are smooth to the naked eyes. In facts, most of the products are typically rough at the microscopic level. Hence, it is essential to find out the direction on how to get low surface roughness effectively in order to improve the quality of machining products. As such, time and cost can be saved on keep testing different cutting parameters to produce better surface finish.

1.3 Objective

The goals of this study are listed as below:

a) To investigate the effect of machining parameters of conventional lathe machine on quality of surface roughness on different materials.
b) To determine whether coolant and lubricant are effective to reduce surface roughness.

1.4 Scope of Project

In this study, the focus is on investigating the effect of spindle speed and feed rate on quality of surface roughness by using conventional lathe machine. Depth of cut is not included as part of investigation. The depth of cut is fixed at 0.5 mm for every cut throughout the study. Besides that, the focus of investigation is on two different materials which are aluminium alloy 6061 and carbon steel AISI 1060. The machining process that is chosen for this study is turning process. As the result, the work pieces are cylindrical in shape. In addition, this study also emphasises on determining whether coolant as well as lubricant bring any effect on producing surface with low roughness. In order to achieve this objective, machining process is conducted under three different conditions which are dry condition, coolant condition and lubricant condition. For surface finish, the focus is on surface roughness in term of arithmetic average surface roughness, Ra. Waviness and lay are not covered in this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter emphasises on the reviews of optimisation of surface roughness that are carried out by researchers. Besides that, this chapter covers on background as well as history of conventional lathe machine. In order to increase the accuracy of this study, most of the reviews that chosen for references are implemented five years ago. However, there are still some older reviews because it is easier to do comparison and collecting information. The information and data collected are very helpful and useful to understand and have an impression on the field of this study. Apart than that, the information can be used in discussion at the end of this study.

2.2 Conventional Lathe Machine

2.2.1 History

Lathe is a tool of machining. Its function is to get rid of unwanted metal from work piece in order to get required form or shape. According to Jay Chris, lathe is an ancient tool which was first used by Egypt in 1300 BC. Other than Egypt, Assyria and Greece also knew and used lathe. The first lathe was a simple lathe which is now referred to as two person lathe. The wood work piece is turned by an individual using rope. At the same time, the work piece is shaped by the other individual using a sharp tool. This machine was then further developed by Ancient

Romans. The modification was made by adding a turning bow which made the wood work easily. Besides that, a later pedal like in a manual sewing machine was merged to the machine too in order to make the work piece rotates. This type of lathe was named as "spring pole" lathe which was used until the early decades of the 20th century. In 1772, a horse-powered boring machine was installed. It was used for making canons. During the Industrial revolution, the application of lathe became familiar in Europe. Steam engines as well as water wheels were assembled to the lathe to turn the work piece at higher speed which made the work quicker and easier. After 1950, many new designs were made. These new designs were improved with better precision of work. With the development of electronics, automated lathes have been developed.

2.2.2 Basic Parts of Conventional Lathe Machine

The conventional lathe machine that is used for this study is manufactured by Gate Machinery. Figure 2.1 below shows the lathe machine of Gate Machinery. The model is G-330E. The parts of basic lathe machine are labelled and shown in Figure 2.2.

Figure 2.1: Conventional lathe machine (G-330E).

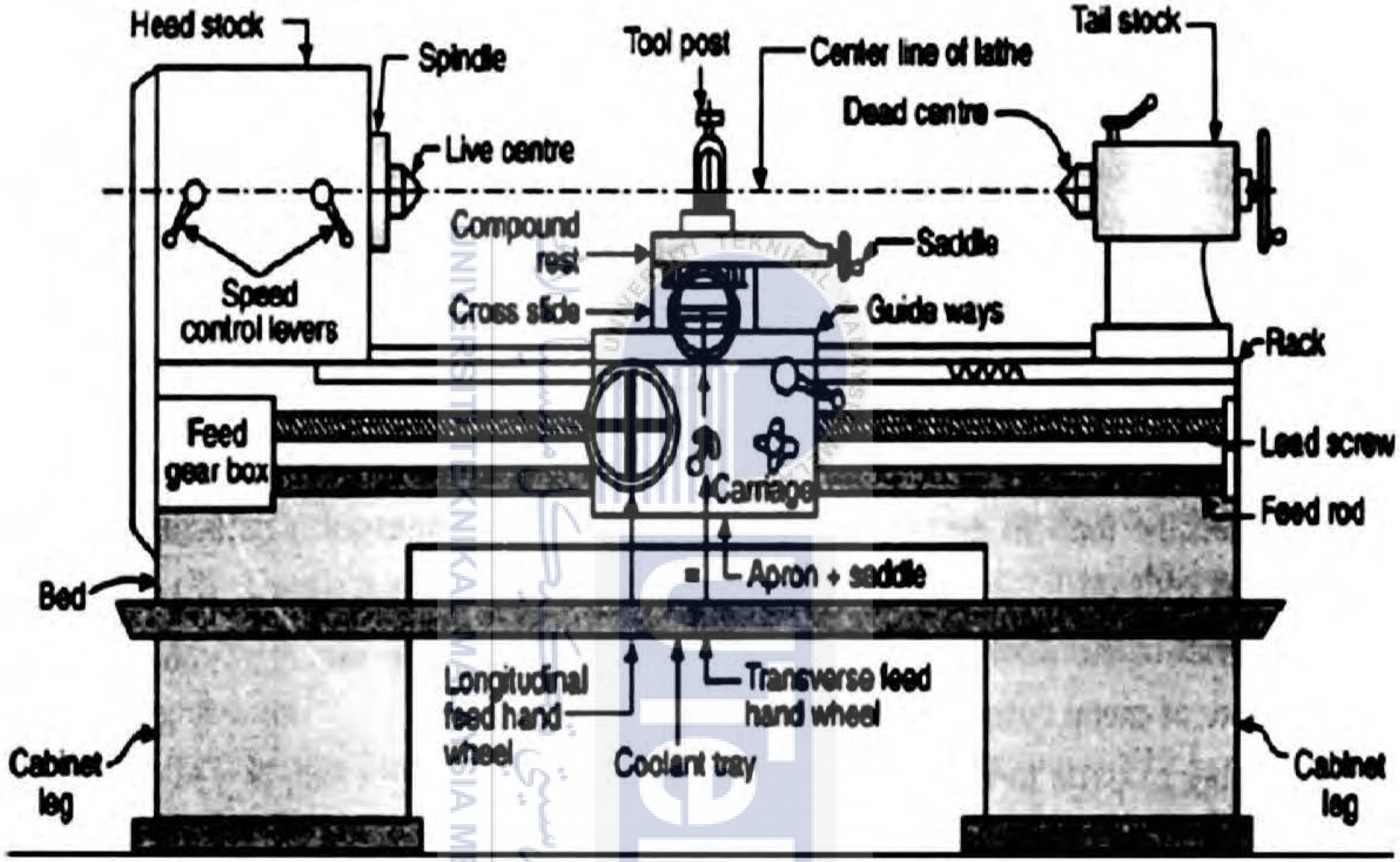

Figure 2.2: Schematic diagram of lathe machine with label.

The dimensions of the parts of the machine (G-330E) are tabulated as shown following table:

Table 2.1: Parts of lathe machine (G-330E) with dimensions.

Part	**Dimension**
Swing over bed	330 mm
Swing over cross slide	195 mm
Distance between centres	1000 mm
Swing over gap	490 mm
Width of bed	190 mm
Spindle speeds	(9) 80-2000 rpm
Spindle bore	40 mm
Spindle nose	D1-4 Cam lock
Spindle taper	MT5
Tailstock taper	MT3
Tailstock quill travel	110 mm
Cross side travel	175 mm
Compound rest travel	100 mm
Metric threads	(30) 0.4-7.0 mm
Modular pitches	(32) 0.4-7 M
Diametric pitches	(34) 4-56P
Inch threads	(32) 4-56 TPI
Longitudinal feed	0.068-0.936 mm
Cross feeds	0.034-0.468 mm
Machine weight	600 kg

Every part of the machine has its particular function. The basic part and its function are shown in Table 2.2 below. (The information is sourced from University of California):

Table 2.2: Basic parts and functions of lathe machine.

Part	**Function**
Spindle speed knob	To adjust the speed of lathe spindle.
Tailstock	To hold the tailstock spindle accurately.
Tailstock hand wheel	To move the tailstock spindle toward or away from the work piece.
Carriage	To move the tool post and cross slide toward or away from the chuck.
Emergency stop button	To shut off the spindle rotation and feeds in case of an emergency.
Collet chuck	Use to hold work piece in the spindle of the lathe.
Tool post	Use to hold and quickly change between different tool holders.
Tool holder	To hold lathe bits and other lathe cutting tools.
Compound slide hand wheel	To manually feed cutting tools at an angle to the spindle.
Cross slide hand wheel	To manually feed cutting tools across the spindle (X-axis).
Carriage hand wheel	To manually feed cutting tools in line with the spindle (Y-axis).
Cross slide feed lever	To turn the auto feed for the cross slide on and off.
Carriage feed lever	To turn the auto feed for the carriage on and off.
Spindle ON/OFF and direction lever	To switch the spindle on or off and to set the direction of rotation.
Feed direction knob	To determine the direction of the carriage or cross slide auto feed.

2.3 Turning

Basically, turning is one of the processes that can be operated by using conventional lathe machine. It is probably the most wide used process among all the machining processes. About one third of the machines in production are employed in turning. It is a machining process that is used to produce round parts in shape by a single point cutting tool. Other than round shape, it normally produces straight, conical, curved, or grooved work pieces. Its working principle is on removal of materials by traversing in a direction parallel to the axis of rotation of axis or along a specified path to form a complex rotational shape. The tool is fed either linearly in a direction parallel or perpendicular to the axis of rotation. Figure 2.3 shows the schematic diagram of turning process.

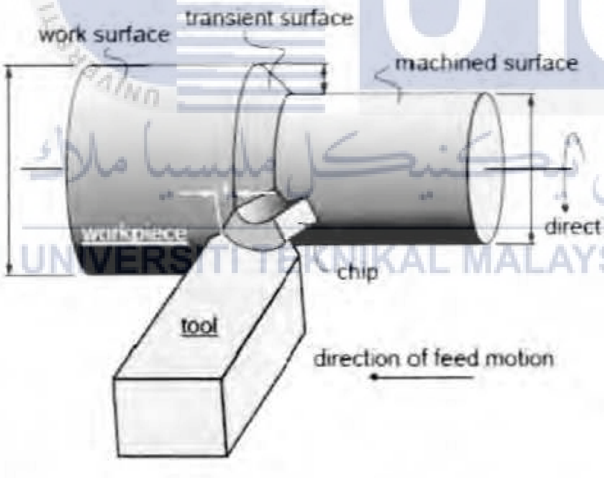

Figure 2.3: Schematic diagram of turning process.

During turning operation, there are three fundamental cutting parameters that need to be identified which are spindle speed, feed rate and depth of cut (S. Thamizhmanii, S. Saparudin, S. Hasan, 2007).

2.4 Surface Roughness

The challenging part of machining industries nowadays is mostly emphasised on the achievement of high quality (S. Thamizhmanii, S. Hasan, 2006). Surface roughness is one of the criteria that need to be considered. Surface roughness is vital feature as it could affect the effectiveness of mechanical components as well as the production costs (Adeel H. Suhail, N. Ismail, S.V. Wong, N.A. Abdul Jalil, 2010). Hence, it is essential to optimise appropriate parameters to get a surface finish. Other than that, cutting temperature is also a significant factor that will influence surface roughness. Cutting temperature will lead to wear of cutting tool, integrity of work piece surface and precision of machining due to the relative motion between the tool and the work piece (Ming et al., 2003).

2.4.1 Measurement of Surface Roughness

The surface of roughness can be quantified by the vertical deviations of a real surface from its ideal form. Great deviation implies that the surface is rough. Conversely, small deviation indicates the surface is smooth.

The instrument that is commonly used to detect the surface roughness is stylus profilometer. The stylus is allowed to move along the surface. The signal produced is then amplified and recorded. The outcome is normally displayed in term of average roughness (Ra). This value is obtained by the arithmetic average value of the deviation. Both deviation above and below the centre (mean) line are taking in account in order to get the Ra value. Figure 2.4 below shows the coordinates used for surface roughness measurement.

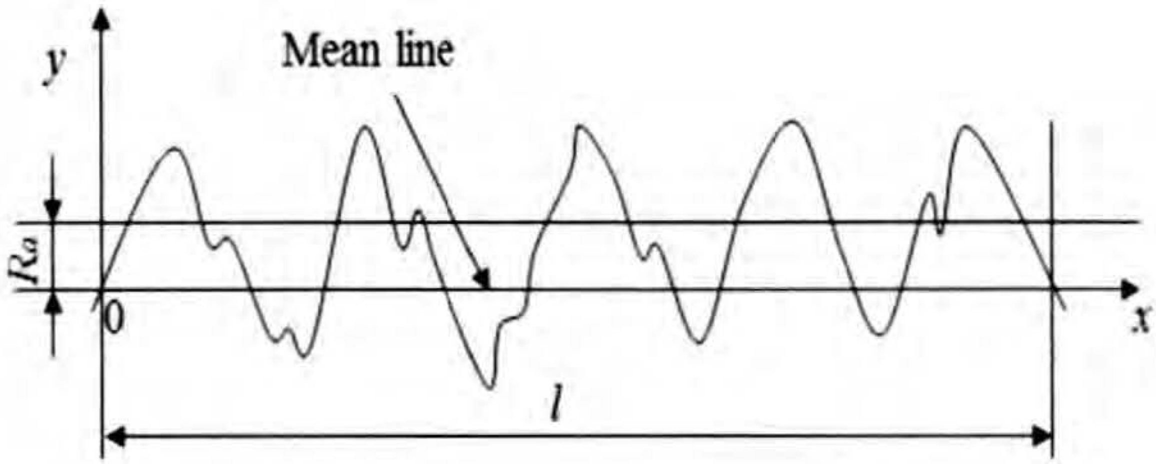

Figure 2.4: Coordinates used for surface roughness measurement.

It is a reliable mean of measuring surface roughness. Many researchers use this method to attain surface roughness. For instance, C. Natarajan et al use TIME TR 100 surface roughness tester to get the surface roughness of brass specimen C26000 materials which are machined in a CNC turning machine in dry cutting condition.

2.5 Parametric Study

As mention above, surface roughness of turning products is dependent on spindle speed, feed rate as well as depth of cut. There are many parametric studies based on these three fundamental factors. Hence, the focus of this study also put on these three parameters. Optimum value for these three parameters is investigated at the end of the study. Moreover, effect of cutting temperature also considered in this study. Hence, coolant and lubricant are used to investigate the effects on surface finish for turning process. The effects of coolant and lubricant on surface finish are compared to identify which one of them is more preferable.

2.5.1 Spindle Speed

Basically, spindle speed refers to the rotational frequency of machine's spindle. It is normally in unit of revolution per minute (rpm). According to Joe Thompson of Canadian Industrial Machinery, increasing speed is one of the tips that able to improve the surface finish of product. This is because higher speed of cut reduces built-up edge. As the result, this extends the life of cutting tool and avoids catastrophic tool failure that destroys finished parts.

2.5.2 Feed Rate

Feed rate can be defined as the velocity of cutting tool being fed towards work piece. It is the distance that travelled by cutting tool during one revolution on the work piece. It is usually measured in millimetres per revolution (mm/rev). Joe Thompson also revealed that feed rate is one of the factors that can influence surface roughness. The surface roughness can be reduced by cutting down the feed rate. This is because lower rate of feed helps reducing flank wear as well as prolong life of insert. It is advisable that feed rate of 0.25 mm/rev may be used for materials which are softer whereas feed rate of 0.10 mm/ rev may be used for materials which are harder (Mohd.Arif. I. Upletawala, Prof. Tushar Katratwar, 2016).

2.5.3 Depth of Cut

Depth of cut is the distance that the tool bit travels into the work piece. This parameter is usually in unit of millimetres. Generally, depth of cut is set up to five times of the feed rate. According to Sachin Thorat, depth of cut should be reduced in case of chattering marks or developing of machine's noise. The depth of cut for operation is dependent on feed rate. Depth of cut that is large is suitable to be used in case of low feed rate. Otherwise, it will lead to high load on the tool and consequently shorten the life of tool (Mohd.Arif. I. Upletawala, Prof. Tushar Katratwar, 2016).

2.5.4 Comparison among Spindle Speed, Feed Rate and Depth of Cut

There are a lot of research papers that reveal on effect of spindle speed, feed rate and depth of cut on surface roughness for machining process.

According to the research by Deore Dhiraj Rajendra, and Prof. Radha R, feed is the most critical influence in turning process. This is then followed by speed which affects the force of feed. On the other hand, depth of cut is the significant factor if the focus is put on tangential force. The next factor is followed by feed in this case. Throughout the study, Taguchi method and analysis of variance are used as the tool in order to identify which parameters have significant effect in turning process.

The study of Deepak Mittal et al indicates that the effects of spindle speed and feed rate are more significant compared to depth of cut. The study is done on Titanium grade 2 by using turning process in conventional lathe machine. It emphasise on material removing rate of material.

C. Natarajan et al put effort on determining surface roughness of a number of brass specimen C26000 material by using CNC turning machine. The process is conducted under dry condition. The tool used for surface roughness measurement is TIME TR 100 surface roughness tester. The outcome of this study shows that feed rate is the most dominant parameter on influencing surface roughness. This is then followed by spindle speed and depth of cut.

U.D. Gulhane et al implement a study on identifying the surface roughness in turning operation of 316L stainless steel. This study is completed by using Taguchi method, orthogonal array and analysis of variance (ANNOVA). From the result obtained, it can be concluded that feed rate is the dominant factor that affecting surface roughness. The following factors are depth of cut and speed.

2.5.5 Coolant and Lubricant

Coolant and lubricant can act as cutting fluids for machining process. As mentioned by Ming et al, cutting temperature will lead to wear of cutting tool, integrity of work piece surface and precision of machining due to the relative motion between the tool and the work piece. This can directly affect the surface roughness of product. Normally, coolant is used as fluid during machining process to reduce temperature from increasing between cutting tool and work piece. Coolant can be in form of liquid, pressurised air or other gases. However, it is more preferable to opt liquid-formed coolant as liquid has the ability to absorb heat greatly in term of quantity. According to machinist SJ Friedman, it is beneficial to use coolant during machining for materials which have high tendency to expand.

On the other hand, lubricant refers to substance that is used to reduce friction which is produced by turning work piece and cutting tool. The form of lubricant can be liquid, solid or gas.

2.6 Materials

It is an actual fact that material of work piece is another vital factor that cannot be ignored in order to get a good surface roughness. Every single of material has its own composition and arrangement. Hence, different material has its particular physical properties in terms of hardness, ductility, tensile strength as well as malleability. Consequently, application of same cutting parameters on different materials may give different effect of surface roughness. However, it is the least effect compared to cutting parameters (Huda Hatem, 2011). According to information from Fox Valley Technical College, it recommends to fabricate hard materials with low cutting speed. Conversely, high cutting speed is recommended to deal with soft materials. Figure 2.5 shows the descending sequence of materials' hardness.

Figure 2.5: Descending sequence of materials' hardness.

2.6.1 Steel

Steel is one of the materials that are widely used due to its good tensile strength and low price. Apart from that, it is ductile and malleable. It can be made into various shapes easily. Furthermore, this material is hard. Steel is not an element. It is alloy which normally contains iron as well as carbon. It usually can be called as carbon steel. Carbon steel can be classified into three categories which are low carbon steel (mild steel), medium carbon steel and high carbon steel. All these are differentiated by content of carbon in the steel. Steel with higher carbon content is harder. There are two systems which are used to number or name the steel based on its carbon content. The systems are American Iron and Steel Industry

(AISI) and Society of Automotive Engineers (SAE). The similarity of these systems is four digit code numbers are used to determine the base carbon and alloy steels. Steel is a material that contributes in many applications. For low carbon steel, it can be used for applications such as bolts, fasteners and screws. For long term wearing property, medium carbon steel is more suitable to be used. Its applications include manufacturing of machinery parts, crankshafts, coupling as well as hand tools like screwdrivers and pliers. For high carbon steel, it is suitable to be used in structural applications such as aircraft engine mounts, welded tubing application, aircraft landing gear axles and shafts for power transmission.

2.6.2 Iron

It is an actual fact that iron is one of the most abundant elements on Earth. It is an element but not in metallic form naturally. It usually exists as iron ore. It is a non-inert element. As such, it is easy to react with other elements. It usually exists as alloy. There are three types of iron alloys which are cast iron, pig iron and wrought iron. Physically, iron which is pure is silver in colour. Besides that, pure iron is soft. Its hardness is improved as it contains carbon just like steel. It is good heat and electric conductors. Another outstanding characteristic of iron is its strong magnetic character. However, the weakness of iron is its high tendency of rusting. It can be oxidised easily when expose to moisture condition. This weakness is undesirable to produce long lasting products as rust can cause failure easily. This causes iron is eliminated and substituted by steel in structural industry nowadays. However, iron is still being used in piping and making automotive parts like cylinder heads, cylinder blocks and some home decoration items.

2.6.3 Aluminium

Aluminium is one of the popular materials that used in machining industries these days. It is widely used to make aircraft and aerospace components, marine fitting, transport, bicycle frames, drive shafts, electrical fitting and connectors, brake components and so on. This is due to its good characteristics especially light weight, high strength of its alloy, high heat and electrical conductivity. However, it is an expensive material. It has good machinability. This implies that it can be easily cut. However, it has high tendency to produce large volume of chips (V. Songmene et al, 2011). Chips are undesirable for good surface finish as it is hard to remove them from cutting zone during fabrication.

2.6.4 Lead

Lead is a relatively soft metal. It physically looks bluish-white in colour. Due to its softness, it is a material with good malleability and ductility. Apart from that, it is highly resistive to corrosion. However, it will become tarnished (a dull and grey layer of carbonate) when exposed to air. Unlike steel, iron and aluminium, it is poor in conducting electricity. The applications of lead include batteries, cable sheaths, machinery manufacturing, shipbuilding, light industry as well as radiation protection. Unfortunately, it is found that usage of lead can cause negative environment effects. One of the adverse effects is water pollution due to corrosion of leaded pipelines in a water transporting system. Besides that, soil pollution is another consequence because of corrosion of leaded paints. What is more, usage of lead can affect humans' health like brain damage, kidney damage, disruption of the biosynthesis of haemoglobin, anaemia, disruption of nervous systems, miscarriages, subtle abortions and so on.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is the method and theory that will be carried out to achieve the objective of this study. The way on how to conducting experiments are covered in this chapter. Besides that, the method on analysing the data from experiments is also explained. This study is divided to two parts. The first part is conducted on aluminium alloy 6061 work pieces and the second part is carried out on carbon steel AISI 1060 work pieces.

3.2 Project Flow Chart

This study is started by having some literature reviews from other researchers. Next, the way of using and operating conventional lathe machine is learnt from teaching engineer in the laboratory. Besides that, machining parameters which are spindle speed and feed rate to be used are selected based on consultation of teaching engineers. This is then followed by conducting experiments. The experiments are carried out in three different conditions which are without coolant and lubricant (dry condition), with coolant and with lubricant. After that, the surfaces of work pieces obtained from experiments are measured by using surface roughness tester to determine its surface roughness. All the data is then tabulated and transformed into line graphs. Then, justifications are made to visualise and observe the trend of surface roughness with increasing machining parameters. From the observation, suggestion and recommendation can be outlined in order to provide direction on how to get better surface finish with low roughness by using conventional lathe machine.

The methodology of this study is summarised in the flow chart as shown in Figure 3.1.

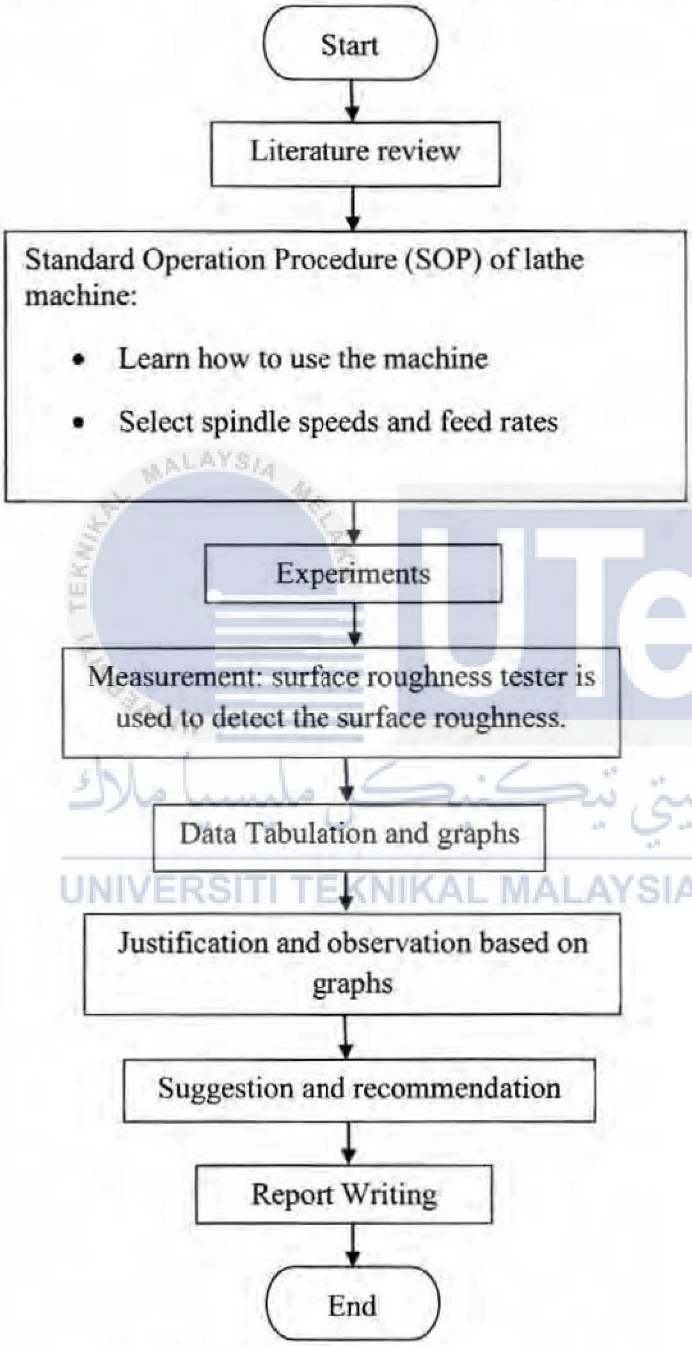

Figure 3.1: Flow chart of project.

3.3 Experimental Flow Chart

In order to design a proper experiment, it is important to have understanding on the related topic. This is started by meeting teaching engineer in the laboratory to get introduction of conventional lathe machine. The spindle speeds and feed rates that can be provided by the machine are noted. Then, five spindle speeds and feed rates are selected respectively to be used for experiment. Next, the standard operating procedures (SOP) on using conventional lathe machine are learnt. The experiment is designed and divided into two parts. The procedures for both parts of experiment are same except for the material involved. The first part of experiment is conducted by using aluminium alloy 6061 work pieces whereas the second part of experiment is carried out by using carbon steel AISI 1060 work pieces. For every part of experiment, there are three conditions of turning process which are without coolant and lubricant, with coolant and with lubricant. After that, the all the surfaces produced by turning process are measured to detect the roughness. The arithmetic average surface roughness, Ra of the surfaces are recorded and tabulated. Graphs of surface roughness against cutting parameters are plotted in order to observe the relationship of variables. Justifications are made based on results obtained. Besides that, surface roughness on aluminium alloy 6061 and carbon steel AISI 1060 is compared. Appropriate spindle speed and feed rate are suggested for conventional lathe machine so that low surface roughness can be achieved. Future researchers can save their time and cost by testing every machining parameter to get better surface finish with low roughness.

The flow of experiment is summarised in Figure 3.2 below:

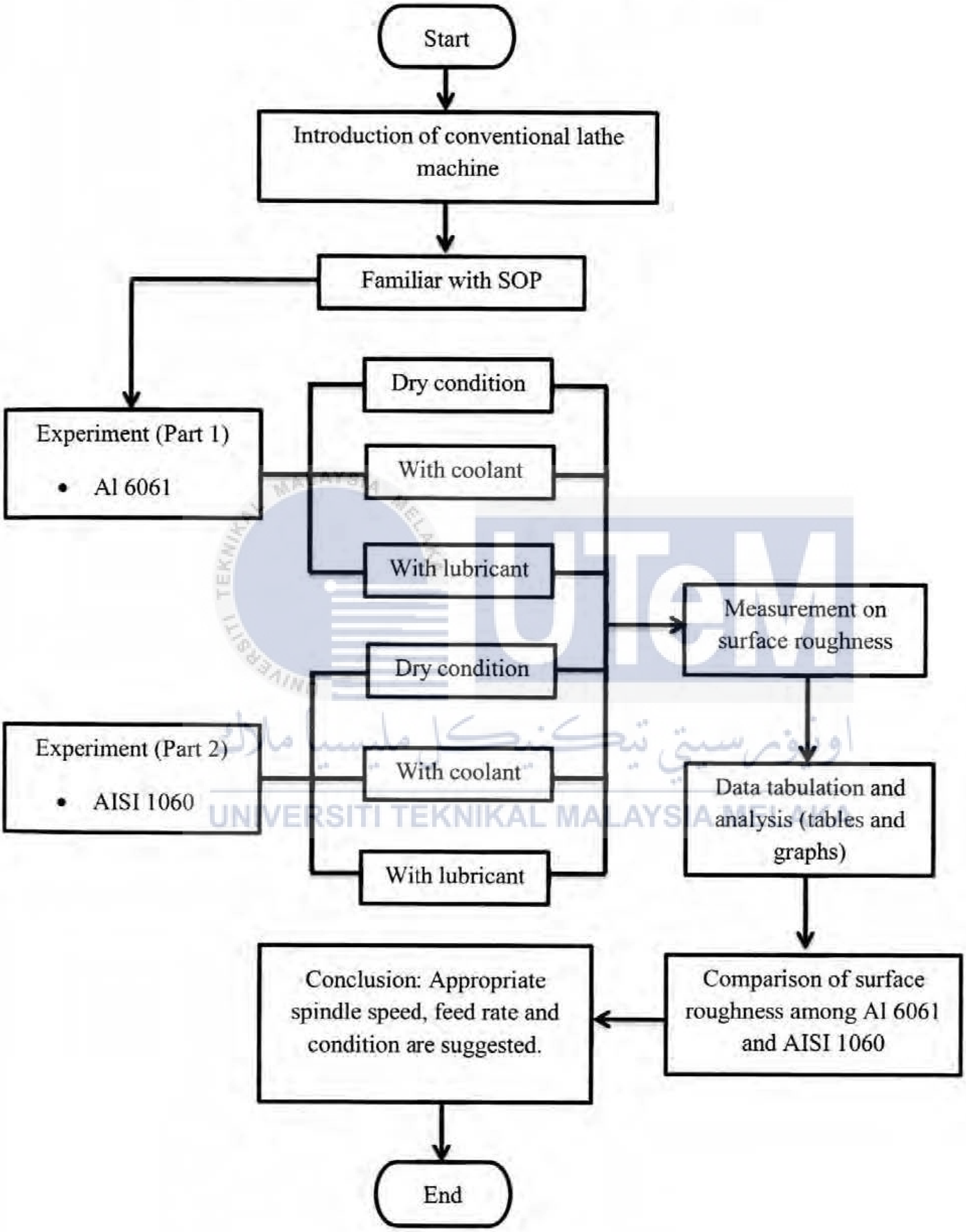

Figure 3.2: Flow chart of experiment.

3.3.1 Introduction of Conventional Lathe Machine

The model of conventional lathe machine that is used for this project is G-330E. It is manufactured by Gate Machinery. Figure 3.3 below shows the conventional machine in the laboratory.

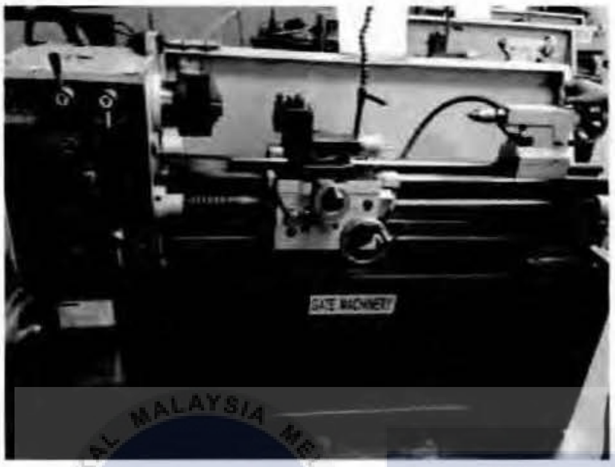

Figure 3.3: Conventional lathe machine.

There are nine spindle speeds that are provided by the machine. The available spindle speeds of the machine in rpm are 82, 165, 300, 400, 550, 770, 1100, 1400 and 2000. Figure 3.4 below shows the available spindle speeds of the machine.

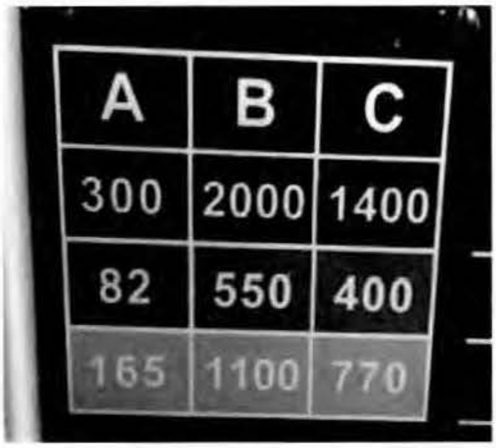

Figure 3.4: Available spindle speeds in rpm.

On the other hand, there are twelve feed rates that can be achieved by the machine. The available feed rates are shown in figure below:

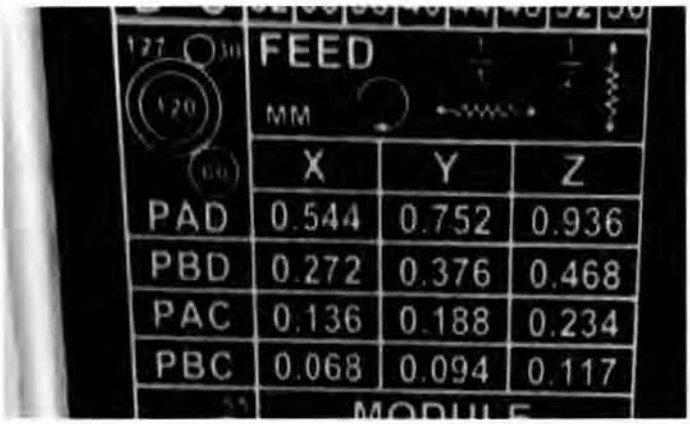

Figure 3.5: Available feed rates of machine in mm/rev.

After discussing with supervisor, the five spindle speeds and feed rates are chosen respectively for experiment. The chosen spindle speeds are 300 rpm, 550 rpm, 770 rpm, 1100 rpm and 1400 rpm. The spindle speed cannot be too fast because this may lead to burn up of cutting tool effect of friction. The chosen feed rates are 0.094 mm/rev, 0.188 mm/rev, 0.272 mm/rev, 0.376 mm/rev and 0.468 mm/rev. The risk of setting high feed rate is cutting tool may break as it feds too large when it moves forward. The feed rate also cannot be too slow as this may cause rubbing (situation of not cutting) and wear out the cutting tool. According to teaching engineer in the laboratory, the depth of cut cannot be too large as this may lead to break of work piece when spindle speed and feed rate getting higher. As the result, 0.5 mm is opted as the depth of cut for experiment.

3.3.2 Standard Operating Procedures (SOP)

There are several standard operating procedures that need to be adhered while using conventional lathe machine. Besides that, it is important to make sure the machine is cleaned after operation. On top of that, safety and precaution steps are vital to avoid any injury throughout the project. The details of SOP are explained in the following sessions.

3.3.2.1 Operating Procedures

There are several procedures that must be taken note when operating the machine. The procedures are described as below:

i) The first step of operating is clamping the work piece to be turned in the chuck firmly. Before that, it is important to make sure that the length of work piece is not too long to avoid work piece from vibrating during operation. Chuck refers to the part that is directly attached to the drive mechanism of the machine. Its motion is manipulated by spindle speed. Figure below shows the image of chuck.

Figure 3.6: Chuck of machine.

ii) It is essential to bear in mind that always starts operating the machine from lower spindle speed and feed rate to prevent heat up situation especially handling with steel work piece. This can be indicated by observing colour of steel chips turn to a blue tint or when the cutting fluid starts to burn off in a visible vapour.

iii) Generally, there are two axes for the machine. X-axis refers to track that allows horizontal movement of cutting tool approaches towards the chuck with work piece for feeding. It is controlled manually by cross slide hand wheel. It can be switched to auto movement by using cross slide feed lever. On the other hand, Y-axis refers to the way that deciding depth of cut for the work piece. The motion also can be manipulated by carriage hand wheel. Figure below shows the image of hand wheels and lever that control movement of cutting tool.

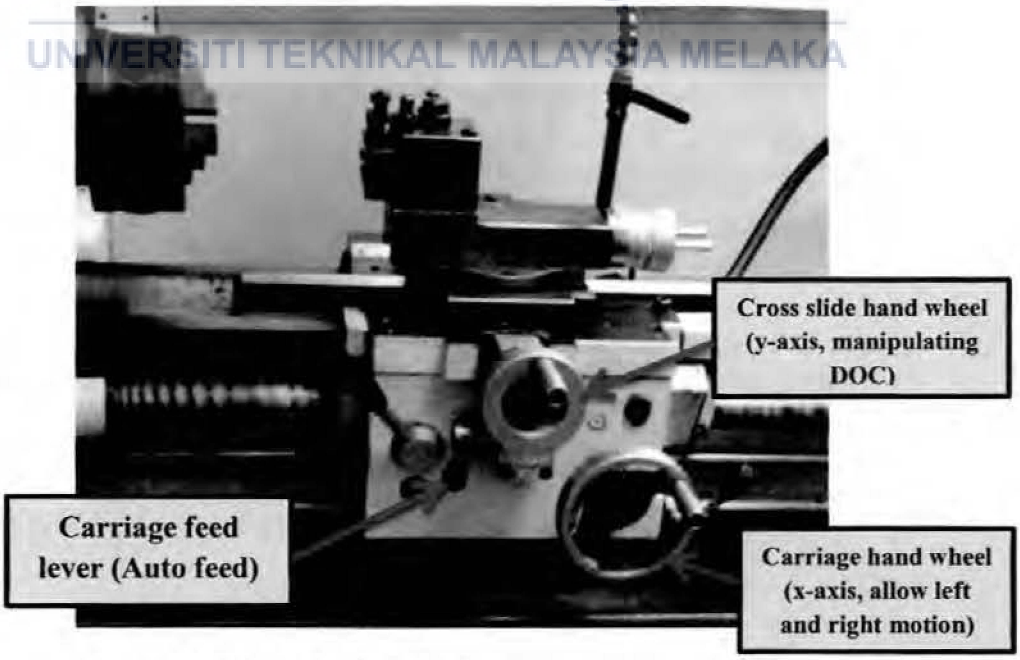

Figure 3.7: Hand wheels and lever.

iv) The cutting tool and tool holder are located at the tool post. In order to ensure safe and efficient cutting, the cutting tool tip must be placed directly on the centre of the part in the chuck. This is utmost important as cutting tool at extreme high position and the base of the tool will push on the work piece. This may destroy the work piece and cutting tool. Conversely, if the cutting tool is too low in position, the tool tip has higher tendency to gouge and lead to cut that is too deep.

3.3.2.2 Cleaning Procedures

The machine must be cleaned after operation. The cleaning procedures are simple and do not take a very long time. The procedures are as below:

i) The machine is turned off and the tool holder is removed. The machine can be cleaned either by brushing, blowing or wiping.

ii) Hand tools, set-up tools and cutting tools are put back to storage positions.

iii) The chips from the vice, table and ways can be cleared by using brush or light blasts of air.

iv) Cutting fluids and oils from the whole machine must be wiped off. Make sure top to bottom of the machine is dry.

v) Make sure the ground of the working area is clean without any chips.

vi) If coolant and lubricant are used for operation, pour the coolant and lubricant away from the storage.

3.3.2.3 Safety and Precaution

All the safety and precaution steps must be followed strictly regardless how experienced the operator is. The steps are listed as below:

i) Do not wear long sleeves, gloves or any jewellery while handling with the machine.

ii) For female operator with long hair, tie up hair to the back.

iii) Put all the clothes away from the machine while operating.

iv) Remember take away chuck key from chuck after using it.

v) Ensure work piece is tightly clamped by chuck so that it will not vibrate vigorously while turning operation.

vi) When inserting or removing work piece, move tailstock to a safe distance from the chuck.

vii) Stop the machine whenever want to approach the work piece by using hands.

viii) Make sure that the tool bit is sharp at the correct height and has the proper clearance all the times.

ix) Avoid grasping or touching of chips or turnings with fingers. Make sure the lathe is switched off before clearing chips with a brush or soft air blasts.

x) Clean the machine after finish using the machine.

3.3.3 Procedures of Experiment

The experiment is conducted in two parts respectively. The procedures are the same except for the material used as the work piece is different. Besides that, the experiment involves three conditions. Plus, there are five spindle speeds, five feed rates and two depths of cut need to be applied to the work pieces. The steps are as below:

i) **Dry Condition**

a) The long aluminium alloy 6061 work piece is cut into half by using hand saw.

Figure 3.8: Aluminium alloy 6061 work piece.

b) The work piece is then clamped firmly in the chuck. The chuck is tightened by using chuck key.

Figure 3.9: Clamping work piece in the chuck.

c) The spindle speed is set to 300 rpm by adjusting the knobs. Then, feed rate is set to 0.094 mm/rev.

d) The safety cover is put down. Next, the cutting tool is adjusted manually to touch the head of the work piece. The X-axis and Y-axis are set to be zero as coordinates. The coordinates of X and Y is shown is the digital display.

Figure 3.10: Safety cover and digital display.

e) The depth of cut is achieved manually altered by using cross slide hand wheel. The hand wheel is turned until Y coordinate in digital display shows 0.5 mm.

f) The machine is turned on. The carriage feed lever is activated to allow auto feed. The machine is stopped when X coordinate in digital display reaches 15 mm.

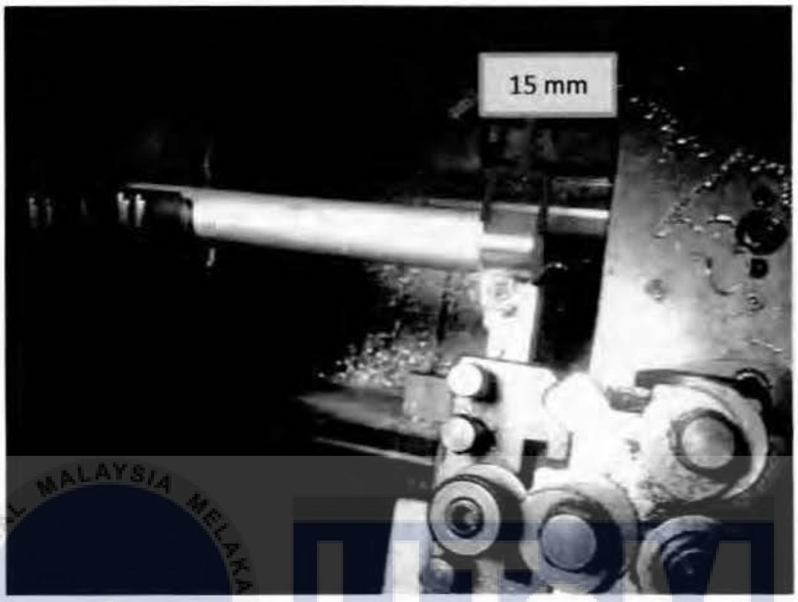

Figure 3.11: 15 mm of feed.

g) The next feed rate is set to 0.188 mm/rev. Step f) is repeated.

h) Step g) is repeated by different feed rates of 0.272 mm/rev, 0.376 mm/rev and 0.468 mm/rev.

i) Steps b) to h) are repeated by substituting 300 rpm to 550 rpm, 770 rpm, 1100 rpm and 1400 rpm respectively.

j) Same procedures are implemented for carbon steel AISI 1060 work piece.

ii) <u>Coolant Condition</u>

a) All the steps in part **i)** are repeated but this time the pipe providing coolant is turned on when turning process is operating. The coolant is spread on the cutting tool and work piece.

Figure 3.12: Coolant is applied during operation.

iii) <u>Lubricant Condition</u>

a) All the steps in part **i)** are repeated but this time the lubricant is poured when turning process is operating. The lubricant is spread on the cutting tool and work piece as shown in following figure.

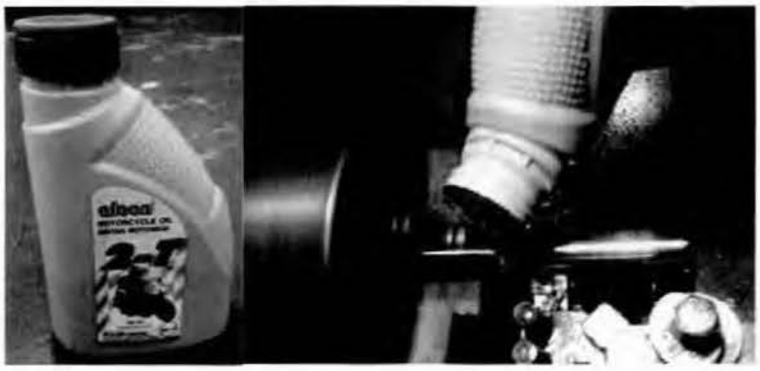

Figure 3.13: Lubricant is applied during operation.

iv) **Procedure on changing cutting tool**

Throughout this study, cutting tool is not taking account as the factor. Cutting tool is replaced once it is found broken as shown in Figure 3.14 below:

Figure 3.14: Broken cutting tool.

The steps on replacing cutting tool are as below:

a) Tool holder is taken out from its position.

Figure 3.15: Tool holder is taken out from its position.

b) Screw is loosened to take out the broken cutting tool.

Figure 3.16: Broken cutting tool is taken out.

c) A new cutting tool is replaced and screw is tightened after replacing new cutting.

Figure 3.17: New cutting tool is replaced.

d) Tool holder is placed back to its position and tightened at the position.

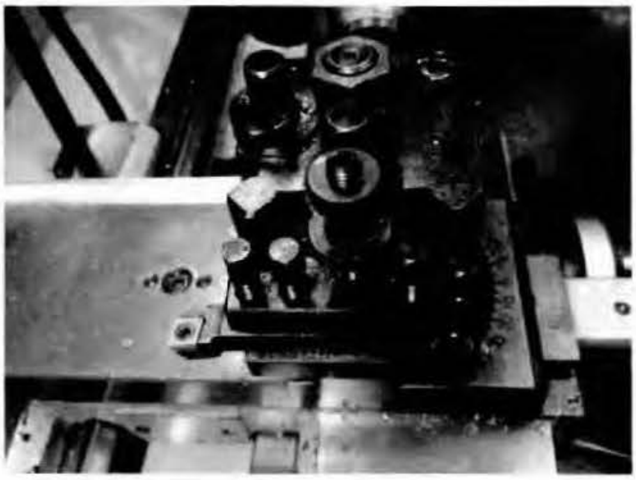

Figure 3.18: Tool holder is placed back to its position.

3.3.4 Measurement on Surface Roughness

From the experiment, 300 surfaces are obtained. 150 of aluminium alloy 6061 work piece surfaces and 150 of carbon steel AISI 1060 work piece surfaces. All the surfaces are measured to get the surface roughness. The apparatus that is used to detect the average roughness, Ra, is surface roughness tester. The model of the tester is TIME TR200. The following figure shows the tester used in this study.

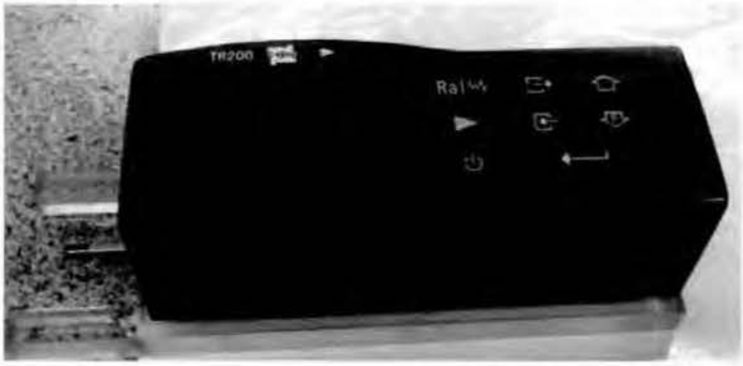

Figure 3.19: TIME TR200 surface roughness tester.

The ways of using are explained as below:

i) The stylus is attached to the monitor of the tester.

Figure 3.20: Stylus.

Figure 3.21: Monitor of tester.

ii) The tester is located at a height that is equal to the diameter of work piece to be measured as shown in following figure.

Figure 3.22: Locating surface roughness tester.

iii) The tester is turned on. The stylus is allowed to drag along the work piece.

iv) The roughness is detected by the tester and average roughness is calculated.

v) The result is displayed on the screen of the monitor.

Figure 3.23: Display of result on monitor.

vi) All the results are recorded and tabulated.

3.3.5 Data Tabulation and Justification

All the data obtained is tabulated in tables. In order to observe the effect of increasing spindle speed, other variables that involved must be the same. The effect of spindle speed is increasing while the feed rate, depth of cut, type of materials and condition of machining must be the same. Same goes to the observation on the effect of feed rate. Line graphs are provided in order to visualise the effect and changes. Justifications are made according to the obtained results.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter covers on results obtained from experiment. In addition, all the results are tabulated. Line graphs are drawn based on the results. After that, effect of machining parameters and conditions on surface roughness is observed. Justifications are made according to observations.

4.2 Effect of Spindle Speed on Surface Roughness

The effect of spindle speed can be observed by comparing the surface roughness obtained under the same feed rate, depth of cut, type of material and condition of machining. Spindle speed is the only variable so that the effect can be observed.

4.2.1 Surface Roughness Obtained under Dry Condition

The surface roughness obtained under dry condition is tabulated in Table 4.1 below. The table is arranged with increasing spindle speed and other variables are kept constant so that the effect of spindle speed can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Spindle speed that contributes to get the lowest surface roughness is highlighted.

Table 4.1: Surface roughness obtained with increasing spindle speed under dry condition.

No.	Material	Feed Rate (mm/rev)	DOC (mm)	Spindle Speed (rpm)	Arithmetic Average Surface Roughness, Ra (µm)
1	Al 6061	0.094	0.5	300	0.412
2	Al 6061	0.094	0.5	550	2.645
3	Al 6061	0.094	0.5	770	1.406
4	Al 6061	0.094	0.5	1100	1.389
5	Al 6061	0.094	0.5	1400	0.446
6	Al 6061	0.188	0.5	300	1.744
7	Al 6061	0.188	0.5	550	1.512
8	Al 6061	0.188	0.5	770	0.843
9	Al 6061	0.188	0.5	1100	1.815
10	Al 6061	0.188	0.5	1400	1.137
11	Al 6061	0.272	0.5	300	4.104
12	Al 6061	0.272	0.5	550	1.377
13	Al 6061	0.272	0.5	770	1.528
14	Al 6061	0.272	0.5	1100	0.628
15	Al 6061	0.272	0.5	1400	0.645
16	Al 6061	0.376	0.5	300	7.640
17	Al 6061	0.376	0.5	550	3.171
18	Al 6061	0.376	0.5	770	1.196
19	Al 6061	0.376	0.5	1100	0.655
20	Al 6061	0.376	0.5	1400	0.662
21	Al 6061	0.468	0.5	300	4.627
22	Al 6061	0.468	0.5	550	3.592
23	Al 6061	0.468	0.5	770	1.875
24	Al 6061	0.468	0.5	1100	1.607
25	Al 6061	0.468	0.5	1400	1.093
26	AISI 1060	0.094	0.5	300	4.763
27	AISI 1060	0.094	0.5	550	3.515
28	AISI 1060	0.094	0.5	770	1.762
29	AISI 1060	0.094	0.5	1100	5.132
30	AISI 1060	0.094	0.5	1400	2.288
31	AISI 1060	0.188	0.5	300	6.302
32	AISI 1060	0.188	0.5	550	4.752
33	AISI 1060	0.188	0.5	770	2.082
34	AISI 1060	0.188	0.5	1100	3.567
35	AISI 1060	0.188	0.5	1400	3.538
36	AISI 1060	0.272	0.5	300	6.241
37	AISI 1060	0.272	0.5	550	6.617
38	AISI 1060	0.272	0.5	770	4.928
39	AISI 1060	0.272	0.5	1100	2.992
40	AISI 1060	0.272	0.5	1400	3.265
41	AISI 1060	0.376	0.5	300	6.502
42	AISI 1060	0.376	0.5	550	7.753
43	AISI 1060	0.376	0.5	770	4.917
44	AISI 1060	0.376	0.5	1100	4.602
45	AISI 1060	0.376	0.5	1400	4.509
46	AISI 1060	0.468	0.5	300	6.502
47	AISI 1060	0.468	0.5	550	7.753
48	AISI 1060	0.468	0.5	770	4.917
49	AISI 1060	0.468	0.5	1100	4.602
50	AISI 1060	0.468	0.5	1400	4.509

Figures 4.1 and 4.2 below are the line graphs that showing the changes of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively with increasing spindle speed.

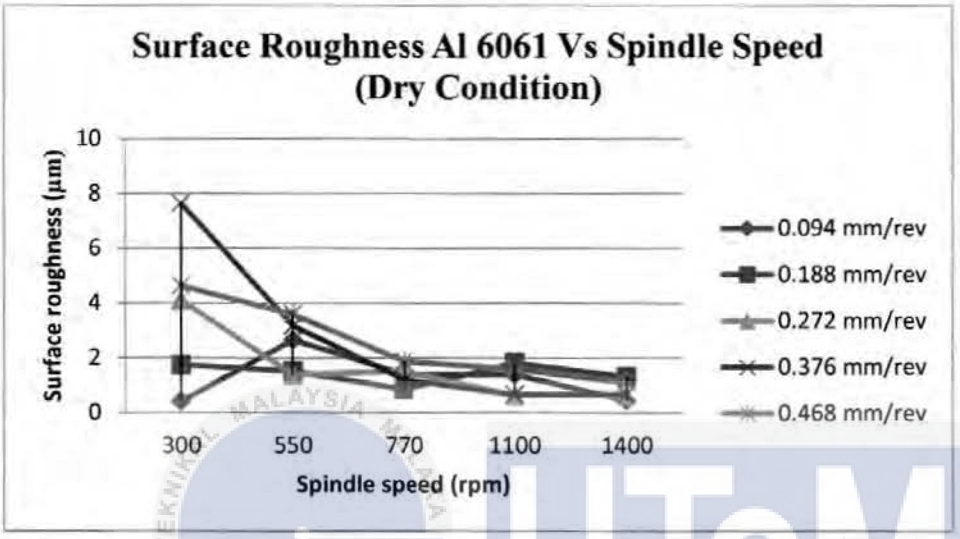

Figure 4.1: Line graph of surface roughness Al 6061 with increasing spindle speed under dry condition.

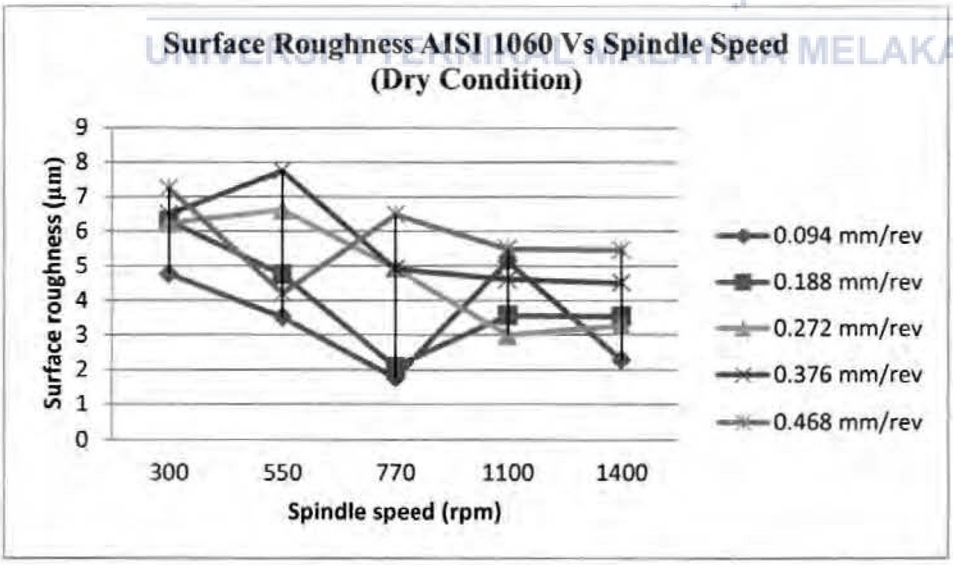

Figure 4.2: Line graph of surface roughness AISI 1060 with increasing spindle speed under dry condition.

4.2.1.1 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.094 mm/rev (DC)

Data from number 1 to 5 in Table 4.1 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under dry condition. It shows 300 rpm is the spindle speed that gives the lowest reading of surface roughness. Surface roughness increases when spindle speed is increased from 300 rpm to 550 rpm. However, surface roughness is getting lower when spindle speed is increased started from 550 rpm. Surface roughness keeps decreasing when spindle speed is increased from 550 rpm to 770 rpm, 1100 rpm and 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.1.

4.2.1.2 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.188 mm/rev (DC)

Data from number 6 to 10 in Table 4.1 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under dry condition. It shows that 770 rpm is the spindle speed that gives the lowest reading of surface roughness. Surface roughness decreases when spindle speed is increased from 300 rpm to 550 rpm and 770 rpm. However, surface roughness increases when spindle speed is increased started from 770 rpm to 1100 rpm. Surface roughness decreases again when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by looking at red line in Figure 4.1.

4.2.1.3 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.272 mm/rev (DC)

Data from number 11 to 15 in Table 4.1 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under dry condition. It shows that 1100 rpm is the spindle speed that gives the lowest reading of surface roughness. Initially, surface roughness decreases when spindle speed is increased from 300 rpm to 550 rpm, 770 rpm, and 1100rpm. However, surface roughness increases slightly when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by looking at green line in Figure 4.1.

4.2.1.4 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.376 mm/rev (DC)

Data from number 16 to 20 in Table 4.1 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under dry condition. It can be noticed that the lowest surface roughness is achieved at 1100 rpm. The surface roughness is decreasing with increasing spindle speed from 300 rpm to 1100 rpm. However, there is a small increment of surface roughness when the spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.1.

4.2.1.5 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.468 mm/rev (DC)

Data from number 21 to 25 in Table 4.1 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under dry condition. It is observable that the surface roughness is decreasing with increasing spindle speed. The lowest surface roughness is achieved at 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.1.

4.2.1.6 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.094 mm/rev (DC)

Data from number 26 to 30 in Table 4.1 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under dry condition. It clearly states that the lowest surface roughness is produced at 770 rpm. The surface roughness decreases with increasing spindle speed from 300 rpm till 770 rpm. Conversely, the surface roughness greatly increases when spindle speed is increased from 770 rpm to 1100 rpm. When spindle speed is getting higher from 1100 rpm to 1400 rpm, the surface roughness reduces. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.2.

4.2.1.7 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.188 mm/rev (DC)

Data from number 31 to 35 in Table 4.1 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under dry condition. It can be clarified that the lowest surface roughness is obtained at 770 rpm. The surface roughness decreases when spindle speed is increased from 300 rpm till 770 rpm. The surface roughness increases when spindle speed is continuously increased from 770 rpm to 1100 rpm. At last, the surface roughness shows a slight drop when spindle speed is getting higher from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by looking at red line in Figure 4.2.

4.2.1.8 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.272 mm/rev (DC)

Data from number 35 to 40 in Table 4.1 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under dry condition. According to the data, it shows that the lowest surface roughness is attained at 1100 rpm. The surface roughness tends to increase when spindle speed is increased from 300 rpm to 550 rpm. However, the surface roughness decreases when spindle speed is getting higher from 550 rpm to 770 rpm and 1100 rpm. At last, the surface roughness increases again when spindle speed is increased to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by looking at green line in Figure 4.2.

4.2.1.9 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.376 mm/rev (DC)

Data from number 41 to 45 in Table 4.1 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under dry condition. It displays that the lowest surface roughness is obtained at 1400 rpm. At first, the surface roughness increases when spindle speed is increased from 300 rpm to 550 rpm. Starting from 550 rpm, the surface roughness decreases with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.2.

4.2.1.10 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.468 mm/rev (DC)

Data from number 46 to 50 in Table 4.1 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under dry condition. It states that the lowest surface roughness is obtained at 1400 rpm. The surface roughness increases at first from 300 rpm to 550 rpm. Starting from that, the surface roughness decreases with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.2.

4.2.2 Surface Roughness Obtained under Coolant Condition

The surface roughness obtained under coolant condition is tabulated in Table 4.2. The table is arranged with increasing spindle speed and other variables are kept constant so that the effect of spindle speed can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Two line graphs are plotted based on the data to illustrate the changing of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively. The lines graphs are shown in Figure 4.3 and Figure 4.4. Spindle speed that contributes to get the lowest surface roughness is highlighted.

Table 4.2: Surface roughness obtained with increasing spindle speed under coolant condition.

No.	Material	Feed Rate (mm/rev)	DOC (mm)	Spindle Speed (rpm)	Arithmetic Average Surface Roughness, Ra (μm)
1	Al 6061	0.094	0.5	300	0.693
2	Al 6061	0.094	0.5	550	0.725
3	Al 6061	0.094	0.5	770	0.492
4	Al 6061	0.094	0.5	1100	0.751
5	Al 6061	0.094	0.5	1400	0.590
6	Al 6061	0.188	0.5	300	1.037
7	Al 6061	0.188	0.5	550	0.866
8	Al 6061	0.188	0.5	770	0.914
9	Al 6061	0.188	0.5	1100	0.585
10	Al 6061	0.188	0.5	1400	0.766
11	Al 6061	0.272	0.5	300	1.016
12	Al 6061	0.272	0.5	550	1.485
13	Al 6061	0.272	0.5	770	1.067
14	Al 6061	0.272	0.5	1100	1.187
15	Al 6061	0.272	0.5	1400	1.055
16	Al 6061	0.376	0.5	300	2.468
17	Al 6061	0.376	0.5	550	1.432
18	Al 6061	0.376	0.5	770	0.506
19	Al 6061	0.376	0.5	1100	1.108
20	Al 6061	0.376	0.5	1400	0.650
21	Al 6061	0.468	0.5	300	3.003
22	Al 6061	0.468	0.5	550	1.592
23	Al 6061	0.468	0.5	770	1.094
24	Al 6061	0.468	0.5	1100	0.948
25	Al 6061	0.468	0.5	1400	0.889
26	AISI 1060	0.094	0.5	300	4.602
27	AISI 1060	0.094	0.5	550	1.730
28	AISI 1060	0.094	0.5	770	4.622
29	AISI 1060	0.094	0.5	1100	6.212
30	AISI 1060	0.094	0.5	1400	5.778
31	AISI 1060	0.188	0.5	300	4.464
32	AISI 1060	0.188	0.5	550	5.033
33	AISI 1060	0.188	0.5	770	5.312
34	AISI 1060	0.188	0.5	1100	5.637
35	AISI 1060	0.188	0.5	1400	3.059
36	AISI 1060	0.272	0.5	300	6.396
37	AISI 1060	0.272	0.5	550	6.225
38	AISI 1060	0.272	0.5	770	6.262
39	AISI 1060	0.272	0.5	1100	6.585
40	AISI 1060	0.272	0.5	1400	1.349
41	AISI 1060	0.376	0.5	300	6.155
42	AISI 1060	0.376	0.5	550	5.779
43	AISI 1060	0.376	0.5	770	6.860
44	AISI 1060	0.376	0.5	1100	4.658
45	AISI 1060	0.376	0.5	1400	0.416
46	AISI 1060	0.468	0.5	300	5.157
47	AISI 1060	0.468	0.5	550	4.325
48	AISI 1060	0.468	0.5	770	5.757
49	AISI 1060	0.468	0.5	1100	4.714
50	AISI 1060	0.468	0.5	1400	7.825

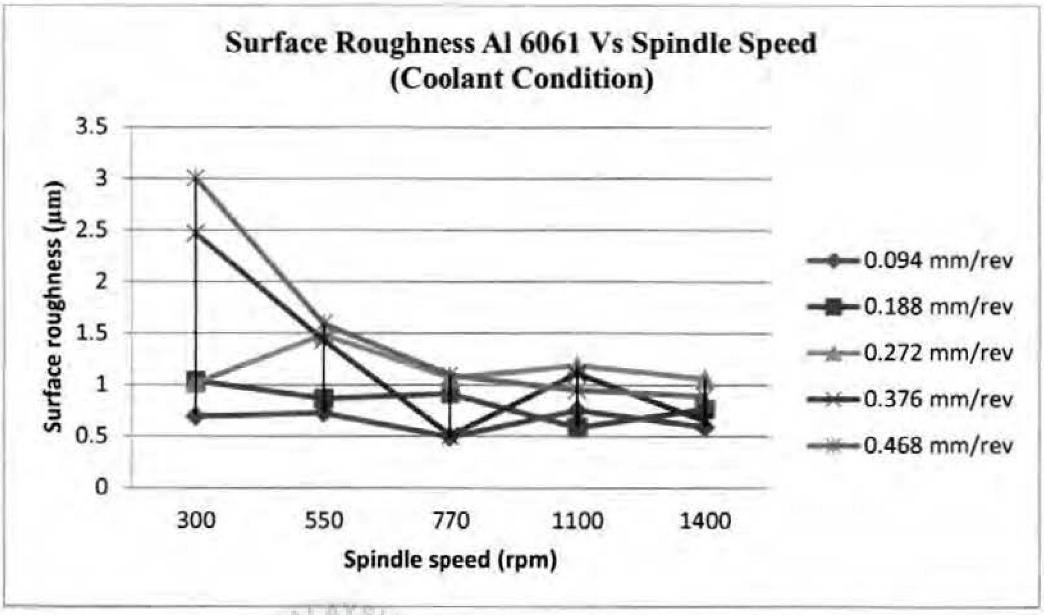

Figure 4.3: Line graph of surface roughness Al 6061 with increasing spindle speed under coolant condition.

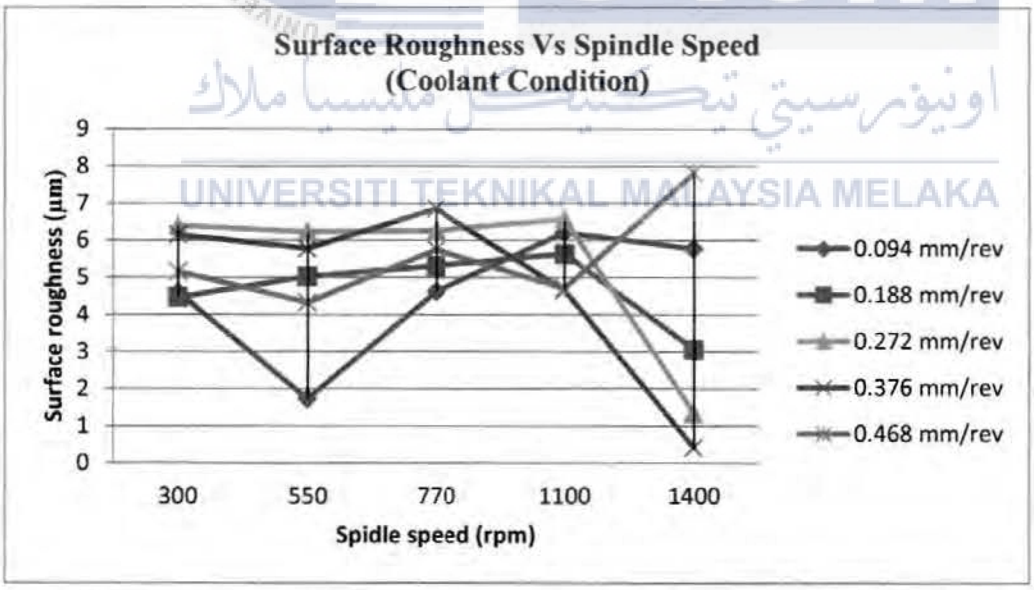

Figure 4.4: Line graph of surface roughness AISI 1060 with increasing spindle speed under coolant condition.

4.2.2.1 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.094 mm/rev (CC)

Data from number 1 to 5 in Table 4.2 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under coolant condition. It shows that 770 rpm is the spindle speed that gives the lowest reading of surface roughness. Surface roughness increases when spindle speed is increased from 300 rpm to 550 rpm. However, surface roughness is getting lower when spindle speed is increased from 550 rpm to 770 rpm. The surface roughness is then increases again when spindle speed is increased from 770 rpm to 1100 rpm. At last, the surface roughness decreases once again when the spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.3.

4.2.2.2 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.188 mm/rev (CC)

Data from number 6 to 10 in Table 4.2 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under coolant condition. It shows that 1100 rpm is the spindle speed that gives the lowest reading of surface roughness. The surface roughness decreases when spindle speed is increased from 300 rpm to 550 rpm. However, surface roughness increases when spindle speed is increased started from 550 rpm to 770 rpm. The surface roughness is then decreases again when spindle speed is getting higher from 770 rpm to 1100 rpm. At last, the surface roughness increases once again when spindle speed is increased from 1100 rpm to 1400 rpm.

The effect of spindle speed on surface roughness can be visualised by referring red line in Figure 4.3.

4.2.2.3 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.272 mm/rev (CC)

Data from number 11 to 15 in Table 4.2 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under coolant condition. It shows that 300 rpm is the spindle speed that gives the lowest reading of surface roughness. Initially, surface roughness increases when spindle speed is increased from 300 rpm to 550 rpm. However, the surface roughness decreases when spindle speed is increased from 550 rpm to 770 rpm. Next, the surface roughness increases when spindle speed is getting higher from 770 rpm to 1100 rpm. Lastly, the surface roughness decreases once again when spindle speed is altered from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring green line in Figure 4.3.

4.2.2.4 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.376 mm/rev (CC)

Data from number 16 to 20 in Table 4.2 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under coolant condition. It can be noticed that the lowest surface roughness is achieved at 770 rpm. The surface roughness is decreasing with increasing spindle speed from 300 rpm to 770 rpm. However, there is an increment of surface roughness when the spindle speed is increased from 770 rpm to 1100 rpm. The surface roughness decreases once again when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.3.

4.2.2.5 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.468 mm/rev (CC)

Data from number 21 to 25 in Table 4.2 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under coolant condition. It is observable that the surface roughness is decreasing with increasing spindle speed. The lowest surface roughness is achieved at 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.3.

4.2.2.6 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.094 mm/rev (CC)

Data from number 26 to 30 in Table 4.2 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under coolant condition. It clearly states that the lowest surface roughness is produced at 550 rpm. The surface roughness decreases when spindle speed is increased from 300 rpm to 550 rpm. The surface roughness is then increasing with increasing spindle speed from 550 rpm up till 1100 rpm. At last, the surface roughness decreases when spindle speed is increased to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.4.

4.2.2.7 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.188 mm/rev (CC)

Data from number 31 to 35 in Table 4.2 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under coolant condition. It can be clarified that the lowest surface roughness is obtained at 1400 rpm. The surface roughness keeps increasing with increasing spindle speed up till 1100 rpm. At last, the surface roughness drops till the lowest at spindle speed 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring red line in Figure 4.4.

4.2.2.8 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.272 mm/rev (CC)

Data from number 35 to 40 in Table 4.2 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under coolant condition. According to data obtained, it shows that the lowest surface roughness is attained at 1400 rpm. Initially, the surface roughness decreases when spindle speed is varied from 300 rpm to 550 rpm. The surface roughness is then increases consecutively at 770 rpm and 1100 rpm respectively. Lastly, the surface roughness greatly reduces when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring green line in Figure 4.4.

4.2.2.9 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.376 mm/rev (CC)

Data from number 41 to 45 in Table 4.2 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under coolant condition. It displays that the lowest surface roughness is obtained at 1400 rpm. At first, the surface roughness decreases when spindle speed is increased from 300 rpm to 550 rpm. The surface roughness increases when spindle speed is altered from 550 rpm to 770 rpm. Starting from 770 rpm, the surface roughness decreases with increasing spindle speed up till 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.4.

4.2.2.10 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.468 mm/rev (CC)

Data from number 46 to 50 in Table 4.2 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under coolant condition. It states that the lowest surface roughness is obtained at 550 rpm. The surface roughness is fluctuating with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.4.

4.2.3 Surface roughness Obtained under Lubricant Condition

The surface roughness obtained under lubricant condition is tabulated in Table 4.3. The table is arranged with increasing spindle speed and other variables are kept constant so that the effect of spindle speed can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Two line graphs are plotted based on the data to illustrate the changing of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively. The lines graphs are shown in Figure 4.5 and Figure 4.6. Spindle speed that contributes to get the lowest surface roughness is highlighted.

Table 4.3: Surface roughness obtained with increasing spindle speed under lubricant condition.

No.	Material	Feed Rate (mm/rev)	DOC (mm)	Spindle Speed (rpm)	Arithmetic Average Surface Roughness, Ra (μm)
1	Al 6061	0.094	0.5	300	0.906
2	Al 6061	0.094	0.5	550	0.622
3	Al 6061	0.094	0.5	770	0.682
4	Al 6061	0.094	0.5	1100	0.339
5	Al 6061	0.094	0.5	1400	1.233
6	Al 6061	0.188	0.5	300	0.843
7	Al 6061	0.188	0.5	550	0.619
8	Al 6061	0.188	0.5	770	0.988
9	Al 6061	0.188	0.5	1100	0.349
10	Al 6061	0.188	0.5	1400	1.144
11	Al 6061	0.272	0.5	300	1.269
12	Al 6061	0.272	0.5	550	1.233
13	Al 6061	0.272	0.5	770	1.098
14	Al 6061	0.272	0.5	1100	0.983
15	Al 6061	0.272	0.5	1400	1.332
16	Al 6061	0.376	0.5	300	2.377
17	Al 6061	0.376	0.5	550	1.176
18	Al 6061	0.376	0.5	770	0.796
19	Al 6061	0.376	0.5	1100	1.503
20	Al 6061	0.376	0.5	1400	1.339
21	Al 6061	0.468	0.5	300	2.119
22	Al 6061	0.468	0.5	550	1.498
23	Al 6061	0.468	0.5	770	1.037
24	Al 6061	0.468	0.5	1100	1.300
25	Al 6061	0.468	0.5	1400	1.740
26	AISI 1060	0.094	0.5	300	5.831
27	AISI 1060	0.094	0.5	550	6.228
28	AISI 1060	0.094	0.5	770	1.304
29	AISI 1060	0.094	0.5	1100	2.747
30	AISI 1060	0.094	0.5	1400	4.638
31	AISI 1060	0.188	0.5	300	6.781
32	AISI 1060	0.188	0.5	550	8.567
33	AISI 1060	0.188	0.5	770	2.680
34	AISI 1060	0.188	0.5	1100	2.303
35	AISI 1060	0.188	0.5	1400	4.733
36	AISI 1060	0.272	0.5	300	8.743
37	AISI 1060	0.272	0.5	550	6.678
38	AISI 1060	0.272	0.5	770	3.187
39	AISI 1060	0.272	0.5	1100	2.160
40	AISI 1060	0.272	0.5	1400	2.858
41	AISI 1060	0.376	0.5	300	8.878
42	AISI 1060	0.376	0.5	550	6.175
43	AISI 1060	0.376	0.5	770	4.203
44	AISI 1060	0.376	0.5	1100	4.534
45	AISI 1060	0.376	0.5	1400	3.552
46	AISI 1060	0.468	0.5	300	8.967
47	AISI 1060	0.468	0.5	550	5.050
48	AISI 1060	0.468	0.5	770	5.018
49	AISI 1060	0.468	0.5	1100	4.534
50	AISI 1060	0.468	0.5	1400	6.022

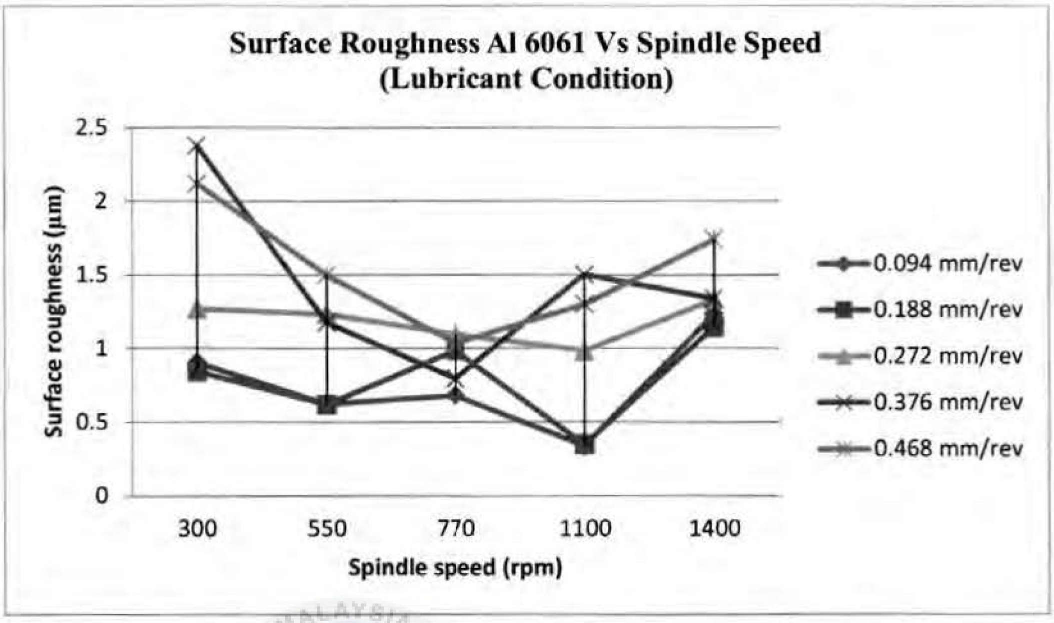

Figure 4.5: Line graph of surface roughness Al 6061 with increasing spindle speed under lubricant condition.

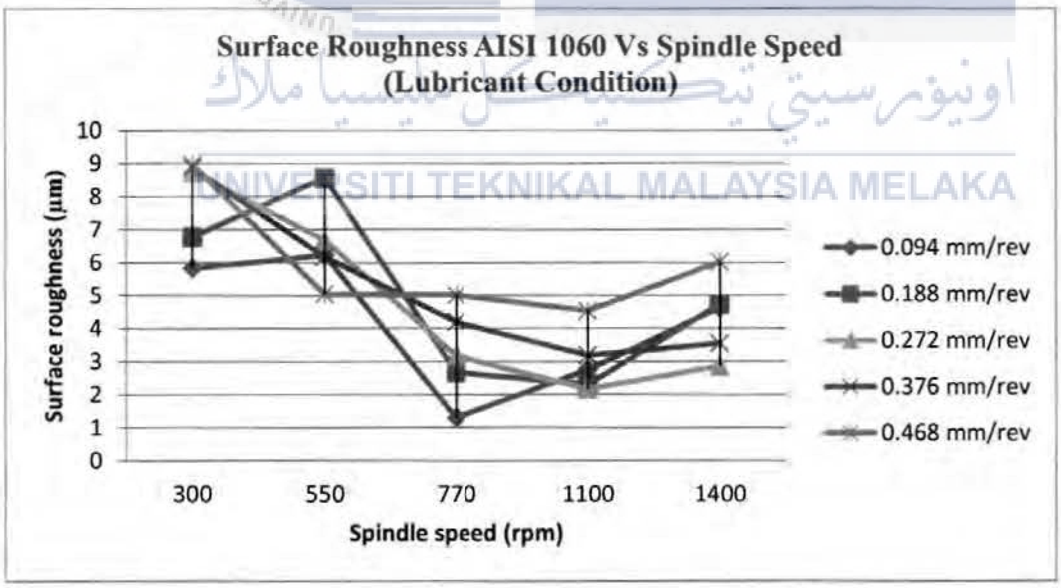

Figure 4.6: Line graph of surface roughness AISI 1060 with increasing spindle speed under lubricant condition.

4.2.3.1 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.094 mm/rev (LC)

Data from number 1 to 5 in Table 4.3 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under lubricant condition. It shows that 1100 rpm is the spindle speed that gives the lowest reading of surface roughness. The surface roughness is fluctuating with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.5.

4.2.3.2 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.188 mm/rev (LC)

Data from number 6 to 10 in Table 4.3 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under lubricant condition. It shows that 1100 rpm is the spindle speed that gives the lowest reading of surface roughness. The surface roughness is fluctuating with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring red line in Figure 4.5.

4.2.3.3 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.272 mm/rev (LC)

Data from number 11 to 15 in Table 4.3 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under lubricant condition. It shows that 1100 rpm is the spindle speed that gives the lowest reading of surface roughness. The surface roughness decreases with increasing spindle speed up till 1100 rpm. The surface roughness experiences an increment when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring green line in Figure 4.5.

4.2.3.4 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.376 mm/rev (LC)

Data from number 16 to 20 in Table 4.3 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under lubricant condition. It can be noticed that the lowest surface roughness is achieved at 770 rpm. The surface roughness is decreasing with increasing spindle speed from 300 rpm to 770 rpm. However, there is an increment of surface roughness when the spindle speed is increased from 770 rpm to 1100 rpm. The surface roughness is then decreases once again when spindle speed is varied from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.5.

4.2.3.5 Effect of Spindle Speed on Surface Roughness of Al 6061 obtained by 0.468 mm/rev (LC)

Data from number 21 to 25 in Table 4.3 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under lubricant condition. It is observable that the lowest surface roughness is obtained at 770 rpm. The surface roughness decreases with increasing spindle speed up till 770 rpm. Starting from 770 rpm, the surface roughness increases with increasing spindle speed up till 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.5.

4.2.3.6 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.094 mm/rev (LC)

Data from number 26 to 30 in Table 4.3 is the surface roughness obtained at 0.094 mm/rev and 0.5 mm under lubricant condition. It clearly states that the lowest surface roughness is produced at 770 rpm. The surface roughness increases when 330 rpm is increased to 550 rpm. Conversely, the surface roughness decreases when spindle speed is increased from 550 rpm to 770 rpm. Starting from 770 rpm till 1400 rpm, the surface roughness is increasing with increasing spindle speed. The effect of spindle speed on surface roughness can be visualised by referring dark blue line in Figure 4.6.

4.2.3.7 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.188 mm/rev (LC)

Data from number 31 to 35 in Table 4.3 is the surface roughness obtained at 0.188 mm/rev and 0.5 mm under lubricant condition. It can be clarified that the lowest surface roughness is obtained at 1100 rpm. The surface roughness increases when spindle speed is increased from 300 rpm to 550 rpm. The surface roughness decreases when spindle speed is continuously increased from 550 rpm up till 1100 rpm. At last, the surface roughness increases greatly when spindle speed is getting higher from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring red line in Figure 4.6.

4.2.3.8 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.272 mm/rev (LC)

Data from number 36 to 40 in Table 4.3 is the surface roughness obtained at 0.272 mm/rev and 0.5 mm under lubricant condition. According to data obtained, it shows that the lowest surface roughness is attained at 1100 rpm. The surface roughness tends to drop with increasing spindle speed from 300 rpm till 1100 rpm. However, the surface roughness increases when spindle speed is getting higher from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring green line in Figure 4.6.

4.2.3.9 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.376 mm/rev (LC)

Data from number 41 to 45 in Table 4.3 is the surface roughness obtained at 0.376 mm/rev and 0.5 mm under lubricant condition. It displays that the lowest surface roughness is obtained at 1400 rpm. At first, the surface roughness decreases when spindle speed is increased from 300 rpm up till 770 rpm. Next, 770 rpm is continuously increased to 1100 rpm, the surface roughness increases. However, the surface roughness drops to the lowest reading when the spindle speed is getting higher from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring purple line in Figure 4.6.

4.2.3.10 Effect of Spindle Speed on Surface Roughness of AISI 1060 obtained by 0.468 mm/rev (LC)

Data from number 46 to 50 in Table 4.3 is the surface roughness obtained at 0.468 mm/rev and 0.5 mm under lubricant condition. It states that the lowest surface roughness is obtained at 1100 rpm. The surface roughness decreases at first from 300 rpm up till 1100 rpm. However, the surface roughness increases when spindle speed is increased from 1100 rpm to 1400 rpm. The effect of spindle speed on surface roughness can be visualised by referring light blue line in Figure 4.6.

4.2.4 Justifications on Effect of Spindle Speed

It is a fact that, surface roughness acts inversely proportional with increasing spindle speed. Low surface roughness should be obtained at high spindle speed. However, data obtained from experiment does not perfectly match this fact. Only two lines which fulfil the fact. Hence, the highest spindle speed is not necessary the best spindle speed to produce surface with low roughness. Optimisation needs to be conducted in order to find out the most appropriate spindle speed to be used. From this study, it shows that the use of spindle speed 1100 rpm has high probability to get low surface roughness as it appears ten times to get the lowest reading of surface roughness. Hence, 1100 rpm can be prioritised when optimisation is planned to be carried out.

4.3 Effect of Feed Rate on Surface Roughness

The effect of feed rate can be observed by comparing the surface roughness obtained under the same spindle speed, depth of cut, type of material and condition of machining. Feed rate is the only variable so that the effect can be observed.

4.3.1 Surface Roughness Obtained under Dry Condition

The surface roughness obtained under dry condition is tabulated in Table 4.4. The table is arranged with increasing feed rate and other variables are kept constant so that the effect of feed rate can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Two line graphs are then plotted to illustrate the effect of feed rate. Figures 4.7 and 4.8 below are the line graphs that showing the changes of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively with increasing feed rate. Feed rate that contributes to get the lowest surface roughness is highlighted.

Table 4.4: Surface roughness obtained with increasing feed rate under dry condition.

No.	Material	Spindle Speed (rpm)	DOC (mm)	Feed Rate (mm/rev)	Arithmetic Average Surface Roughness, Ra (μm)
1	Al 6061	300	0.5	0.094	0.412
2	Al 6061	300	0.5	0.188	1.744
3	Al 6061	300	0.5	0.272	4.104
4	Al 6061	300	0.5	0.376	7.640
5	Al 6061	300	0.5	0.468	4.627
6	Al 6061	550	0.5	0.094	2.645
7	Al 6061	550	0.5	0.188	1.512
8	Al 6061	550	0.5	0.272	1.377
9	Al 6061	550	0.5	0.376	3.171
10	Al 6061	550	0.5	0.468	3.592
11	Al 6061	770	0.5	0.094	1.406
12	Al 6061	770	0.5	0.188	0.843
13	Al 6061	770	0.5	0.272	1.528
14	Al 6061	770	0.5	0.376	1.196
15	Al 6061	770	0.5	0.468	1.875
16	Al 6061	1100	0.5	0.094	1.389
17	Al 6061	1100	0.5	0.188	1.815
18	Al 6061	1100	0.5	0.272	0.628
19	Al 6061	1100	0.5	0.376	0.655
20	Al 6061	1100	0.5	0.468	1.607
21	Al 6061	1400	0.5	0.094	0.446
22	Al 6061	1400	0.5	0.188	1.137
23	Al 6061	1400	0.5	0.272	0.645
24	Al 6061	1400	0.5	0.376	0.662
25	Al 6061	1400	0.5	0.468	1.093
26	AISI 1060	300	0.5	0.094	4.763
27	AISI 1060	300	0.5	0.188	6.302
28	AISI 1060	300	0.5	0.272	6.241
29	AISI 1060	300	0.5	0.376	6.502
30	AISI 1060	300	0.5	0.468	7.242
31	AISI 1060	550	0.5	0.094	3.515
32	AISI 1060	550	0.5	0.188	4.752
33	AISI 1060	550	0.5	0.272	6.617
34	AISI 1060	550	0.5	0.376	7.753
35	AISI 1060	550	0.5	0.468	4.202
36	AISI 1060	770	0.5	0.094	1.762
37	AISI 1060	770	0.5	0.188	2.082
38	AISI 1060	770	0.5	0.272	4.928
39	AISI 1060	770	0.5	0.376	4.917
40	AISI 1060	770	0.5	0.468	6.488
41	AISI 1060	1100	0.5	0.094	5.132
42	AISI 1060	1100	0.5	0.188	3.567
43	AISI 1060	1100	0.5	0.272	2.992
44	AISI 1060	1100	0.5	0.376	4.602
45	AISI 1060	1100	0.5	0.468	5.490
46	AISI 1060	1400	0.5	0.094	2.288
47	AISI 1060	1400	0.5	0.188	3.538
48	AISI 1060	1400	0.5	0.272	3.265
49	AISI 1060	1400	0.5	0.376	4.509
50	AISI 1060	1400	0.5	0.468	5.458

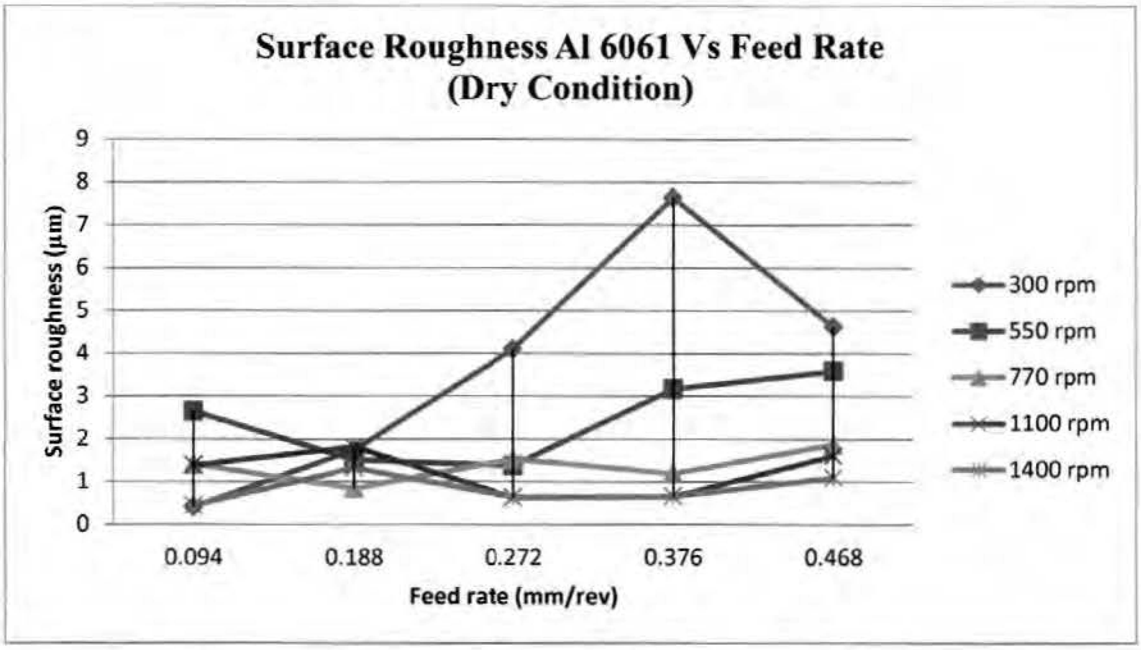

Figure 4.7: Line graph of surface roughness Al 6061 with increasing feed rate under dry condition.

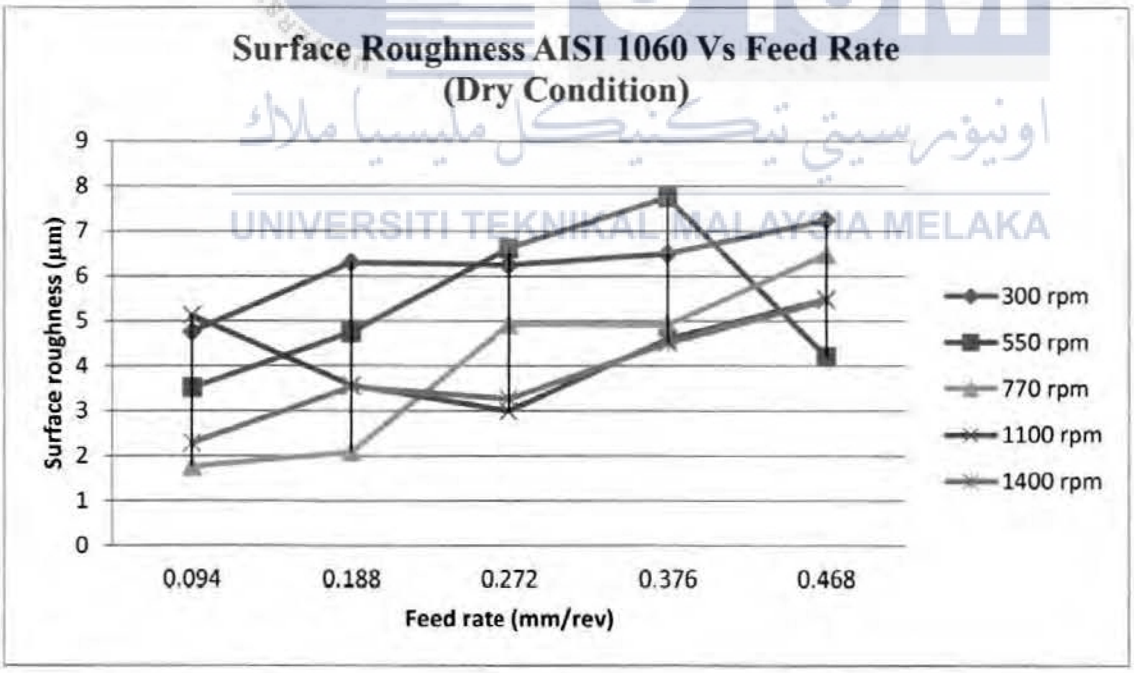

Figure 4.8: Line graph of surface roughness AISI 1060 with increasing feed rate under dry condition.

4.3.1.1 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 300 rpm (DC)

Data from number 1 to 5 in Table 4.4 is the surface roughness obtained at 300 rpm and 0.5 mm under dry condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.376 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring dark blue line in Figure 4.7.

4.3.1.2 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 550 rpm (DC)

Data from number 6 to 10 in Table 4.4 is the surface roughness obtained at 550 rpm and 0.5 mm under dry condition. The result shows that the lowest surface roughness is produced at 0.272 mm/rev. Initially, the surface roughness decreases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. However, the surface roughness increases when the feed rate is allowed to increase from 0.272 mm/rev to 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by looking at red line in Figure 4.7.

4.3.1.3 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 770 rpm (DC)

Data from number 11 to 15 in Table 4.4 is the surface roughness obtained at 770 rpm and 0.5 mm under dry condition. The lowest reading of surface roughness is obtained at 0.188 mm/rev. The surface roughness reflects a fluctuating trend with increasing feed rate. The effect of feed rate on surface roughness can be visualised by looking at green line in Figure 4.7.

4.3.1.4 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1100 rpm (DC)

Data from number 16 to 20 in Table 4.4 is the surface roughness obtained at 1100 rpm and 0.5 mm under dry condition. The result shows that the lowest surface roughness is attained at 0.272 mm/rev. At first, the surface roughness increases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. Next, the surface roughness decreases when feed rate is further increased to 0.272 mm/rev. Starting from 0.272 mm/rev, the surface roughness increases with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be observed by referring purple line in Figure 4.7.

4.3.1.5 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1400 rpm (DC)

Data from number 21 to 25 in Table 4.4 is the surface roughness obtained at 1400 rpm and 0.5 mm under dry condition. The lowest surface roughness is recorded at 0.094 mm/rev. Initially, the surface roughness increases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. The surface roughness experiences a down turn when feed rate is increased to 0.272 mm/rev. Starting from 0.272 mm/rev, the surface roughness increases with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring light blue line in Figure 4.7.

4.3.1.6 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 300 rpm (DC)

Data from number 26 to 30 in Table 4.4 is the surface roughness obtained at 300 rpm and 0.5 mm under dry condition. The lowest reading of surface roughness is obtained at 0.094 mm/rev. The surface roughness increases when feed rate is increased to 0.188 mm/rev. However, the surface roughness drops slightly when feed rate is increased to 0.272 mm/rev. After that, the surface roughness keeps increasing with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be tracked by referring dark blue line in Figure 4.8.

4.3.1.7 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 550 rpm (DC)

Data from number 31 to 35 in Table 4.4 is the surface roughness obtained at 550 rpm and 0.5 mm under dry condition. The lowest reading of surface roughness in this case is achieved at 0.094 mm/rev. The surface roughness increases with increasing feed rate. However, this trend stops at 0.376 mm/rev. The surface roughness decreases when feed rate is increased from 0.376 mm/rev to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring red line in Figure 4.8.

4.3.1.8 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 770 rpm (DC)

Data from number 36 to 40 in Table 4.4 is the surface roughness obtained at 770 rpm and 0.5 mm under dry condition. The best surface with lowest roughness is obtained at 0.094 mm/rev. The surface roughness increases with increasing feed rate up till feed rate 0.272 mm/rev. There is a small drop on surface roughness when feed rate is increased from 0.272 mm/rev to 0.376 mm/rev. However, the surface roughness increases once again when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by looking at green line in Figure 4.8.

4.3.1.9 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1100 rpm (DC)

Data from number 41 to 45 in Table 4.4 is the surface roughness obtained at 1100 rpm and 0.5 mm under dry condition. The lowest record of surface roughness in this case is accomplished at 0.272 mm/rev. The surface roughness decreases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. Starting from that, the surface roughness increases with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness is illustrated by purple line in Figure 4.8.

4.3.1.10 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1400 rpm (DC)

Data from number 46 to 50 in Table 4.4 is the surface roughness obtained at 1400 rpm and 0.5 mm under dry condition. The lowest reading of surface roughness is obtained at 0.094 mm/rev. The surface roughness increases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. Next, the surface roughness decreases when the feed rate is increased from 0.188 mm/rev to 0.272 mm/rev. After that, the surface roughness keeps increasing with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate can be observed by looking at light blue line in Figure 4.8.

4.3.2 Surface Roughness Obtained under Coolant Condition

The surface roughness obtained under coolant condition is tabulated in Table 4.5. The table is arranged with increasing feed rate and other variables are kept constant so that the effect of feed rate can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Two line graphs are plotted based on the data to illustrate the changing of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively. The lines graphs are shown in Figure 4.9 and Figure 4.10. Feed rate that contributes to get the lowest surface roughness is highlighted.

Table 4.5: Surface roughness obtained with increasing feed rate under coolant condition.

No.	Material	Spindle Speed (rpm)	DOC (mm)	Feed Rate (mm/rev)	Arithmetic Average Surface Roughness, Ra (μm)
1	Al 6061	300	0.5	0.094	0.693
2	Al 6061	300	0.5	0.188	1.037
3	Al 6061	300	0.5	0.272	1.016
4	Al 6061	300	0.5	0.376	2.468
5	Al 6061	300	0.5	0.468	3.003
6	Al 6061	550	0.5	0.094	0.725
7	Al 6061	550	0.5	0.188	0.866
8	Al 6061	550	0.5	0.272	1.485
9	Al 6061	550	0.5	0.376	1.432
10	Al 6061	550	0.5	0.468	1.592
11	Al 6061	770	0.5	0.094	0.492
12	Al 6061	770	0.5	0.188	0.914
13	Al 6061	770	0.5	0.272	1.067
14	Al 6061	770	0.5	0.376	0.506
15	Al 6061	770	0.5	0.468	1.094
16	Al 6061	1100	0.5	0.094	0.751
17	Al 6061	1100	0.5	0.188	0.585
18	Al 6061	1100	0.5	0.272	1.187
19	Al 6061	1100	0.5	0.376	1.108
20	Al 6061	1100	0.5	0.468	0.948
21	Al 6061	1400	0.5	0.094	0.590
22	Al 6061	1400	0.5	0.188	0.766
23	Al 6061	1400	0.5	0.272	1.055
24	Al 6061	1400	0.5	0.376	0.650
25	Al 6061	1400	0.5	0.468	0.889
26	AISI 1060	300	0.5	0.094	4.602
27	AISI 1060	300	0.5	0.188	4.464
28	AISI 1060	300	0.5	0.272	6.396
29	AISI 1060	300	0.5	0.376	6.155
30	AISI 1060	300	0.5	0.468	5.157
31	AISI 1060	550	0.5	0.094	1.730
32	AISI 1060	550	0.5	0.188	5.033
33	AISI 1060	550	0.5	0.272	6.225
34	AISI 1060	550	0.5	0.376	5.779
35	AISI 1060	550	0.5	0.468	4.325
36	AISI 1060	770	0.5	0.094	4.622
37	AISI 1060	770	0.5	0.188	5.312
38	AISI 1060	770	0.5	0.272	6.262
39	AISI 1060	770	0.5	0.376	6.860
40	AISI 1060	770	0.5	0.468	5.757
41	AISI 1060	1100	0.5	0.094	6.212
42	AISI 1060	1100	0.5	0.188	5.637
43	AISI 1060	1100	0.5	0.272	6.585
44	AISI 1060	1100	0.5	0.376	4.658
45	AISI 1060	1100	0.5	0.468	4.714
46	AISI 1060	1400	0.5	0.094	5.778
47	AISI 1060	1400	0.5	0.188	3.059
48	AISI 1060	1400	0.5	0.272	1.349
49	AISI 1060	1400	0.5	0.376	0.416
50	AISI 1060	1400	0.5	0.468	7.825

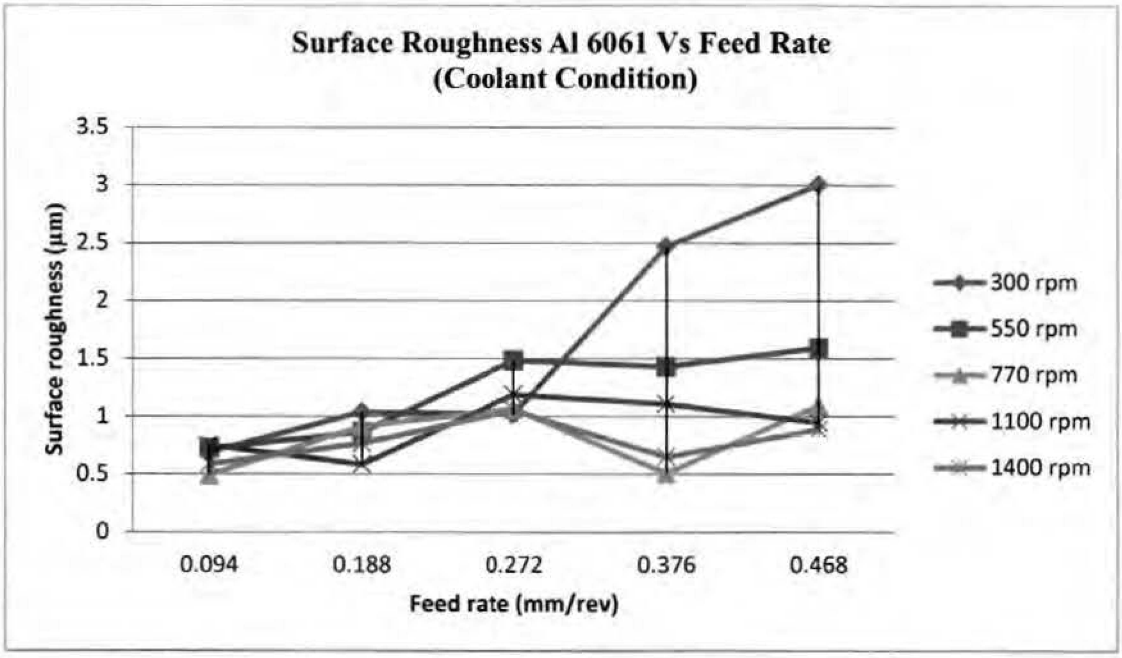

Figure 4.9: Line graph of surface roughness Al 6061 with increasing feed rate under coolant condition.

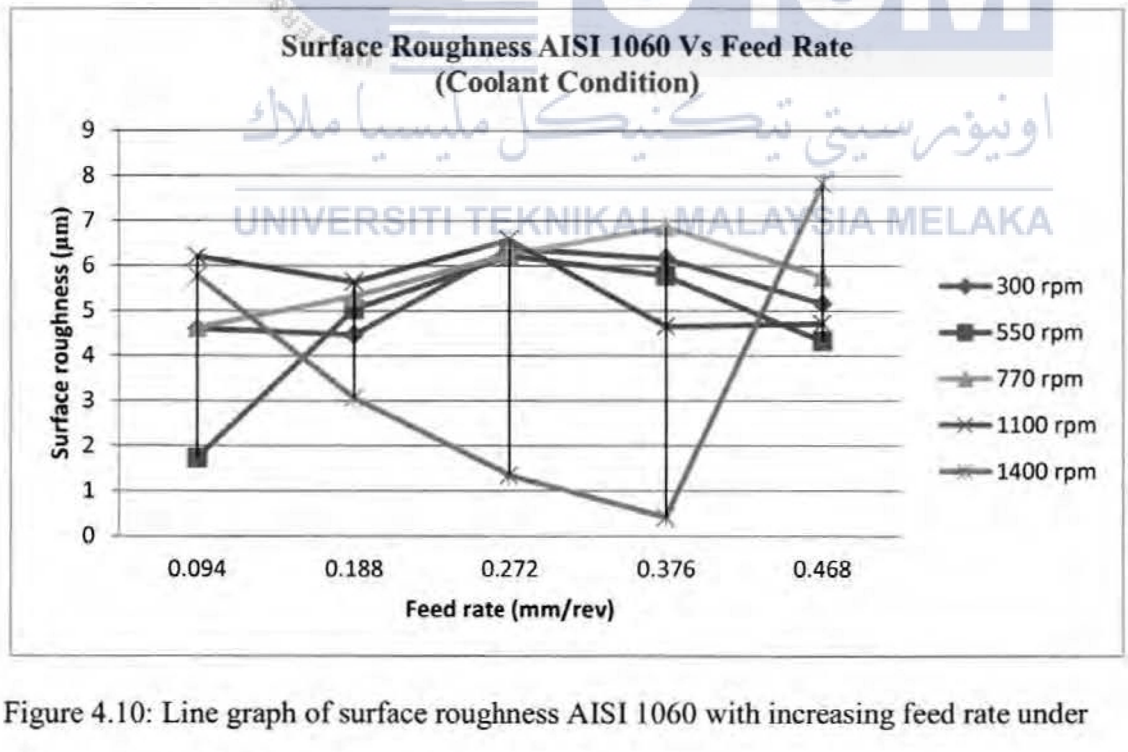

Figure 4.10: Line graph of surface roughness AISI 1060 with increasing feed rate under coolant condition.

4.3.2.1 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 300 rpm (CC)

Data from number 1 to 5 in Table 4.5 is the surface roughness obtained at 300 rpm and 0.5 mm under coolant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev to 0.188 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases slightly when feed rate is increased to 0.272 mm/rev. After that, the surface roughness keeps increasing with increasing feed rate up till 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring dark blue line in Figure 4.9.

4.3.2.2 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 550 rpm (CC)

Data from number 6 to 10 in Table 4.5 is the surface roughness obtained at 550 rpm and 0.5 mm under coolant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.376 mm/rev. Lastly, the surface roughness increases once again at 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring red line in Figure 4.9.

4.3.2.3 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 770 rpm (CC)

Data from number 11 to 15 in Table 4.5 is the surface roughness obtained at 770 rpm and 0.5 mm under coolant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.376 mm/rev. When feed rate is kept increased to 0.468 mm/rev, the surface roughness increases once again. The effect of feed rate on surface roughness can be visualised by referring green line in Figure 4.9.

4.3.2.4 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1100 rpm (CC)

Data from number 16 to 20 in Table 4.5 is the surface roughness obtained at 1100 rpm and 0.5 mm under coolant condition. It can be observed that the lowest surface roughness is obtained at 0.188 mm/rev. Besides that, it shows that surface roughness decreases with increasing feed rate from 0.094 mm/rev up to 0.188 mm/rev. Next, the feed rate is increased to 0.272 mm/rev. It shows an increment of surface roughness. After that, the surface roughness decreases with increasing feed rate at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring purple line in Figure 4.9.

4.3.2.5 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1400 rpm (CC)

Data from number 21 to 25 in Table 4.5 is the surface roughness obtained at 1400 rpm and 0.5 mm under coolant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.376 mm/rev. However, the surface roughness increases once again when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring light blue line in Figure 4.9.

4.3.2.6 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 300 rpm (CC)

Data from number 25 to 30 in Table 4.5 is the surface roughness obtained at 300 rpm and 0.5 mm under coolant condition. The lowest record of surface roughness in this case is accomplished at 0.188 mm/rev. The surface roughness decreases with increasing feed rate from 0.094 mm/rev to 0.188 mm/rev. After that, the surface roughness increases when feed rate is increased to 0.272 mm/rev. Next, the surface roughness decreases with increasing feed rate at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness is illustrated by dark blue line in Figure 4.10.

4.3.2.7 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 550 rpm (CC)

Data from number 31 to 35 in Table 4.5 is the surface roughness obtained at 550 rpm and 0.5 mm under coolant condition. The lowest record of surface roughness in this case is obtained at 0.094 mm/rev. The surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. Starting from that, the surface roughness decreases with increasing feed rate which are at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness is illustrated by red line in Figure 4.10.

4.3.2.8 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 770 rpm (CC)

Data from number 36 to 40 in Table 4.5 is the surface roughness obtained at 770 rpm and 0.5 mm under coolant condition. The lowest record of surface roughness in this case is achieved at 0.094 mm/rev. The surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.376 mm/rev. However, the surface roughness does not increase when feed rate is increased to 0.468 mm/rev. Instead, it shows a decrement. The effect of feed rate on surface roughness is illustrated by green line in Figure 4.10.

4.3.2.9 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1100 rpm (CC)

Data from number 41 to 45 in Table 4.5 is the surface roughness obtained at 1100 rpm and 0.5 mm under coolant condition. The lowest record of surface roughness in this case is accomplished at 0.376 mm/rev. The surface roughness shows fluctuating trend with increasing feed rate. The effect of feed rate on surface roughness is illustrated by purple line in Figure 4.10.

4.3.2.10 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1400 rpm (CC)

Data from number 46 to 50 in Table 4.5 is the surface roughness obtained at 1400 rpm and 0.5 mm under coolant condition. The lowest record of surface roughness in this case is accomplished at 0.376 mm/rev. The surface roughness decreases with increasing feed rate from 0.094 mm/rev up to 0.376 mm/rev. Next, the surface roughness increases greatly when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness is illustrated by light blue line in Figure 4.10.

4.3.3 Surface roughness Obtained under Lubricant Condition

The surface roughness obtained under lubricant condition is tabulated in Table 4.6. The table is arranged with increasing feed rate and other variables are kept constant so that the effect of feed rate can be observed. Data numbers 1 to 25 are surface roughness of aluminium alloy 6061 whereas data numbers 26 to 50 are surface roughness of carbon steel AISI 1060. Two line graphs are plotted based on the data to illustrate the changing of surface roughness of aluminium alloy 6061 and carbon steel AISI 1060 respectively. The lines graphs are shown in Figure 4.11 and Figure 4.12. Feed rate that contributes to get the lowest surface roughness is highlighted.

Table 4.6: Surface roughness obtained with increasing feed rate under lubricant condition.

No.	Material	Spindle Speed (rpm)	DOC (mm)	Feed Rate (mm/rev)	Arithmetic Average Surface Roughness, Ra (μm)
1	Al 6061	300	0.5	0.094	0.906
2	Al 6061	300	0.5	0.188	0.843
3	Al 6061	300	0.5	0.272	1.269
4	Al 6061	300	0.5	0.376	2.377
5	Al 6061	300	0.5	0.468	2.119
6	Al 6061	550	0.5	0.094	0.622
7	Al 6061	550	0.5	0.188	0.619
8	Al 6061	550	0.5	0.272	1.233
9	Al 6061	550	0.5	0.376	1.176
10	Al 6061	550	0.5	0.468	1.498
11	Al 6061	770	0.5	0.094	0.682
12	Al 6061	770	0.5	0.188	0.988
13	Al 6061	770	0.5	0.272	1.098
14	Al 6061	770	0.5	0.376	0.796
15	Al 6061	770	0.5	0.468	1.037
16	Al 6061	1100	0.5	0.094	0.339
17	Al 6061	1100	0.5	0.188	0.349
18	Al 6061	1100	0.5	0.272	0.984
19	Al 6061	1100	0.5	0.376	1.503
20	Al 6061	1100	0.5	0.468	1.300
21	Al 6061	1400	0.5	0.094	1.233
22	Al 6061	1400	0.5	0.188	1.144
23	Al 6061	1400	0.5	0.272	1.332
24	Al 6061	1400	0.5	0.376	1.339
25	Al 6061	1400	0.5	0.468	1.740
26	AISI 1060	300	0.5	0.094	5.831
27	AISI 1060	300	0.5	0.188	6.781
28	AISI 1060	300	0.5	0.272	8.743
29	AISI 1060	300	0.5	0.376	8.878
30	AISI 1060	300	0.5	0.468	8.967
31	AISI 1060	550	0.5	0.094	6.228
32	AISI 1060	550	0.5	0.188	8.567
33	AISI 1060	550	0.5	0.272	6.678
34	AISI 1060	550	0.5	0.376	6.175
35	AISI 1060	550	0.5	0.468	5.050
36	AISI 1060	770	0.5	0.094	1.304
37	AISI 1060	770	0.5	0.188	2.680
38	AISI 1060	770	0.5	0.272	3.187
39	AISI 1060	770	0.5	0.376	4.203
40	AISI 1060	770	0.5	0.468	5.018
41	AISI 1060	1100	0.5	0.094	2.747
42	AISI 1060	1100	0.5	0.188	2.303
43	AISI 1060	1100	0.5	0.272	2.160
44	AISI 1060	1100	0.5	0.376	3.191
45	AISI 1060	1100	0.5	0.468	4.534
46	AISI 1060	1400	0.5	0.094	4.638
47	AISI 1060	1400	0.5	0.188	4.733
48	AISI 1060	1400	0.5	0.272	2.858
49	AISI 1060	1400	0.5	0.376	3.552
50	AISI 1060	1400	0.5	0.468	6.022

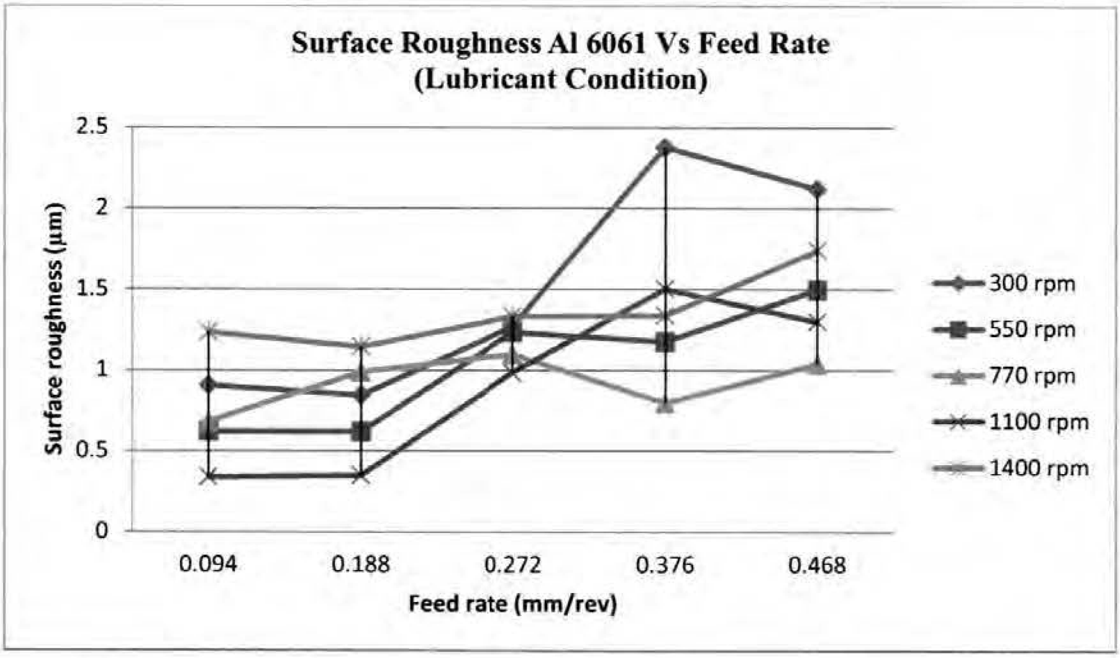

Figure 4.11: Line graph of surface roughness Al 6061 with increasing feed rate under lubricant condition.

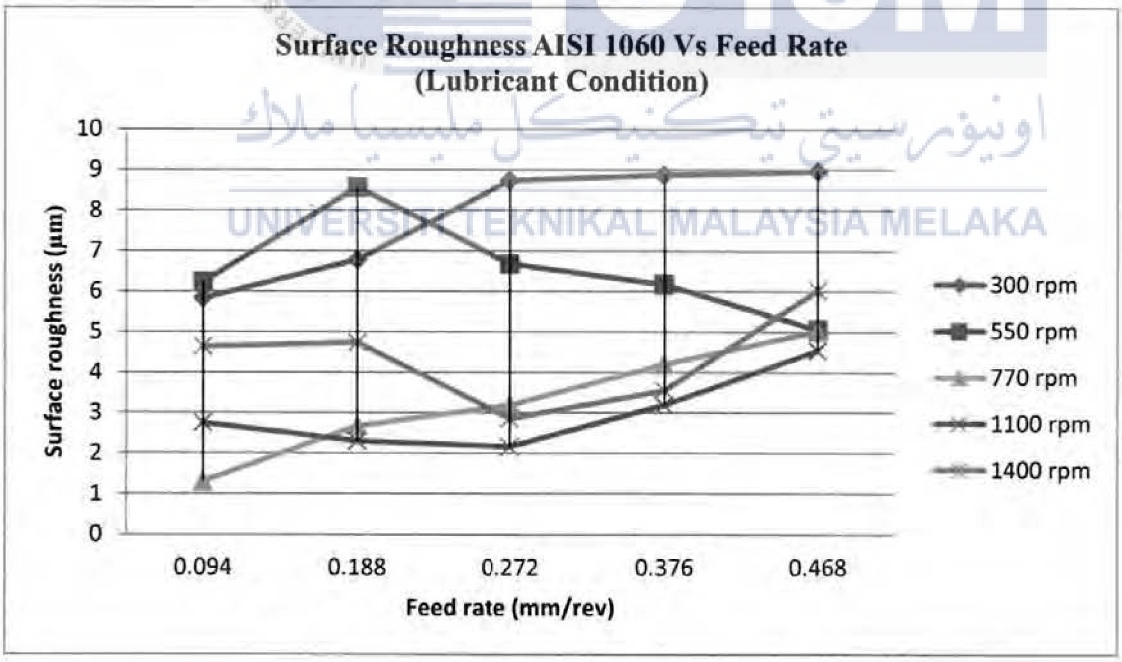

Figure 4.12: Line graph of surface roughness AISI 1060 with increasing feed rate under lubricant condition.

4.3.3.1 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 300 rpm (LC)

Data from number 1 to 5 in Table 4.6 is the surface roughness obtained at 300 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.188 mm/rev. The surface roughness initially decreases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. After that, the surface roughness increases with increasing feed rate from 0.188 mm/rev to 0.272 mm/rev and 0.376 mm/rev. Lastly, the surface roughness drops when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring dark blue line in Figure 4.11.

4.3.3.2 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 550 rpm (LC)

Data from number 6 to 10 in Table 4.6 is the surface roughness obtained at 550 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is achieved at 0.188 mm/rev. The surface roughness is fluctuating with increasing feed rate. The effect of feed rate on surface roughness can be visualised by referring red line in Figure 4.11.

4.3.3.3 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 770 rpm (LC)

Data from number 11 to 15 in Table 4.6 is the surface roughness obtained at 770 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.376 mm/rev. When feed rate is kept increased to 0.468 mm/rev, the surface roughness increases once again. The effect of feed rate on surface roughness can be visualised by referring green line in Figure 4.11.

4.3.3.4 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1100 rpm (LC)

Data from number 16 to 20 in Table 4.6 is the surface roughness obtained at 1100 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. Besides that, it shows that surface roughness increases with increasing feed rate from 0.094 mm/rev up to 0.376 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring purple line in Figure 4.11.

4.3.3.5 Effect of Feed Rate on Surface Roughness of Al 6061 obtained by 1400 rpm (LC)

Data from number 21 to 25 in Table 4.6 is the surface roughness obtained at 1400 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.188 mm/rev. Besides that, it shows that surface roughness decreases when feed rate is increased from 0.094 mm/rev up to 0.188 mm/rev. The next increment of feed rate does not cause the decrease in surface roughness. Instead, the surface roughness increases with increasing feed rate up till 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring dark blue line in Figure 4.11.

4.3.3.6 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 300 rpm (LC)

Data from number 26 to 30 in Table 4.6 is the surface roughness obtained at 300 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. The surface roughness increases with increasing feed rate. The effect of feed rate on surface roughness can be visualised by referring dark blue line in Figure 4.12.

4.3.3.7 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 550 rpm (LC)

Data from number 31 to 35 in Table 4.6 is the surface roughness obtained at 550 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.468 mm/rev. Besides that, it shows that surface roughness increases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. Starting from 0.188 mm/rev, the surface roughness decreases with increasing feed rate up till

0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring red line in Figure 4.12.

4.3.3.8 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 770 rpm (LC)

Data from number 36 to 40 in Table 4.6 is the surface roughness obtained at 770 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.094 mm/rev. The surface roughness increases with increasing feed rate. The effect of feed rate on surface roughness can be visualised by referring green line in Figure 4.12.

4.3.3.9 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1100 rpm (LC)

Data from number 41 to 45 in Table 4.6 is the surface roughness obtained at 1100 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.272 mm/rev. Besides that, it shows that surface roughness decreases with increasing feed rate from 0.094 mm/rev up to 0.272 mm/rev. The next increment of feed rate does not cause the decrease in surface roughness. Instead, the surface roughness decreases when feed rate is increased from 0.272 mm/rev to 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring purple line in Figure 4.12.

4.3.3.10 Effect of Feed Rate on Surface Roughness of AISI 1060 obtained by 1400 rpm (LC)

Data from number 46 to 50 in Table 4.6 is the surface roughness obtained at 1400 rpm and 0.5 mm under lubricant condition. It can be observed that the lowest surface roughness is obtained at 0.272 mm/rev. Besides that, it shows that surface roughness increases when feed rate is increased from 0.094 mm/rev to 0.188 mm/rev. The next increment of feed rate does not cause the increase in surface roughness. Instead, the surface roughness decreases when feed rate is increased to 0.272 mm/rev. After that, the surface roughness increases with increasing feed rate at 0.376 mm/rev and 0.468 mm/rev. The effect of feed rate on surface roughness can be visualised by referring light blue line in Figure 4.12.

4.3.4 Justifications on Effect of Feed Rate

It is undeniable that, surface roughness acts proportional with increasing feed rate. From previous studies by other researchers, it reveals that low surface roughness should be obtained at low feed rate. However, data obtained from experiment does not perfectly match this fact. Only two lines which fulfil the fact. Hence, the lowest feed rate is not necessary the best feed rate to achieve surface with low roughness. Optimisation needs to be conducted in order to find out the most appropriate feed rate to be used. From this study, it shows that the use of feed rate 0.094 mm/rev has high probability to get low surface roughness as it appears sixteen times to get the lowest reading of surface roughness. Hence, 0.094 mm/rev can be prioritised when optimisation is planned to be carried out.

4.4 Effect of Coolant and Lubricant on Surface Roughness

In order to determine the effectiveness of coolant and lubricant on improving surface roughness, all the roughness of surfaces are compared according to conditions. Table 4.7 shows the comparison of surface roughness among dry condition, coolant condition and lubricant condition. The lowest surface roughness is highlighted. The condition which records the highest number of lowest surface roughness implies that it is the most effective condition.

Table 4.7: Comparison among dry condition, coolant condition and lubricant condition.

No.	Materials	Spindle Speed (rpm)	Feed Rate (mm/rev)	Arithmetic Average Surface Roughness, Ra (μm)		
				Dry Condition	Coolant Condition	Lubricant Condition
1	Al 6061	300	0.094	0.412	0.693	0.906
2	Al 6061	300	0.188	1.744	1.037	0.843
3	Al 6061	300	0.272	4.104	1.016	1.269
4	Al 6061	300	0.376	7.640	2.468	2.377
5	Al 6061	300	0.468	4.627	3.003	2.119
6	Al 6061	550	0.094	2.645	0.725	0.622
7	Al 6061	550	0.188	1.512	0.866	0.619
8	Al 6061	550	0.272	1.377	1.485	1.233
9	Al 6061	550	0.376	3.171	1.432	1.176
10	Al 6061	550	0.468	3.592	1.592	1.498
11	Al 6061	770	0.094	1.406	0.492	0.682
12	Al 6061	770	0.188	0.843	0.914	0.988
13	Al 6061	770	0.272	1.528	1.067	1.098
14	Al 6061	770	0.376	1.196	0.506	0.796
15	Al 6061	770	0.468	1.875	1.094	1.037
16	Al 6061	1100	0.094	1.389	0.751	0.339
17	Al 6061	1100	0.188	1.815	0.585	0.349
18	Al 6061	1100	0.272	0.628	1.187	0.984
19	Al 6061	1100	0.376	0.655	1.108	1.503
20	Al 6061	1100	0.468	1.607	0.948	1.300
21	Al 6061	1400	0.094	0.446	0.590	1.233
22	Al 6061	1400	0.188	1.137	0.766	1.144
23	Al 6061	1400	0.272	0.645	1.055	1.332
24	Al 6061	1400	0.376	0.662	0.650	1.339
25	Al 6061	1400	0.468	1.093	0.889	1.740
26	AISI 1060	300	0.094	4.763	4.602	5.831
27	AISI 1060	300	0.188	6.302	4.464	6.781
28	AISI 1060	300	0.272	6.241	6.396	8.743
29	AISI 1060	300	0.376	6.502	6.155	8.878
30	AISI 1060	300	0.468	7.242	5.157	8.967
31	AISI 1060	550	0.094	3.515	1.730	6.228
32	AISI 1060	550	0.188	4.752	5.033	8.567
33	AISI 1060	550	0.272	6.617	6.225	6.678
34	AISI 1060	550	0.376	7.753	5.779	6.175
35	AISI 1060	550	0.468	4.202	4.325	5.050
36	AISI 1060	550	0.094	1.762	4.622	1.304
37	AISI 1060	550	0.188	2.082	5.312	2.680
38	AISI 1060	550	0.272	4.928	6.262	3.187
39	AISI 1060	550	0.376	4.917	6.860	4.203
40	AISI 1060	550	0.468	6.488	5.757	5.018
41	AISI 1060	770	0.094	5.132	6.212	2.747
42	AISI 1060	770	0.188	3.567	5.637	2.303
43	AISI 1060	770	0.272	2.992	6.585	2.160
44	AISI 1060	770	0.376	4.602	4.658	3.191
45	AISI 1060	770	0.468	5.490	4.714	4.534
46	AISI 1060	1400	0.094	2.288	5.778	4.638
47	AISI 1060	1400	0.188	3.538	3.059	4.733
48	AISI 1060	1400	0.272	3.265	1.349	2.858
49	AISI 1060	1400	0.376	4.509	0.416	3.552
50	AISI 1060	1400	0.468	5.458	7.825	6.022

From Table 4.7, it shows that lubricant is the most effective condition to produce low roughness surface. There are twenty surfaces with the lowest roughness are obtained under lubricant condition. This is then followed by coolant condition which records seventeen surfaces with the lowest roughness. Lastly, dry condition also has thirteen surfaces that achieve the lowest roughness.

4.5 Effect of Materials used on Surface Roughness

Surface roughness is no doubt can be affected by the materials used for machining. This is because every material has its specific physical properties such as malleability, ductility as well as hardness. In this study, two materials are used to be machined which are aluminium alloy 6061 and carbon steel AISI 1060. Table 4.8 below shows the comparison of properties between these two materials.

Table 4.8: Comparison of properties between Al 6061 and AISI 1060.

Al 6061	Physical Properties	AISI 1060
95	**Hardness, Brinell (metric)**	183
120	**Hardness, Knoop (metric)**	204
60	**Hardness, Rockwell B (metric)**	89
107	**Hardness, Vickers (metric)**	192
310 MPa	**Ultimate Tensile Strength**	620 MPa
77-370 MPa	**Tensile Yield Strength**	400-560 MPa
69 GPa	**Modulus of Elasticity**	210 GPa
7.5-19%	**Elongation**	10-13%

From all the results obtained, it shows that surface roughness of aluminium alloy 6061 is typically lower than that of carbon steel AISI 1060 regardless the condition of machining. This can be explained by referring Table 4.8 which displays the physical properties of these two materials. From Table 4.8, it reveals that carbon steel AISI 1060 is harder than aluminium alloy 6061. This means that aluminium alloy 6061 is softer than carbon steel AISI 1060. Hence, machinability of aluminium alloy 6061 is higher than that of carbon steel AISI 1060. Other than hardness, the factors that cause aluminium alloy 6061 is easier to be cut are its high ultimate tensile strength and tensile yield strength. This causes cutting tool requires less amount of force to cut off the unwanted part during machining. As the result, lower roughness surfaces can be obtained frequently by aluminium alloy 6061. Besides that, the modulus of elasticity and ductility are also factors that can influence surface roughness. Both of the properties describe the ability of material to deform. Material which has lower ability of deformation implies that it has higher machinability. From Table 4.8, it shows that aluminium alloy 6061 has lower modulus of elasticity and elongation. This indicates that aluminium alloy 6061 lack of deformation before fracture. In other words, aluminium alloy 6061 can be easily get rid its unwanted part as it has less deformation before break. Hence, aluminium alloy is easier to produce low surface roughness compared to carbon steel AISI 1060.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Justification of Objectives

As indicated earlier in the introduction, the purpose of this study are to investigate the effect of machining parameters of conventional lathe machine on quality of surface roughness on different materials and determine whether coolant and lubricant are effective to reduce surface roughness.

5.2 Review of Methods

The methodology that is used in this study is by conducting experiment. After doing literature review from other researchers, experiment is planned. Five spindle speeds and five feed rates are chosen to fabricate both aluminium alloy 6061 and carbon steel AISI 1060 under three different conditions which are dry condition, coolant condition and lubricant condition. All the obtained surfaces are measured by using surface roughness tester to determine their quality of surface finish. The effect of spindle speed and feed rate on surface roughness is identified. Justifications are made according the results that are obtained.

5.3 Review of Findings

The most significant finding that emerges from this study is that it is not necessary the highest spindle speed can contribute to get the lowest surface roughness. At the same time, it is also not necessary the lowest feed rate can contribute to get surface with the lowest surface roughness. Besides that, this study finds that lubricant condition is the most effective condition to produce low surface roughness. In addition, coolant is also effective to reduce surface roughness compared to dry condition. Moreover, material with low hardness, strength and ability of deformation has high machinability.

5.4 Explanation of Findings

Spindle speed cannot act solely to produce low surface roughness. It is the same goes to feed rate. Machining parameters are related to each other in order to achieve low surface roughness. From this study, spindle speed 1100 rpm and feed rate 0.094 mm/rev contribute the most to get low surface roughness. Hence, both of the machining parameters can be prioritised as candidates for optimization study. Moreover, lubricant condition is the most effective condition as most of the surface with low roughness is obtained under this condition. This is then followed by coolant condition. Apart from that, results from this study shows that aluminium alloy Al 6061 which is softer, lower strength and lower ability of deformation is easier to be cut and hence produce lower surface roughness.

5.5 Limitation of the Study

The limitation of the study is that cutting tool is not taken as one of the factors that affecting the surface roughness due to budget limitation. Cutting tool is substituted once it is observed broken. Consequently, some results obtained show fluctuating trend on both spindle speed and feed rate.

5.6 Implication of the Study

This study is extremely timely and vital as it provides crucial findings to help producing better quality of surface by using conventional lathe machine. This helps saving cost and time for manufacturers to investigate on how to improve quality of products with longer lifespan.

5.7 Recommendation for the Research

Further studies should focus on optimizing the machining parameters so that low surface roughness can be achieved by following the optimized parameters. Besides that, future studies ought to determine all the factors that can influence surface roughness. Apart from that, more materials should be used in order to identify on how to get low surface roughness on those materials.

REFERENCES

Jay Chris and Lamar Stonecypher (2010), The Lathe Machine. Retrieved from *http://www.brighthubengineering.com/manufacturing-technology/59033-what-is-a-lathe-machine-history-parts-and-operation/*

University of California Riverside (2011), Standard Operating Procedures for Manual Toolroom Lathes. Retrieved from *http://www.me.ucr.edu/UCR-ME-SOP-Manual-Lathes-v5.pdf*

S. Thamizhmanii, S. Hasan, Analyses of roughness, forces and wear in turning gray cast iron, Journal of achievement in Materials and Manufacturing Engineering, 17, 2006.

Adeel H. Suhail, N. Ismail, S.V. Wong, N.A. Abdul Jalil, Optimization of Cutting Parameters Based on Surface Roughness and Assistance of Workpiece Surface Temperature in Turning Process, Journal of Engineering and Applied Sciences, vol. 3, issue 1, pp. 102-108, 2010.

S. Thamizhmanii, S. Saparudin, S. Hasan, Analyses of surface roughness by turning process using Taguchi method, Journal of Achievements in Materials and Manufacturing Engineering, vol. 20, issue 1-2, pp. 503-506, 2007.

Ming, C., S. Fanghong, W. Haili and Y. Renwei, Experimental research on the dynamic characteristics of the cutting temperature in the process of high-speed milling. Journal of Materials Processing Technology, vol. 138, issue 1-3, pp. 468-471, 2003.

Mohd.Arif. I. Upletawala, Prof. Tushar Katratwar, A Literature Review on Various Factors affecting Turning Operation, International Journal of Engineering Technology, Management and Applied Sciences, vol. 4, issue 4, pp. 104-109, 2016.

DeoreDhirajRajendra, and Prof. Radha R, "Optimization of Machining parameters in turning operation of EN19 steel," International journal of research in mechanical engineering, vol. 2, no. 6, pp. 01-07, November-December 2014.

Deepak Mittal, M.P. Garg and Rajesh Khanna, An Investigation of the Effect of Process Parameters on MRR in turning of Pure Titanium (Grade-2), International Journal of Engineering Science and Technology, vol. 3, no.8, pp. 6345-6349, 2011.

C. Natarajan, S. Muthu and P. Karuppuswamy, Investigation of cutting parameters of surface roughness for a non-ferrous material using artificial neural network in CNC turning, Journal of Mechanical Engineering Research, vol. 3(1), pp. 1-14, January 2011.

U. D. Gulhane, A.B. Dixit, P.V. Bane and G.S. Salvi, Optimization of process parameters for 316L stainless steel using taguchi method and anova, International journal of mechanical engineering and technology, vol. 3, no. 2, pp. 67-72, 2012.

Huda Hatem, Study the Effect of Cutting Conditions for turning process on the Machined Surface, Nahrain University, College of Engineering Journal (NUCEJ), vol.14, no.1, pp.61-66, 2011.

V. Songmene, R. Khettabi, I. Zaghbani, J. Kouam, and A. Djebara (2011). Machining and Machinability of Aluminum Alloys. Retrieved from *http://cdn.intechopen.com/pdfs/13408.pdf*

SJ Friedman (2015). What effect does adding coolant during a turning process do for a workpiece's roughness? How does coolant effect dimensional tolerance in a turning operation? Retrieved from *https://www.quora.com/What-effect-does-adding-coolant-during-a-turning-process-do-for-a-workpieces-roughness-How-does-coolant-effect-dimensional-tolerance-in-a-turning-ooperation*

Joe Thompson (2012). 10 Tips to Improve Surface Finish. Retrieved from *http://www.cimindustry.com/article/tooling/10-tips-to-improve-surface-finish*

Sachin Thorat (2016). What is Cutting Speed, Feed, Depth of Cut in Machine Tools. Retrieved from *http://www.mechengg.net/2016/04/what-is-cutting-speedfeed-depth-of-cut.html*

Fox Valley Technical College (2000-2002). Turning Speeds & Feeds - RPM Calculations. Retrieved from *https://www.wisc-online.com/LearningContent/mtl11802/MLT11802.htm*