STUDY INTO THE EFFECT OF CUTTING SPEED ON THE SURFACE ROUGHNESS, ROUNDNESS, TOOL WEAR AND CHIP FORMATION DURING LATHE CUTTING OPERATION

By

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CERTIFICATION OF APPROVAL

Study into the Effect of Various Dilution and Cutting Parameters of Commercial Cutting Fluid on the Tool Wear and Surface Finish during Lathe Cutting Operation

By

Nadiah binti Amir

A project dissertation submitted to the

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NADIAH BINTI AMIR

ABSTRACT

Water soluble metal cutting fluids are used extensively in metal removal processes to act as a cooling and lubricating agent. The application of the metal cutting fluid is typically used according to the concentration recommended by the manufacturer. To minimize the production cost, metal cutting fluid usually diluted with the minimum recommended concentration given. The objective of this project is to recommend the best cutting condition during lathe cutting operation using the minimum concentration recommended. A commercial metal cutting fluid recommended that the minimum concentration for turning operation is 8%. Therefore, this project is conducted by turning AISI 304 Austenitic Stainless Steel workpiece with the application of 8% concentration of metal cutting fluid. The machining parameter of turning operation involved was cutting speed. A comparative study was conducted to study the effect of variation of cutting speed to surface roughness, roundness, tool wear and chip formation. Experiments started with turning sample of AISI 304 Austenitic Stainless Steel workpiece by heavy duty lathe machine using the smallest cutting speed, 60m/min which was selected based on the standard that fit with the machine capabilities. The analyzing development was conducted using Mitutoyo Surface Profiler and Mitutoyo Round Test machine to measure surface roughness and roundness respectively. 3D Non Contact Measurement was used to identify tool flank wear occurred and types of chip produced with perfect image. The results obtained were compared with three other experiment conditions, 90m/min, 180m/min, 200m/min. From this analysis, it is realized that performance of both cutting tool and machining parts was highly influenced by cutting speed.

ACKNOWLEDGEMENT

Assalamualaikum w.b.t. and Alhamdulillah,

Firstly, I would like to express my sincere, deep gratitude and thanks to Allah, the Almighty, for bestowing me the opportunity and strength to complete this project until its end.

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ABBREVIATIONS AND NOMENCLATURES

UTP – Universiti Teknologi PETRONAS

DOE – Design of Experiment

PDS – Product Data Sheet

ISO – International Standards Organization

DIN – Deutsches Institut for Normung

ASME – American Society of Mechanical Engineers

AISI – American Iron and Steel Institute

LSC – Least Square Circle

CNC – Computer Numerical Control

rpm – Revolution per minute

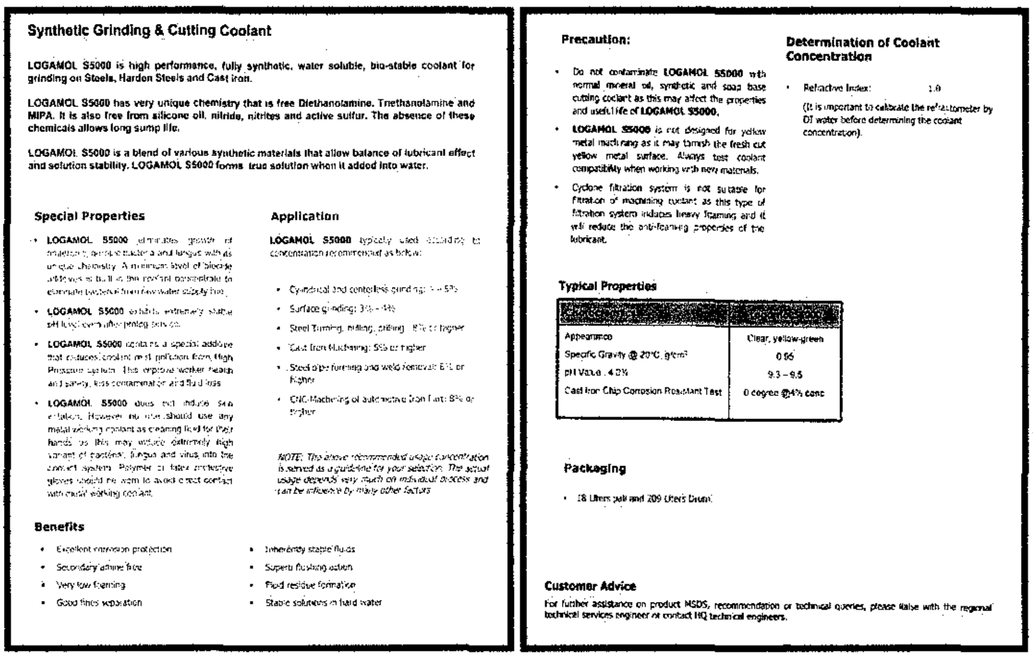
TiN – Titanium Nitride

BUE – Build-up edge

CHAPTER 1
INTRODUCTION

1.1 Project Background

Water soluble metal cutting fluids are used extensively in metal machining to improve tool life, reduce workpiece thermal deformation, improve surface finish and flushing away chips from the cutting zone. Common practice practiced by UTP's laboratory to make the dilution is using a conventional method which is mixing the oil and water using a pail without accurately checks the coolant concentration. Cutting parameters for different material used are determined by the laboratory technicians and always varied with no specific guidelines as long as the parameters are provided by the machine without taking into consideration the cutting quality.



Synthetic Grinding & Cutting Coolant

LOGAMOL S5000 is high performance, fully synthetic, water soluble, bio-stable coolant for grinding on Steels, Hardon Steels and Cast iron.

LOGAMOL S5000 has very unique chemistry that is free Diethanolamine. Triethanolamine and MIPA. It is also free from silicone oil, nitride, nitrites and active sulfur. The absence of these chemicals allows long sump life.

LOGAMOL S5000 is a blend of various synthetic materials that allow balance of lubricant effect and solution stability. LOGAMOL S5000 forms true solution when it added into water.

Special Properties

- **LOGAMOL S5000** [illegible]
- **LOGAMOL S5000** [illegible]
- **LOGAMOL S5000** [illegible]
- **LOGAMOL S5000** [illegible]

Application

LOGAMOL S5000 [illegible]

Benefits

- Excellent corrosion protection
- Secondary amine free
- Very low foaming
- Good fines separation
- Inherently stable fluids
- Superb flushing action
- Fluid residue formation
- Stable solutions in hard water

Precaution:

- Do not contaminate **LOGAMOL S5000** with normal mineral oil, synthetic and soap base cutting coolant as this may affect the properties and useful life of **LOGAMOL S5000.**
- **LOGAMOL S5000** is not designed for yellow metal machining as it may tarnish the fresh cut yellow metal surface. Always test coolant compatibility when working with new materials.
- Cyclone filtration system is not suitable for filtration of machining coolant as this type of filtration system induces heavy foaming and it will reduce the anti-foaming properties of the lubricant.

Determination of Coolant Concentration

- Refractive Index: 1.0

(It is important to calibrate the refractometer by DI water before determining the coolant concentration).

Typical Properties

Appearance	Clear, yellow-green
Specific Gravity @ 20°C, g/cm³	0.95
pH Value , 4.0%	9.3 – 9.5
Cast Iron Chip Corrosion Resistant Test	0 degree @4% conc

Packaging

- 18 Liters pail and 209 Liters Drum

Customer Advice

For further assistance on product MSDS, recommendation or technical queries, please liaise with the regional technical services engineer or contact HQ technical engineers.

Figure 1 : Product Data Sheet of a Commercial Metal cutting Fluid

Figure 1 shows Product Data Sheet, PDS of a commercial water soluble metal cutting fluid produced by a leading lubricants manufacturer in Malaysia. PDS is a document summarizing the performance, and other technical characteristic of a product in sufficient detail to be used by people to integrate the product into a system. Basically, all lubricant PDS from other manufacturer will have the same layout providing the same information of technical characteristics of product [1,2]. The main objective of the manufacturer is to help people choose product or to help use the product. However, the consumer's attention is to have a very economic use of the lubricants by getting maximum performance with lowest cost.

By looking into detail at the PDS in **Figure 1**, the information on the application just give wide range of recommended concentration with respect to the material operation. With wide recommended concentration range given without being supported by any cutting condition do not guarantee to produce better cutting performance unless the cutting parameters are also considered / specified in the Product Data Sheet.

Machining or metal cutting operation is an operation that removes metal into chip. One of the machining operations is turning process. Turning is the operation that produces cylindrical parts [3]. Turning is performed on a machine called a lathe in which the tool is stationary and the part is rotated.

There are many parameters and variable that will influence the turning operation. Optimization of parameters not only improves output quality, but also ensures low cost manufacturing. The product quality depends very much on surface roughness. Decrease of surface roughness quality also leads to decrease of product quality. Cutting parameters include feed rate, cutting speed, depth of cut, cutting fluids and machining time.

1.2 Problem Statement

Although the significance of cutting fluid in machining is widely recognized, cooling lubricants are often regarded as supporting media that are necessary but not important [4]. In many cases the type of cutting fluid for a particular machining operation is often based on recommendations of sales representatives of cutting fluid supplier's without clearly understanding the nature of this operation and clear objectives of cutting application. Therefore, a complete and informative Product Data Sheet is needed to ensure maximum performance of the product.

However, the customers want to maximize use of the metal cutting fluid by getting the most optimum performance with lowest cost. Therefore, maintaining the lowest recommended concentration is the most effective way to economically use the metal cutting fluid as oil concentrate to water ratio is low.

Proper concentration selection of metal cutting fluid and cutting condition of the turning operation becomes very important in determining superior quality of machined product. In this project, turning operations will be carried out to generate the optimum surface finish by using cutting speed as parameters. Therefore, this study is conducted to highlight the influence of cutting speed at the lowest recommended concentration.

1.3 Objective

The main objectives of this of this study are as follow:

i. To study the quality of surface finish; surface roughness and roundness when using the lowest cutting speed; 60m/min in lathe machining.

ii. To study the types of chip formation and tool flank wear at lowest cutting speed; 60m/min in lathe machining.

iii. To compare the result of surface finish and roundness with other cutting speed, 90m/min, 180m/min and 200m/min

iv. To analyze and recommend the best cutting speed in relation to lowest recommended concentration on the stainless steel workpiece.

1.4 Scope of Study

Scope of this project is conducting a machining operation using heavy duty conventional lathe machine with four different cutting speed and lowest concentration of metal cutting fluids. A metal cutting fluid use in this experiment is a fully synthetics and water soluble oil. During the machining operation, cutting tool used is Titanium Nitride (TiN) coated carbide. Other parameters such as feed rate and depth of cut are set followed to the design of experiment (DOE). Result obtained is to define and evaluate the cutting performance at the cutting surface on workpieces, tool and chip formation during turning operation with application of lowest concentration of metal cutting fluid. Other scope of study in this project involves:

i. Study the product specification of commercial metal cutting fluid from the technical data sheet; Product Data Sheet (PDS)

ii. Prepare the right metal cutting fluid concentration.

iii. Determine the standard cutting parameters of lathe machining process for stainless steel.

iv. Construct an experimental set up technique or methodology for experimenting different cutting speed in the lathe machining process.

v. Conduct the experiment and collecting data for further interpretations and analysis on the effects of cutting speed to surface roughness, roundness, tool flank wear and types of chip formation occurred during the turning process.

vi. Conclude the experiment and make some recommendations for further development of industrial reference.

CHAPTER 2
LITERATURE REVIEW

2.1 Metal cutting Fluid

Cutting fluid provides lubricating and cooling effects which are absolutely essential to the economical production of precisely machines parts. Lubrication form the fluid aids in generating the desired workpiece shape, surface finish and surface integrity while increasing tool life. The cooling provided by cutting fluids extends tool life primarily by preventing tools from exceeding their critical temperature range while in the cut. No one type of fluid will provide optimum lubrication and optimum cooling characteristic. Straight; non-water miscible oil provide excellent lubrication but have relatively poor cooling properties. Water, while it is the best coolant known and will removed heat 2.5 times more rapidly than oil cannot be used as is as a practical cutting fluid. Water has extremely poor lubricating properties and will cause severe corrosion [5]. To make water usable as a cutting fluid, metal cutting fluid manufacturers formulate numerous fluid concentrates designed to be diluted with water to form a working solution. They enable the metalworker to take advantage of water's excellent cooling properties while imparting some degree of lubrication to it.

There are three types of water soluble metal cutting fluid which are soluble oil type, semi synthetics and synthetics. Water soluble metal cutting fluids are diluted with water for use. But the main concern of a water soluble metal cutting fluid's user is to run the metal cutting fluid at its lowest mixing dilution to makes them very economic to use which in turn makes them extremely cost effective.

Soluble oil is a fluid with 50% to 80% oil content and little or no water content. When mixed with water, it creates an emulsion that is milky in appearance. A Semi-synthetic fluid is a fluid with a 5% to 30% content of mineral oil and 30% to 60% water content. For Synthetic fluid it is a fluid that contains no mineral oil. Some synthetics are totally water soluble (chemical solutions), while others are emulsions of water insoluble, synthetically derived lubricants (synthetic emulsions) [6].

2.2 Cutting Parameter

2.2.1 Cutting Speed

Cutting speed is the relative speed at which the tool passes through the work material and removes metal. It is normally expressed in meters per minute (or feet per inch in British units). It has to do with the speed of rotation of the workpiece or the tool, as the case may be. The higher the cutting speed, the better the productivity. For every work material and tool material combo, there is always an ideal cutting speed available, and the tool manufacturers generally give the guidelines for it.

$$V = \pi DN$$

2.2.2 Spindle Speed

Spindle speed is expressed in RPM (revolutions per minute). It is derived based on the cutting speed and the work diameter cut (in case of turning/ boring) or tool diameter (in case of drilling/ milling etc). If V is the cutting speed and D is the diameter of cutting, then Spindle speed, N :

$$N = \frac{V}{\pi \times D}$$

2.3 Surface Roughness Measurement

Surface roughness or surface finish roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth [7]. Roughness is important in metal cutting lubrication and determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces [7].

There are many different roughness parameters in measuring the surface of workpiece based on the standard by DIN EN ISO 4287, ASME B46.1 [8]. The parameters are as followed:

i. ***Ra*** : (Mean Surface Roughness) Arthmetic average of the absolute values of the roughness profile ordinates

$$R_a = \frac{1}{l}\int_0^l |Z(x)|\,dx$$

Figure 2 : Arithmetic average roughness value Ra [9]

ii. ***Rzi*** : (Single Roughness Depth) Vertical distance between the highest peak and the deepest valley within a sampling length

iii. ***Rz*** : (Mean Roughness Depth) Rz is the arithmetic mean value of the single roughness depths Rzi of consecutive sampling length

$$Rz = \frac{1}{n}(R_{z1} + R_{z2} + \dots + R_{zn})$$

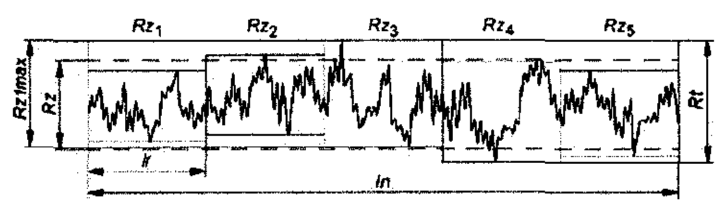


Figure 3 : Total height of the roughness profile Rt, surface roughness depth Rz and maximum surface roughness Rzmax [9]

iv. ***Rmax*** : (Maximum Roughness Depth) largest single roughness depth with the evolution length.

But ***Ra*** is by far the most commonly used parameter in evaluating the surface roughness.

2.3.1 Effect of Cutting Speed on Surface Roughness

Mark Thomas, Yvess Beauchamp, Youssed A. Youssed and Jacques (1997) [10] on the surface roughness in lathe dry turning. By turning the carbon steel workpiece, the result was found that with a feed rate 0.35mm/rev and depth of cut of 0.2mm, the best surface roughness is obtained at a high cutting speed, which is greater than 160m/min.

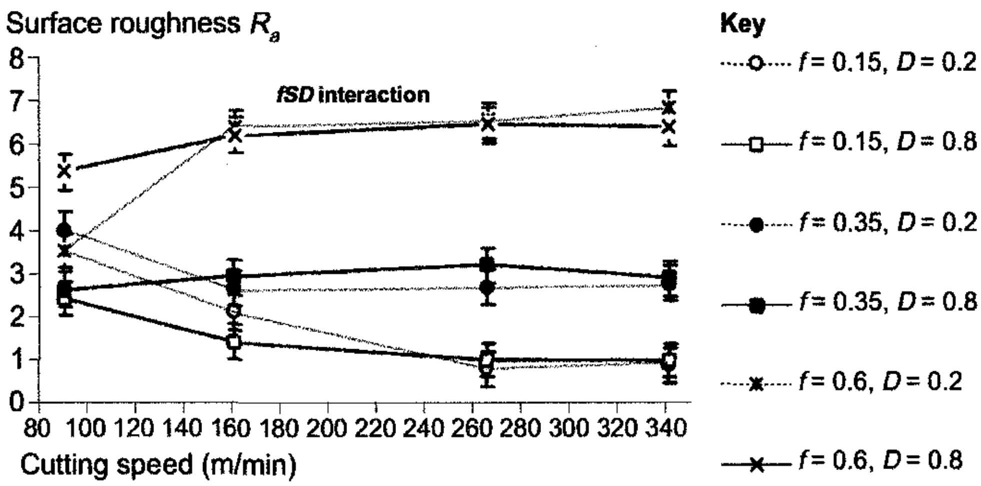


Figure 4 : Feed rate, cutting speed and depth of cut interaction [10]

Based on **Appendix 2-1,** range of surface roughness obtained in various machining processes, the most common value of surface roughness Ra for turning metal cutting operation is between 0.4µm – 6.3µm.

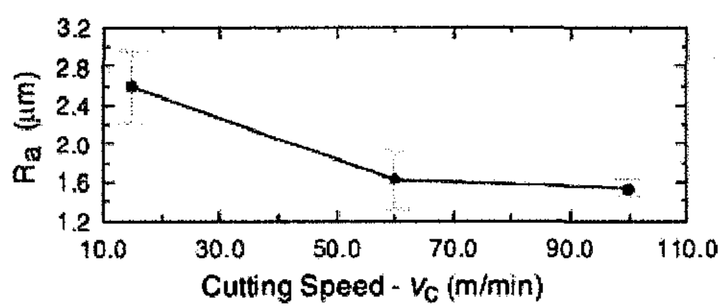


Figure 5 : Influence of cutting speed on surface roughness [11]

Figure 5 shows the result when turning AISI 4140 steel. It is determined that, there is an improvement of the surface roughness by the increase of cutting speed. The surface roughness increase initially rapidly, then slowly with increasing cutting speed. (Benardos and Vosniakos, 2003, Bailey, Jeelani and Becker, 1976 and Abouelatta and Mádl, 2001) [11].

2.4 Surface Roundness Measurement

Measurements of roundness require 360° traces of the workpiece made with a turntable-type instrument or a stylus-type instrument. A least squares fit of points on the trace to a circle define the parameters of non circularity of the workpiece. There are many methods of generating these circle. The Least Square Circle (LSC) is used.

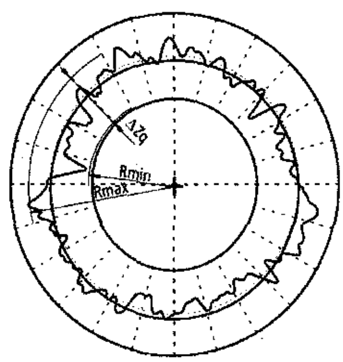


Figure 6 : Least Square Circle, (LSC) method

A circle is fitted to the measured profile such that the sum of the square of the departure of the profile data from this circle is a minimum. The roundness figure is then defined as the difference between the maximum departures of the profile from this circle; highest peak to the lowest valley [12]. The following data can be obtained from the calculation using radius R_0 of the reference circle: [13]

i. **Peak height, P** : Maximum deviation (Rmax – R0) of the measured profile that projects outside (positive) the reference circle.

ii. **Valley depth, V** : Maximum deviation (R0 – Rmin) of the measured profile that projects inside (negative) the reference circle.

iii. **Mean roundness** : The arithmetical mean of the absolute values of the deviation of the measured profile form the reference circle.

iv. **Peak count** : Number of peaks that are outside the reference circle.

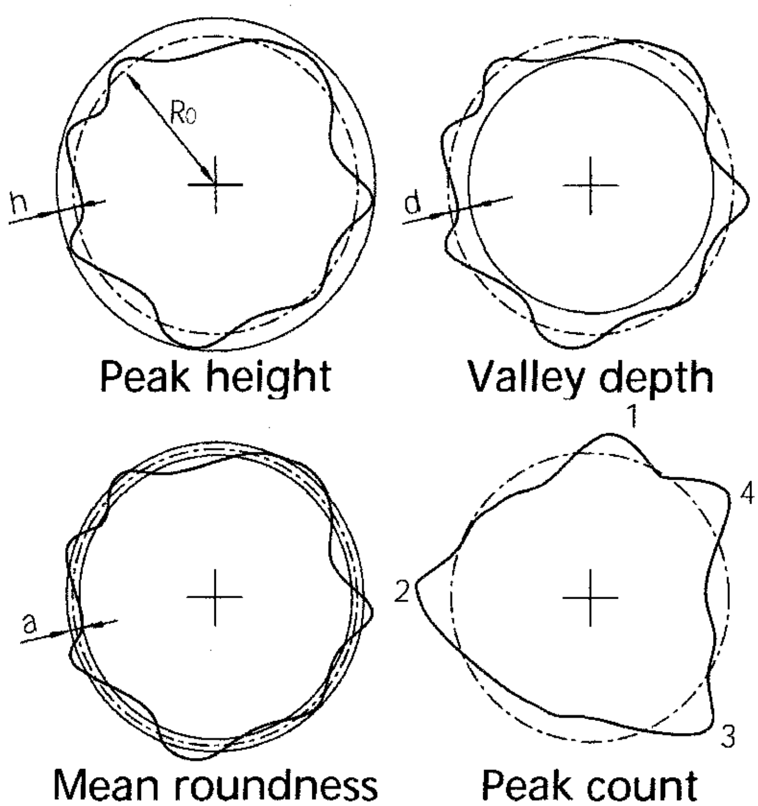


Figure 7 : Analysis term [13]

2.4.1 Effect of Cutting Speed on Surface Roundness

For the effect of the cutting parameters on the roundness of the turned part has not been sufficiently studied, Chorng et al., (2009) report that only the cutting speed affects significantly the roundness of a cylindrical bar.

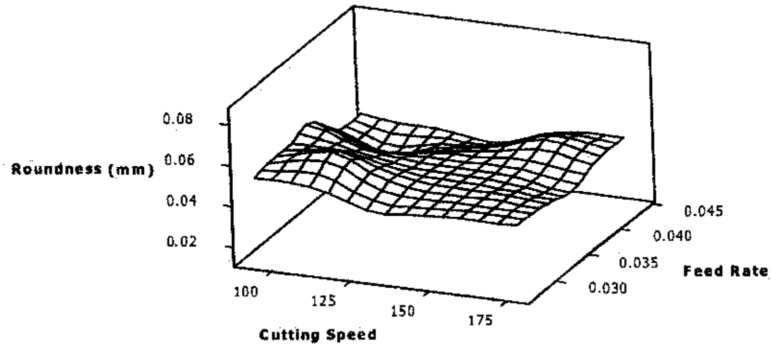


Figure 8 : Surface plot of roundness (mm) vs. feed rate, cutting speed [14]

Figure 8 shows the effect of the cutting speed and the feed rate on the roundness. L.Rico, A. Naranjo, S. Noriega, E. Martínez, and L. Vida (2010) determined that when the bar is machined to high cutting speed and low feed rate, the roundness is low.[14]

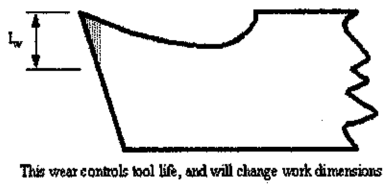
2.5 Tool Flank Wear Measurement

Tool life is the length of cutting time that the tool can be used before it begins to fail. Another definition for the tool life is the usable time that has elapsed before the criterion value of flank wear is reached (Bouzid, 2005; Bouzid et al., 2005) [15].

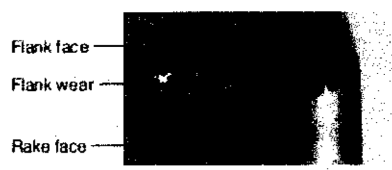
Ozel & Nadgir (2002) is very definite: "The prediction and detection of tool wear before the tool causes any damage on the machined surface becomes highly valuable in order to avoid loss of product, damage to the machine tool and associated loss in productivity" [16].

Cutting tool experience complex wear behaviors under high temperature, high pressure, high sliding velocity and mechanical or thermal shock in cutting area. This consists of some basic wear types such as crater wear, flank wear, thermal crack, brittle crack, fatigue crack, insert breakage, plastic deformation and build-up edge (Gupta, 2005; Olortegui & Kwon, 2007) [17,18]

Flank wear is usually used to determine the tool life because it directly influences the size and quality of the surface and can affect fatigue endurance limit by affecting surface finish due to changing in the distribution of heights and slopes of the surface (Nwokah & Hurmuzlu, 2002).



(a)



(b)

Figure 9 : Flank wear; (a)the point tool degrade (b) 3D image tool flank wear [19]

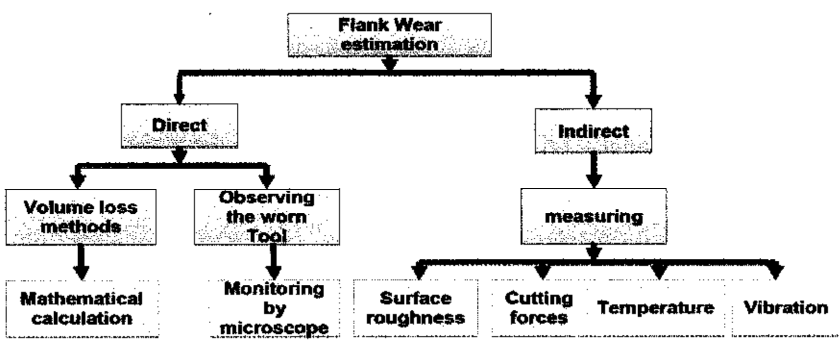


Figure 10 : Extimating flank wear methods [20]

Figure 10 illustrates the estimating methods that can be used in estimating flank wear progress [20]. In this research, the flank wear will be estimated by observing the worn tool under the microscope. Flank wear occurs on the flank of a cutting tool and caused by friction between the newly machined work piece surface and the contact area on the tool flank. Because of the rigidity of the work piece, the flank wear land must be parallel to the resultant cutting direction and normally the width of the wear land will be taken as the measurement of the amount of wear. This situation is shown in **Figure 11**.

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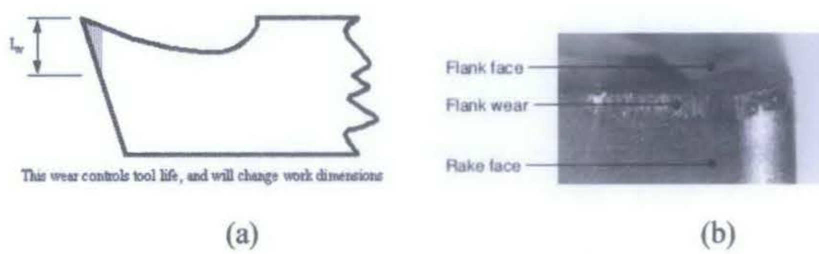

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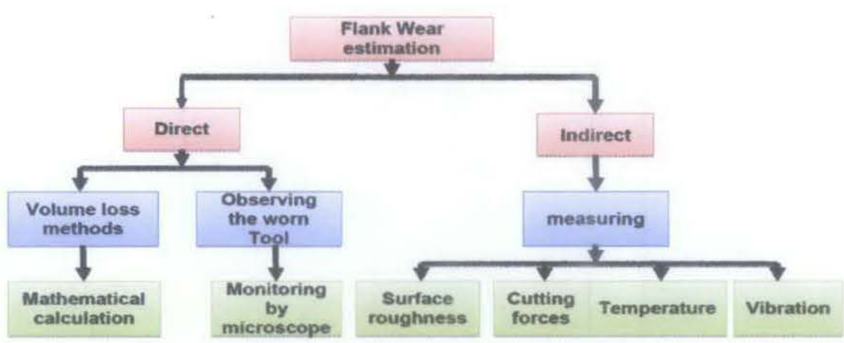

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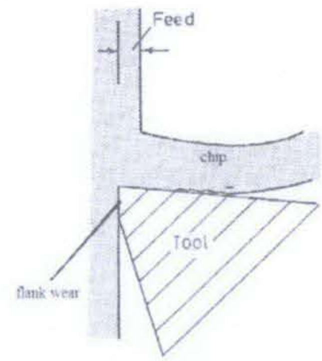


Figure 11 : Flank wear

And **Figure 12** below shows the relationship between the different affecting factors that will give the basic relations to develop a direct estimation method for the tool life.

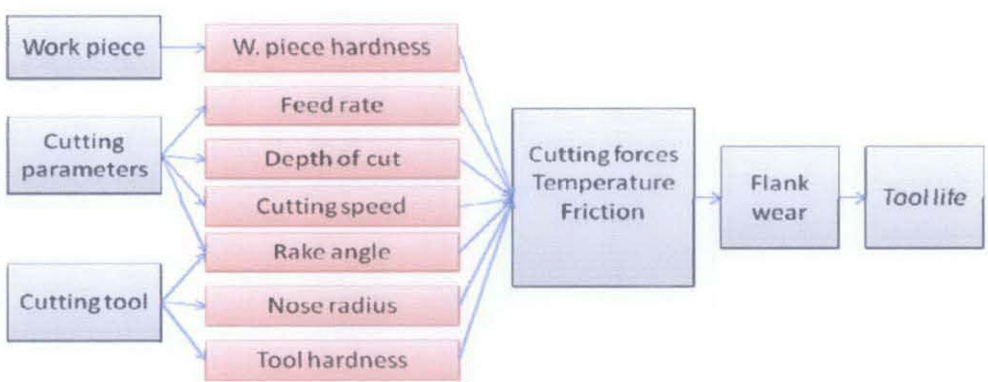


Figure 12 : The effect of different parameters on tool life [20]

Mathematically the tool life can be expressed in the following equation (Taylor equation)

$$V_c T^n = C$$

Where; Vc is cutting speed, T is tool life, and n & C are constant.

2.5.1 Effect of Cutting Speed on Tool Flank Wear

The wear phenomenon also occurs due to machining parameters and many studies have been completed in order to look into this problem. Regarding to studies on surface finish and tool flank wear in turning of AISI D2 steel with ceramic wiper inserts, tool flank wear reaches to a tool life criterion value at high cutting speed. The studies also stated that better tool life is obtained in lowest feed rate and lowest cutting speed combination (Ozel et al, 2007).

Study by Astakhov (2004) : "The properties of the work and tool materials, tool geometry and the cutting regime determine the contact phenomena of the tool–workpiece interface. As such, the cutting speed has the strongest influence." [21].

Studies about tool wear in turning have been made in order to develop reliable method to predict flank wear precisely using a mathematical model by estimating the flank wear by means of the diffusion coefficient and the other input cutting parameters. The wear is shown experimentally that the cutting velocity and the index of diffusion have the most significant effect followed by the feed and the depth of cut (Choudhury and Srinivas, 2004) [22].

Feed (mm/rev)	Cutting speed (m/min)		
	120	180	240
0.050	0.400	0.429	0.438
0.125	0.441	0.461	0.482
0.200	0.510	0.536	0.615

Figure 13 : Measured flank wear land (mm) after 5min cutting time [22]

2.6 Chip Morphology

The chip forming process occurs by a mechanism called plastic deformation. This deformation can be visualized as shearing, that is when a metal is subjected to a load exceeding its elastic limit. **Figure 14** shows four different types of chip produced. Figure14(a) that is a continuous chip which are considered to be non-oscillatory material flow in which profiles of chip properties; strain, stress, temperature remain approximately constant over time. Figure 14(b) shows a segmented chip that is a continuous chip in which shear zones appear aperiodically and chip thickness varies with time. Komanduri [23], explain that this type of chip morphology appears due to stick-slip oscillation and damage in the shear zone. Shaw [24] identified serrated or shear-localized chips as shown in Figure 14(c) and characterized them as oscillatory material flow. Finally, Figure 14(d) shows the discontinuous chip that can be obtained when chip segmentation increases to the point where each segment breaks.

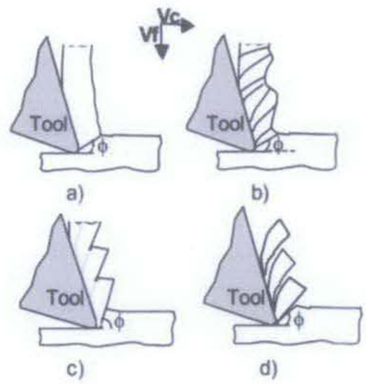


Figure 14 : Different chip types produced during turning operation :
(a) continuous; (b) segmented; (c) serrated or sheared localized; (d) discontinuous

2.6.1 Effect of Cutting Speed on Types of Chip Formed

Jiang Hua, Rajiv Shivpuri, (2004) conducted an experiment turning of Ti-641-4V annealed rod using CNC Turning Center at cutting speeds of 60, 120 and 240 m/min, feeds of 0.127 and 0.35mm/rev and DOC of 2.54mm. **Figure 14** below shows that as the cutting speed increases, the segment spacing decreases. "Chip formation is strongly influenced by crack initiation and propagation which results in discontinuous or serrated chip morphology. When cutting Ti–6Al–4V at low cutting speed, the chip obtained is discontinuous, while at high cutting speed the chip obtained is serrated" [25].

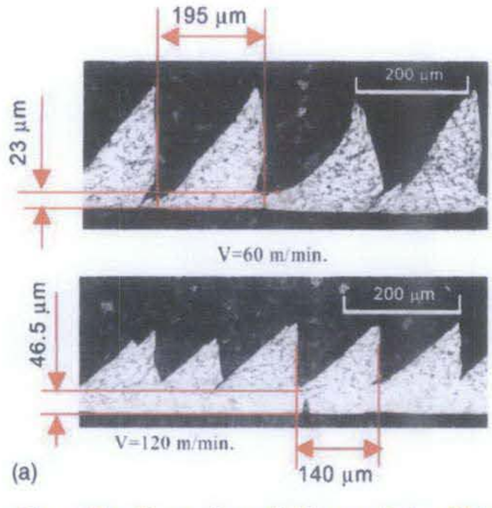


Figure 15 : Comparison of chip morphology[25]

Study by A. Daymi, M. Boujelbene, S. Ben Salem, B. Hadj Sassi and S. Torbaty (2008) indicates that Ti-6Al-4V in annealed state shows a saw-type chip starting from the speed of 100 m/min. Below this speed, there is a flow chip. They concluded that continuous chip produced at speed of 50m/min, flow chip for speeds ranging around 100m/min and shear localized chip starting from the transition speed of 125/min and above [26].

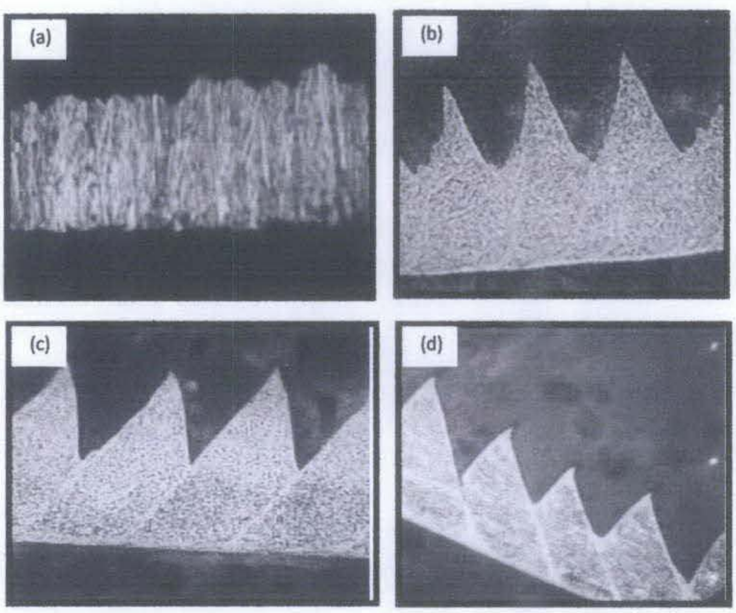


Figure 16 : SEM micrograph of the different chip types produced during a orthogonal turning operation: (a) continuous, Vc = 50 m/min (b) segmented, Vc = 100 m/min (c,d) serrated or sheared localized, Vc = 175 - 250 m/min [26]

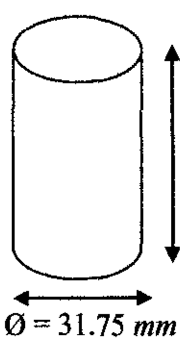
3.2 Experimental Conditions

This experiment is conducted using the turning process. Turning process is a process whereby a stationary tool is moved axially along a rotating workpiece. Such an action may produce a straight cylindrical shaft, or by offsetting the tool path or by interpolating in two axes, a tapered shaft may be produced. The equipment used to conduct this experiment is the Heavy Duty Conventional Lathe Machine. Throughout this experiment, the author will be using the same machine and cutting fluid.

Table 1 : Experimental conditions

Cutting Fluid	XXX – Commercial Metal Cutting Fluid Concentration : 8%

Based on the general recommendation for Turning Operation (refer **Appendix 3-1**), these are the parameter for roughing and finishing of AISI 304 Austenitic Stainless Steel.



Workpiece Material	:	AISI 304 Austenitic Stainless Steel
Cutting Tool	:	Titanium nitride (TiN) coated carbide
Cutting Speed, V	:	60 m/min 90 m/min 180 m/min 200 m/min
Depth of cut, d	:	1.0 mm
Feed, f	:	0.35 mm/rev

3.3 List of Equipment Used

The following equipments were used in this experimental works :

i. Digital Refractometer

Brand : Sper Scientific

Model : 30034

Figure 17 : Digital Refractometer

This instrument is used to measure the concentration of the metal cutting fluid emulsion.

ii. Heavy Duty Conventional Lathe Machine

Brand : Excel

Model : XL 510

Figure 18 : Heavy duty conventional lathe machine

This equipment is used to conduct turning operation for the testing of cutting speed influence in the experiments.

iii. Surface Profiler

Brand : Mitutoyo

Model : Surftest SV 3000

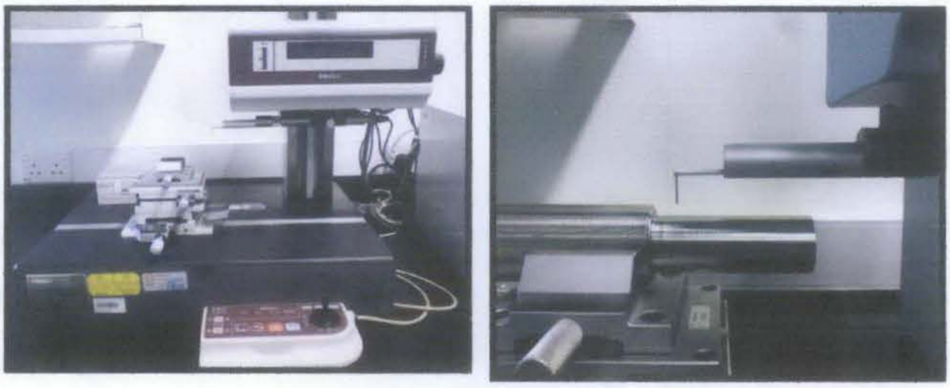


Figure 19 : Mitutoyo, Surftest SV 3000

This equipment is used to measure surface roughness of the turned workpiece.

iv. Round Test Machine

Brand : Mitutoyo

Model : Roundtest RA-114

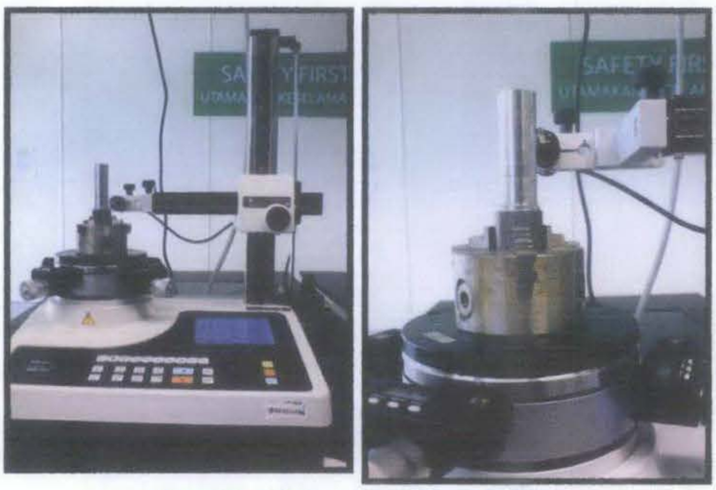


Figure 20 : Mitutoyo Round Test Machine

This equipment is used to measure surface roundness of the turned workpiece

v. 3D Non Contact Measurement Machine

Brand : Mitutoyo

Model : 3D CNC Vision Measuring Machine

Figure 21 : 3D Non-Contact Measurement

To measure the tool flank wear, examine types of chip formation and to capture perfect image of tool flank wear and chip produced with

3.4 Experiment Procedures

As mentioned in **Section 3.2,** the experiment will be conducted in lowest concentration of metal cutting fluid environments with four different cutting speeds. These are the general steps for the experiment to be conducted:

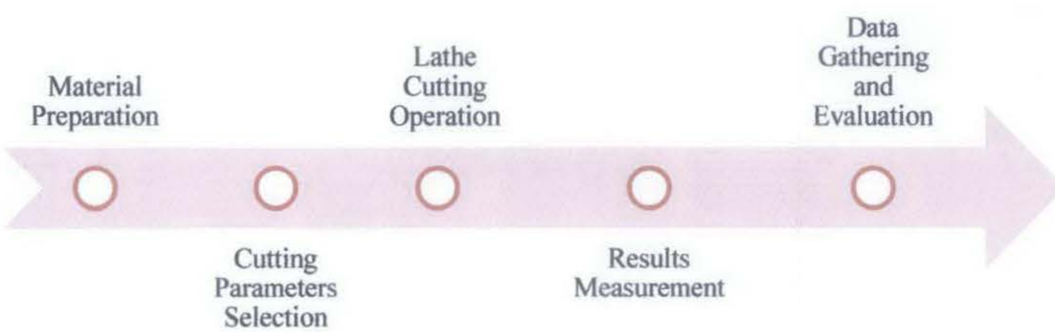


Figure 22 : Experimental Procedure

3.4.1 Material Preparation

Metal cutting fluid used in this project is a water soluble type which has to dilute with water to get the desired concentration which is 8% concentration. To get the desired concentration, these steps must be taken. [27]

1. Determine the total metal cutting fluid tank size;

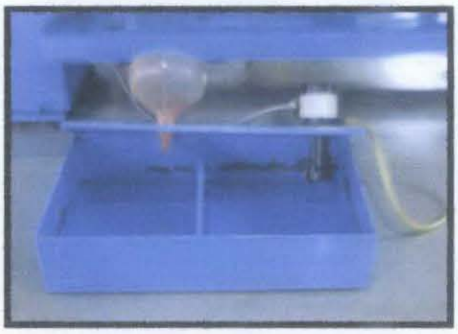


Figure 23 : Metal cutting Fluid Tank

Tank Size $= L \times W \times H$

$= 0.8m \times 0.47m \times 0.13m$

$= 0.04888\ m^3$

$= 48.88$ litres ≈ 49 litres

2. Determine the volume concentrate needed for the entire tank volume of 49 litres at the desired concentration of 8%

   Volume of concentrate $= 0.08 \times 49$litre $= 3.92$ litre ≈ 4 litre

3. Mix 4 litre of oil concentrate with 45 litre of water
4. Add the oil concentrate into the water, not the reverse [28]
5. Check the concentration with digital refractometer

3.4.2 Cutting Parameters Selection

As mentioned in **Section 3.2**, these are the cutting parameters selected. All these parameters taken are referred to the standard in **Appendix 3-2**

Workpiece Material	:	AISI 304 Austenitic Stainless Steel
Cutting Tool	:	Titanium nitride (TiN) coated carbide

Cutting Speed, *V*	:	60 m/min 90 m/min 180 m/min 200 m/min
Depth of cut, *d*	:	1.0 mm x 5 runs
Feed, *f*	:	0.35 mm/rev

The calculation shown below shows how the spindle speed calculated based on the recommended cutting speed.

Spindle Speed, N,

$$N = \frac{V}{\pi D_o}$$

$$= \frac{60\ m/min}{\pi \times 0.03175m}$$

$$= \mathbf{601\ rpm\ (\sim 710\ rpm)}$$

During roughing, the cutting speed required by standard is 60m/min thus the spindle speed corresponds to the speed is 601rpm. However, the heavy duty conventional lathe machine does not have the exact spindle speed value. Thus, the spindle speed is set at the nearest point available, provided by the machine which is 710rpm. Same goes with the remaining cutting speed. **Table 2** below summarizes the calculated and matched spindle speed provided by the machine.

Table 2 : Summary of calculated and machine spindle speed with respect to cutting speed

Cutting speed, V (m/min)	Calculated Spindle speed (rpm)	Machine Spindle speed, (rpm)
60	601	710
90	917	1000
180	1804	1400
200	2005	2000

3.4.3 Lathe Cutting Operation

The general steps for the experiment to be conducted:

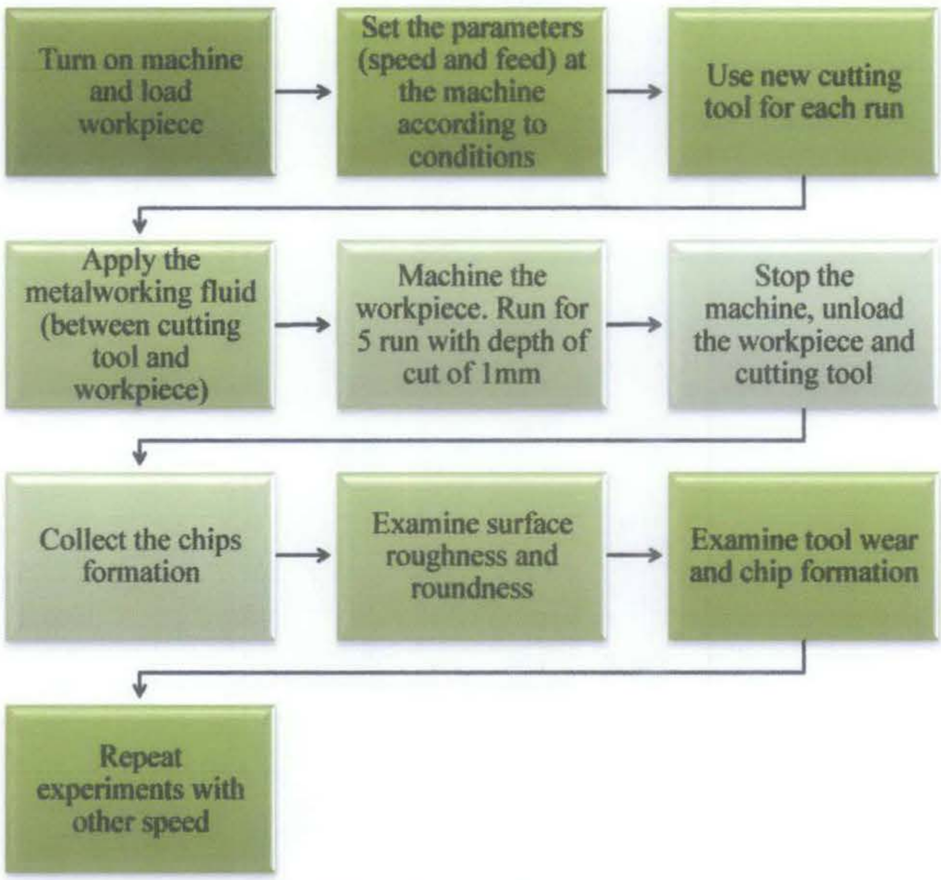


Figure 24 : Procedure for Lathe Cutting Operation

Figure 25: Application of Metal cutting Fluid during Lathe Cutting Operation

3.4.4 Surface Roughness Measurement

A Mitutoyo Surface Profiler will be used to measure the surface roughness of the turned workpiece. To ensure the accuracy of the measurement, several readings are taken. The turned parts will be divided into three segments of three different measurement length, 20mm, 40mm, 60mm as shown in **Figure 26** below. Then the workpiece will be measured at three different face, face A, B, C respectively as shown in **Figure 27.**

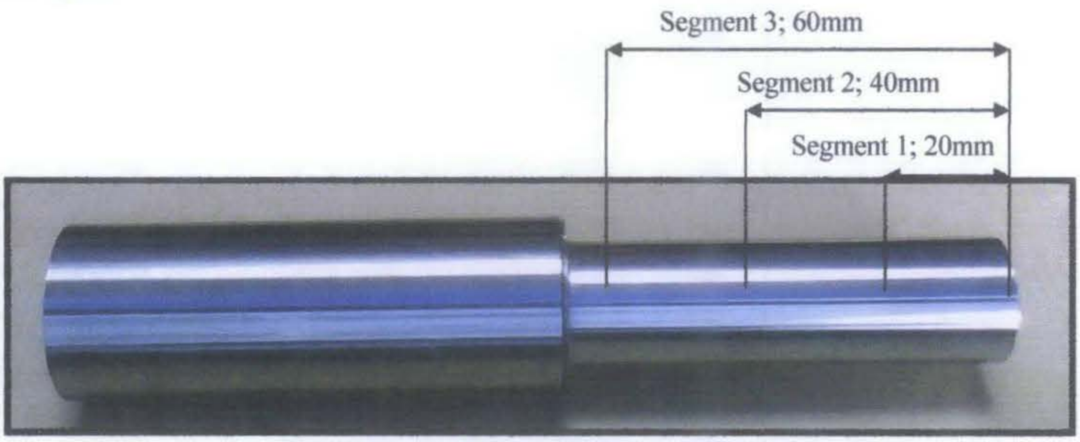


Figure 26 : Segments for three different measurement length

Figure 27 : Three different face point

3.4.5 Surface Roundness Measurement

A Mitutoyo Round Test Machine will be used to measure the surface roundness of the turned workpiece. The stylus or detector is bring into contact with the workpiece as shown in **Figure 28**. When the start button is pushed, the workpiece will be turned to get the reading of surface roughness which covers every face of the workpiece. So, for more accurate result, the measurement length is added to six instead of 3measurement length; **Figure 29.**

Figure 28 : Workpiece and stylus/detector

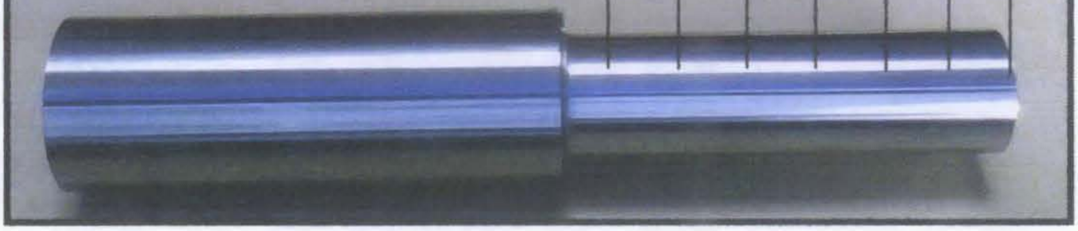


Figure 29 : Six different measurement length

3.4.6 Tool Flank Wear and Chip Formation

A Mitutoyo 3D Non-Contact Measurement Machine; modeled 3D QVPAK Quick Pro will be used to measure the tool flank wear and capture perfect image and determine the types of chip formation. The machine is able to capture perfect image up to 6times (6x) magnification.

Figure 30 : Mitutoyo 3D Non-Contact Measurement

Figure 31 below shows the measurement of flank wear turning cutting tool.

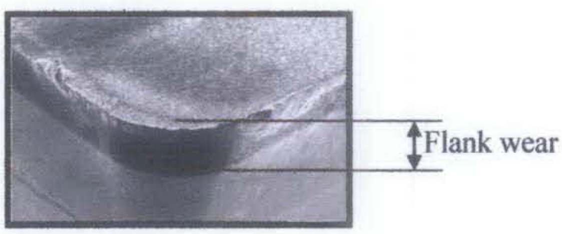


Figure 31 : Measurement of Flank wear [8]

3.5 Project Milestone

Table 3 : FYP 1 Gantt Chart

No	Details / Week	1	2	3	4	5	6	Mid Semester Break	7	8	9	10	11	12	13	14	15
1	Selection of Project Topic																
2	Project Identification and Planning																
3	Preliminary Research Work																
4	Preparation for Preliminary Report																
5	Submission of Preliminary Report				●												
6	Further Research and Study																
7	Literature Review																
8	Submission of Progress report									●							
9	Seminar (compulsory)																
10	Defining project constraints and criteria to be evaluated																
11	Developing the analysis technique																
12	Submission of Interim Report																
13	Oral presentation																

● Milestone Progress

Table 4 : FYP 2 Gantt Chart

continued from previous																	
No	**Details / Week**	16	17	18	19	20	21	22	Mid Semester Break	23	24	25	26	27	28	29	30
14	Project Work Continues:																
	• Machine familiarization & training																
	• Cutting of austenitic stainless steel																
	• Measurement of results and analysis																
15	Submission of Progress Report									●							
16	Project Work Continues:																
	• Cutting of stainless steel																
	• Measurement of results and analysis																
17	Pre-EDX												●				
18	Submission of Draft Report													●			
19	Submission of Dissertation (Soft Bound)														●		
20	Submission of Technical Paper														●		
21	Oral Presentation															●	
22	Submission of Project Dissertation (Hard Bound)																●

● Milestone Progress

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Work Completed

The projects were successfully finished with four different speeds with minimum concentration of metal cutting fluid, 8% dilution. In this turning process, the minimum cutting speed was 60m/min and the maximum cutting speed was 200m/min. Other cutting parameters such as feed rate and depth of cut are fixed. After conducting the turning, the turned workpiece were tested with roughness and roundness while the cutting tool was tested with tool flank wear and the type of chip formed was also examined. All the results were tabulated and plotted. Results obtained were then being interpreted and analyzed. To archive the objective of the experiment, recommendation on the best cutting speed for AISI 304 Austenitic Stainless Steel based on the results gained from the project was made.

4.2 Data Gathering

4.2.1. Surface Roughness Testing

Roughness is the irregularities which are inherent in the production process. There is several roughness parameters that need to be consider in measuring the surface of workpiece as mention in *Section* 2.3. As in this project, only mean surface roughness, ***Ra*** is being analyzed. Primary results of Mean surface roughness values obtained after the turning of the stainless steel are given in **Table 5**. The average of roughness is shown in **Table 6.**

Table 5 : Primary result of mean surface roughness, μm

Cutting Speed, m/min	Face	Mean Surface Roughness Ra, μm		
		Segment 1 20mm	Segment 2 40mm	Segment 3 60mm
60	A	0.653	0.694	0.674
	B	0.926	0.651	0.645
	C	0.549	0.596	0.575
90	A	0.72	0.79	0.661
	B	0.646	0.707	0.61
	C	0.706	0.76	0.754
180	A	1.175	0.828	0.811
	B	1.14	0.887	0.8
	C	1.141	0.977	0.925
200	A	0.862	1.357	1.636
	B	1.297	0.949	0.94
	C	1.951	0.745	0.787

Table 6 : Average value of mean surface roughness, μm

Cutting Speed, m/min	Mean Surface Roughness Ra, μm		
	Segment 1 20mm	Segment 2 40mm	Segment 3 60mm
60	0.709	0.647	0.631
90	0.691	0.752	0.675
180	1.152	0.897	0.845
200	1.370	1.017	1.121

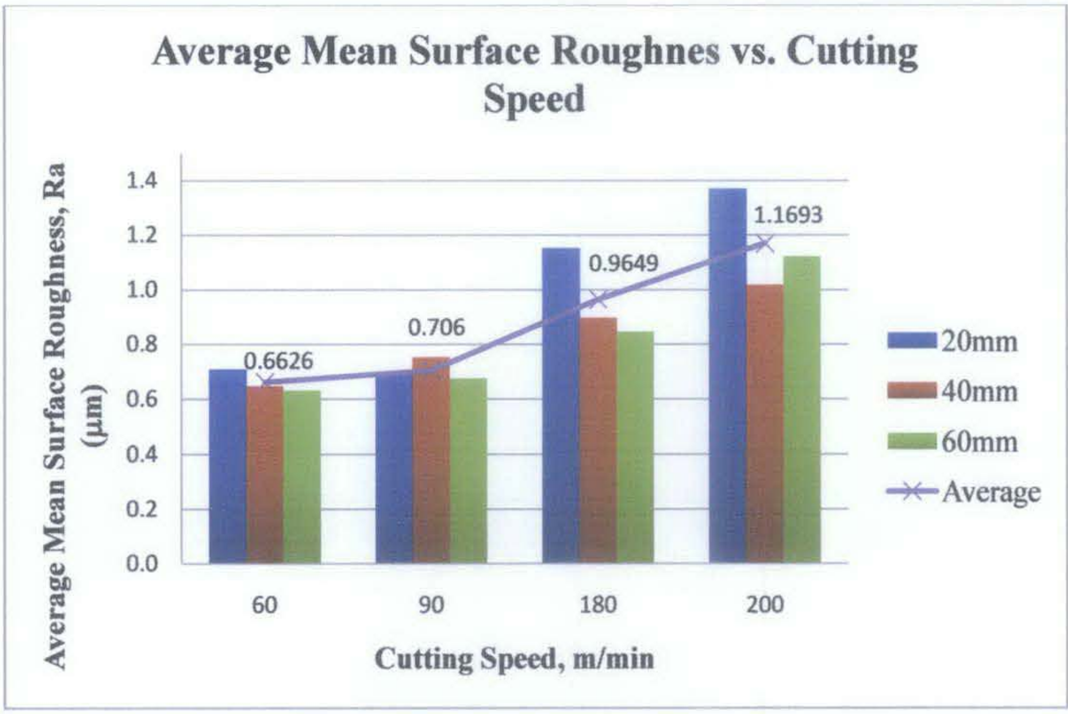


Figure 32 : Graph of Average surface roughness versus cutting speed

By considering the range of waviness, the average mean surface roughness is taken for three measurement length as mention in *Section 3.4.4*, which is 20mm, 40mm and 60mm. The averages of three different face points for every measurement length are used to plot the graph as shown in **Figure 32**. A trend line are then being plot showing a value of surface roughness by taking the average of surface roughness from all the measurement length for corresponding cutting speed to simplify the interpretation. From the plotted chart, it can be seen that value of average mean surface roughness increase or surface roughness become worst with increasing cutting speed. The best surface roughness value obtained was at the cutting speed of 60m/min with Ra value of 0.6626µm.

Stainless steel is hardened steel and it is slightly difficult to be machined due to its high material properties such as high ductility, high strength, high work hardening rate and low thermal conductivity. The difficult to cut material can be operated at high cutting speed in order to eliminate formation of BUE. If the BUE disappeared at high cutting speed, it was possible to obtain low surface roughness. The decrease in surface roughness with increase in cutting speed may be related to the increase in cutting temperature which in turn might lead to little reduction in material adhesion. However, from the results obtain it clearly depicts that best quality of surface roughness of austenitic stainless steel was obtained with the lowest cutting speed.

From previous studies, high cutting speed with low feed rate, or low cutting speed with high feed rate will give the best surface roughness. Since the result obtained from the experiments give the best surface roughness, it indicates that the high feed rate is selected and used for cutting austenitic stainless steel in this project.

4.2.2. Surface Roundness Testing

Primary results of surface roundness obtained after the turning of the stainless steel and the average are given in **Table 7** and **Table 8** respectively.

Figure 33 : Measurement of surface roundness using roundtest machine

Table 7 : Primary result of mean surface roundness, μm

Cutting Speed, m/min	Face	Surface Roundness R, μm					
		Segment 1 10mm	Segment 2 20mm	Segment 3 30mm	Segment 4 40mm	Segment 5 50mm	Segment 6 60mm
60	A	16.6	20.2	11.5	11.0	16.2	10.3
	B	17.4	22.2	15.2	13.7	10.0	7.5
	C	20.2	23.4	17.9	16.5	8.5	12.7
90	A	13.9	11.2	7.7	7.4	8.8	3.8
	B	11.8	10.7	8.9	7.5	10.3	4.4
	C	10.8	10.9	8.2	7.5	9.3	3.9
180	A	18.0	17.2	16.8	15.9	14.8	8.4
	B	18.3	17.5	14.8	14.0	11.7	5.9
	C	15.8	20.7	15.8	14.1	11.3	10.4
200	A	22.4	20.7	12.1	12.8	12.9	8.6
	B	20.6	17.4	16.1	14.1	8.6	7.5
	C	17.6	16.2	18.1	11.2	12.0	6.6

Table 8 : Average value of mean surface roundness, μm

Cutting Speed, m/min	Surface Roundness R, μm					
	Segment 1 10mm	Segment 2 20mm	Segment 3 30mm	Segment 4 40mm	Segment 5 50mm	Segment 6 60mm
60	18.067	21.933	14.867	13.733	11.567	10.167
90	12.167	10.933	8.267	7.467	9.467	4.033
180	17.367	18.467	15.800	14.667	12.600	8.233
200	20.200	18.100	15.433	12.700	11.167	7.567

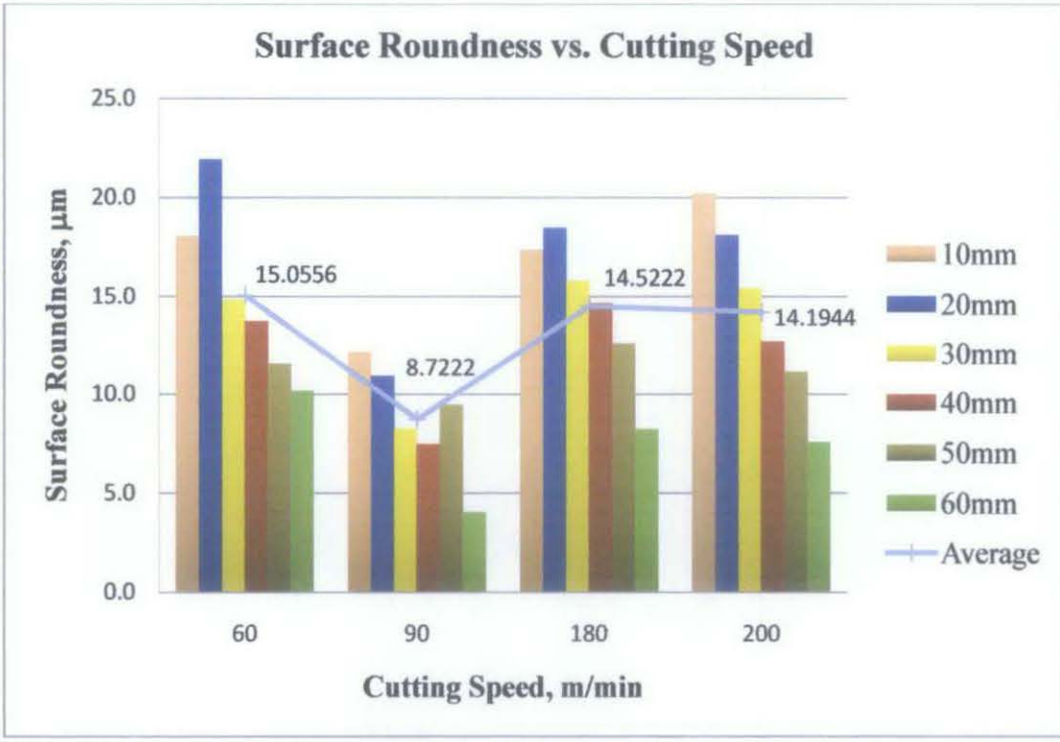


Figure 34 : Graph of surface roundness versus cutting speed

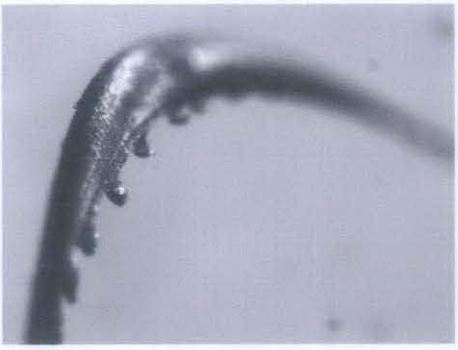
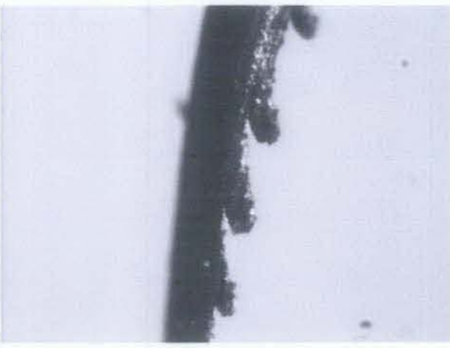
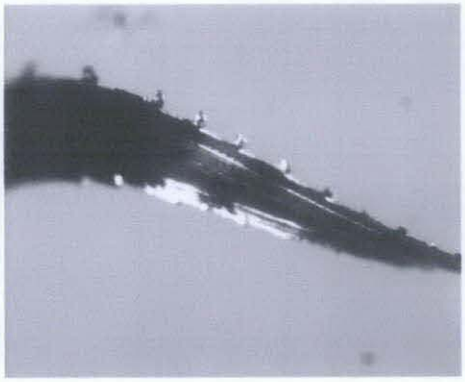
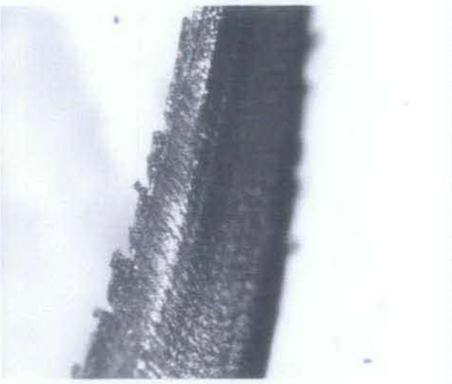
As mention in *Section 3.4.5*, the measurement lengths for surface roundness are 10mm, 20mm, 30mm, 40mm, 50mm and 60mm. Same as surface roughness measurement, average value of three different face point for every measurement length are used to plot the graph as shown in **Figure 34**. A trend line also being plotted showing a value of surface roundness to simplify the interpretation. From the plotted chart, it can be seen that value of surface roundness decrease or better surface roundness with increasing cutting speed. The best average surface roundness value obtained was at the cutting speed of 90m/min with roundness value of 8.72μm.

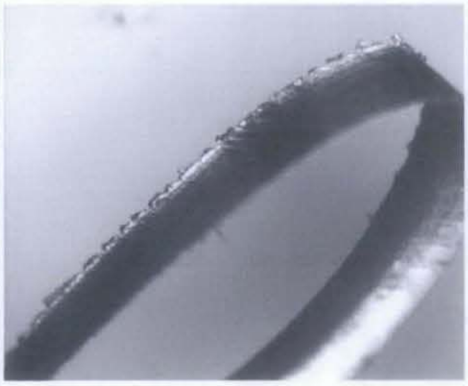
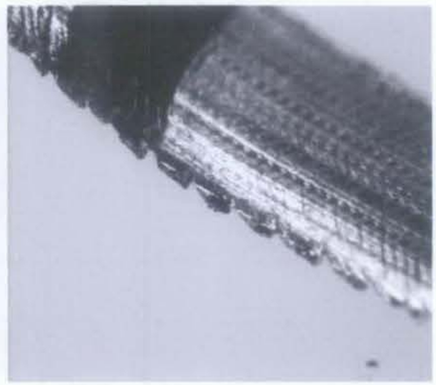
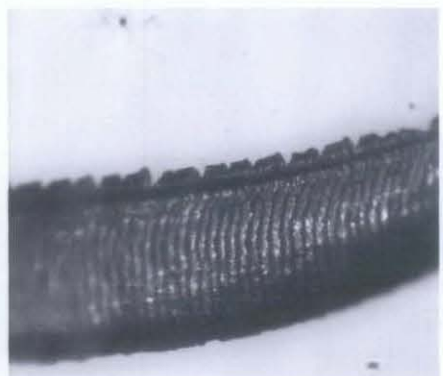
The same trend of surface roundness with respect to measurement length is observed. Better surface roundness was obtained at the largest measurement length which is at the nearest point to the workpiece holder during turning operation. This is because; roundness is influenced by the lack of support on long workpiece. During turning, only 60mm is utilized to clamp the workpiece at headstock. The remaining 90mm is turned without supporting from tailstock which will influence workpiece roundness because higher vibration will occur at the end of the workpiece

4.2.3. Chip Formation

The chip samples were collected and examined for all experiment conditions. **Table 9** shows the results of the chip obtained throughout the experiments.

Table 9 : Image of chip formation captured by Mitutoyo 3D Non Contact Measurement

Cutting Speed m/min	1X magnification	2X magnification
60		
90		

Cutting Speed m/min	1X magnification	2X magnification
180		
200		

First observation made is the continuity of the chip formed. For all four cutting speed, the chip formed was a long, continuous chip having different size of tubular/helical and curly shape. The size of the helical chip was increased from chip sample of cutting speed of 60m/min, followed by 90m/min, 180m/min and largest helical size is 200m/min.

When the chips formed were examined under the microscope, the image obtained shows that the shape of the chip formed for all cutting speeds almost smooth with small cracks at the edge. Since the chip formation (continuous or discontinuous) and the shape are more or less the same, a comparative study is done by comparing the helical chip radius and color of the chip formed.

Table 10 : Radius of the helical chip

Cutting Speed (m/min)	Color	Radius of the helical chip (mm)
60	Yellow	1 – 1.5
90	Yellow	1 - 2
180	Silver	6 - 7
200	Silver	6.5 – 8

Table 10 above shows the color and radius of the helical chip formed during turning of AISI Austenitic Stainless Steel with varies cutting speed. Small chip radius formed at the low cutting speed which is 60m/min and 90m/min.

The color of the chip produced can be used to examine the effect of heat generated on the chips. Smaller curl radius experience larger effect of heat formation. The chips with small curl radius have smaller surface area compared to the larger curl radius. It means that heat produced during the cutting easily get trapped and more difficult to be released [30]. Then, as the chips with small curl radius were formed at the lowest cutting speed (60m/min), the chips remained longer time contact with the tool since the cutting time is proportional to the cutting speed; lower cutting speed, longer cutting time. Hence, it leads to more friction between the chip and the tool.

At higher cutting speed, 180m/min and 200m/min, the chips have brighter color than those obtained at 60m/min and 90m/min. With a highest cutting speed of 200m/min, the chips became silver, similar to the workpiece materials. This indicates that the least influence of heat.

4.2.4. Tool Flank Wear

Table 10 below shows the image of tool flank wear captured by Mitutoyo 3D Non Contact Measurement after 5 runs measured in the experiment at four different tool faces as shown in **Figure 35.**

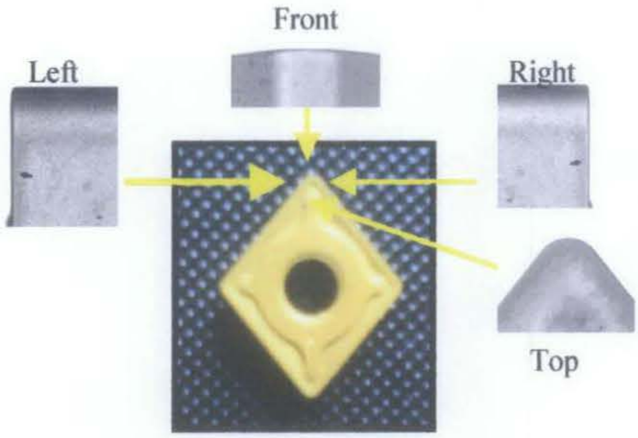


Figure 35 : Parts nomenclature

Figure 36 shows the measurement point of tool flank wear. Two points were taken which is from the right face of the cutting tool, Point 1; where it is expected to have higher degree of tool flank wear compared to the tool flank wear at left face of the cutting tool, Point 2.

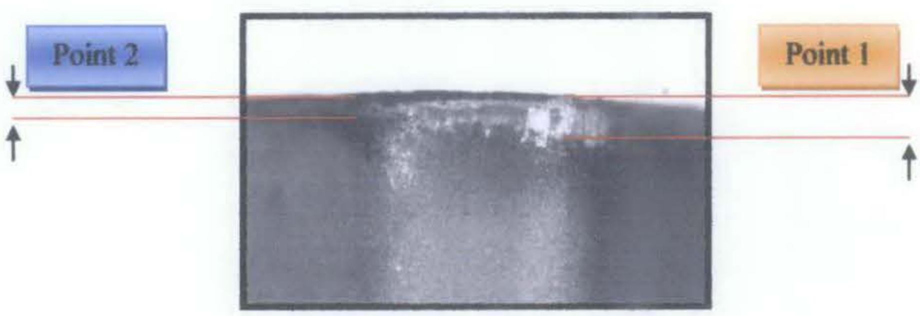


Figure 36 : Measurement point

Table 11 : Image of tool flank wear captured by Mitutoyo 3D Non Contact Measurement after 5 runs

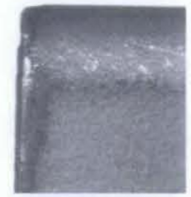
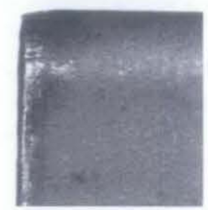
Cutting Speed	Top	Front	Right	Left
60 m/min				
90 m/min				
180 m/min				
200 m/min				

Table 12: Results of the tool flank wear

Cutting Speed, m/min	Point	0run	5runs
60	Point 1	0.000	0.2158
	Point 2	0.000	0.1519
90	Point 1	0.000	0.1275
	Point 2	0.000	0.0883
180	Point 1	0.000	0.1667
	Point 2	0.000	0.1079
200	Point 1	0.000	0.2060
	Point 2	0.000	0.1030

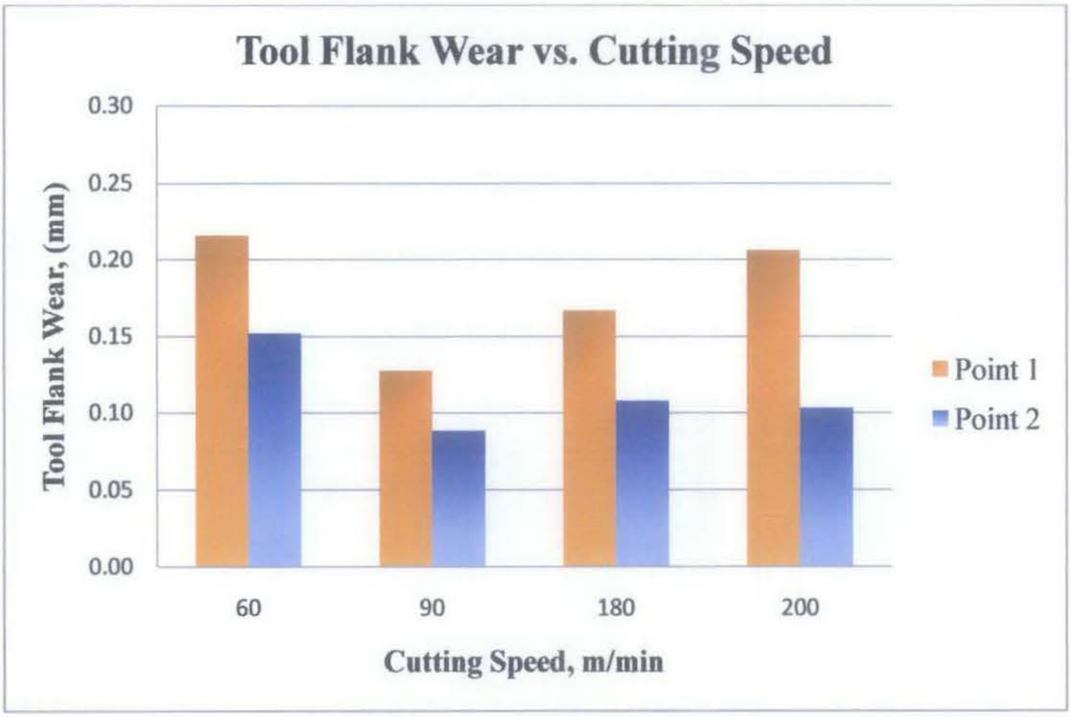


Figure 37 : Graph of tool flank wear at point 1 and point 2 after 5 runs with depth of cut of 1.0 mm

All the tools were a new insert tool for every condition of experiment. With a depth of cut of 1mm, these tools were used for 5 runs cutting with same depth of cut. To make it more comparable, number of run should be increased up to 10 runs.

Figure 37 shows the progression of flank wear for different cutting speed and it clearly demonstrated that the cutting speed has significant influence on flank wear while machining AISI 304 Austenitic Stainless Steel. The lowest performance of the tool is at the lowest cutting speed, 60m/min where it experience highest degree of tool flank wear. By increasing the cutting speed to 80m/min, greatest performance of the tool archived but as the cutting speed is further increased, the length of tool flank wear increased.

Other observation that can be made is flank wear occurs more at Point 1 compared to Point 2. This is due to the direction of cutting during cutting operation.

Poor performance of the tool at the lower cutting speeds can be explained by the influence of the heat generated on the cutting tool during the cutting process. As mention in *Section 4.2.1* AISI 304 Austenitic Stainless Steel has the characteristic of low thermal conductivity that will affect the heat dissipation rate.

As mentioned in *Section 4.2.3, t*he chips formed at 60 m/min cutting speed were affected most from the heat and therefore had the highest temperature when compared to the others. Besides had the highest temperature, lower cutting speeds also lead to increasing contact time on the rake face as the chips moved slowly when compared to the higher cutting speeds. In view of these findings, the high chip temperature and the long contact time on the rake face gave rise to thermal softening of the tool by conduction of the heat from the chips to the tool. This will reduces wear resistance of the tool. The tool rejection criteria for the machining was maximum flank wear land of >0.8mm.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The influence of the cutting speed on the surface roughness, roundness, tool flank wear and types of chip formed is analyzed for turning cutting operation of AISI 304 Austenitic Stainless Steel in the range of cutting speeds V from 60m/min to 200m/min.

All the performance criteria and the cutting speed are tabulated in the **Table 13** below. For each criteria, score '4' given to the most preferable cutting speed and score '1' to the least preferable speed. The recommendation is based on the highest score.

Table 13 : Score of every cutting speed for each performance criteria evaluated

Performance	Cutting Speed, m/min			
	60	**90**	**180**	**200**
Surface Roughness	4	3	2	1
Surface Roundness	1	4	2	3
Tool Flank Wear	1	4	3	2
Chip Formation	1	2	3	4
Total score	7	**13**	10	10

Based on a thorough analysis of the experiment results, the conclusions that can be made is

- Surface roughness and roundness values were found to increase with the increasing cutting speed.
- Tool flank wear decreased with increasing cutting speed. The poor performance of the tool is due to the thermal softening of the tool due to the higher influence

of the heat on the cutting tool and less efficient heat dissipation at the lower cutting speed.

- Radius size of helical chip formed was increasing with increasing cutting speed due to decreasing influence of the heat generated.

In the machining AISI 304 Austenitic Stainless Steel with the application of *8% metal cutting fluid*, feed rate of *0.35mm/rev* and depth of cut *1.0mm*, the optimum cutting speed is *90m/min*.

5.2 Recommendation

Based on the results that have been obtained from this project, these are several recommendations that can be highlighted to assist future work for expansion.

- Adding the number of runs up to 10runs to investigate the growth of tool flank wear and have clearer view on effect of cutting speed on tool flank wear.
- Measure the thickness of the chip formed because chip thickness can be related to the shear plane angle since from the previous studies, it indicate that lower shear plane angle increases heat and cutting forces.

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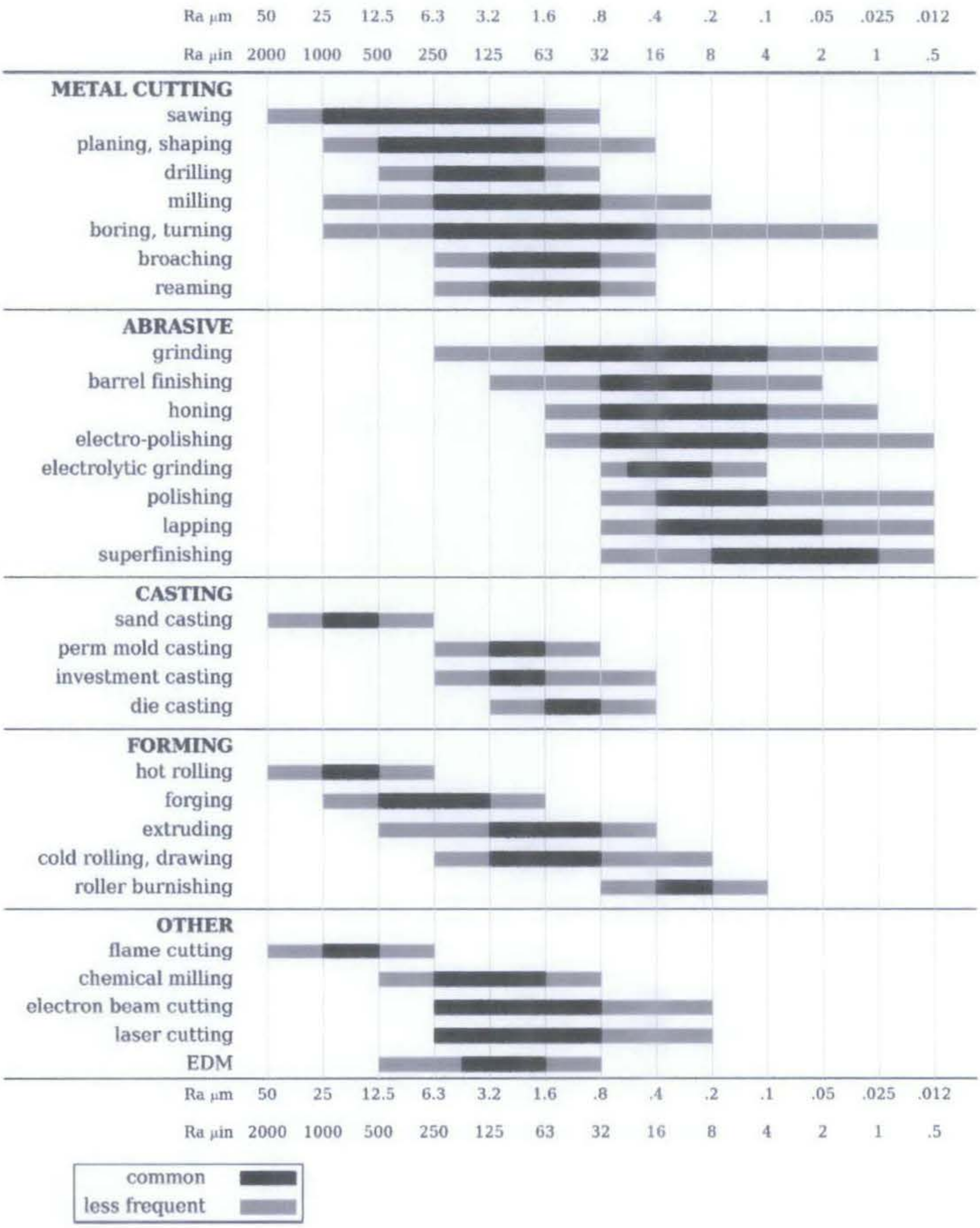
APPENDICES

APPENDIX 2-1 : Range of Surface Roughness Obtained in Various Machining Processes[29]



APPENDIX 3-1 : General Recommendation of Turning Operation

TABLE 23.4 *(Continued)*

General Recommendations for Turning Operations

		General-purpose starting conditions			Range for roughing and finishing		
Stainless steel, austenitic	Triple-coated carbide	1.5–4.4	0.35	150	0.5–12.7	0.08–0.75	75–230
	TiN-coated carbide	*	*	85–160	*	*	55–200
	Cermet	*	0.30	185–215	*	*	105–290
High-temperature alloys, nickel based	Uncoated carbide	2.5	0.15	25–45	0.25–6.3	0.1–0.3	15–30
	Ceramic-coated carbide	*	*	45	*	*	20–60
	TiN-coated carbide	*	*	30–55	*	*	20–85
	Al_2O_3 ceramic	*	*	260	*	*	185–395
	SiN ceramic	*	*	215	*	*	90–215
	Polycrystalline cBN	*	*	150	*	*	120–185
Titanium alloys	Uncoated carbide	1.0–3.8	0.15	35–60	0.25–6.3	0.1–0.4	10–75
	TiN-coated carbide	*	*	30–60	*	*	10–100
Aluminum alloys							
Free machining	Uncoated carbide	1.5–5.0	0.45	490	0.25–8.8	0.08–0.62	200–670
	TiN-coated carbide	*	*	550	*	*	60–915
	Cermet	*	*	490	*	*	215–795
	Polycrystalline diamond	*	*	760	*	*	305–3050
High silicon	Polycrystalline diamond	*	*	530	*	*	365–915

(Continued)