# OPTIMIZATION OF TOOL LIFE IN MILLING USING RADIAL BASIS FUNCTION

MOHD FAIZAL BIN AZIZ

BACHELOR OF ENGINEERING
UNIVERSITI MALAYSIA PAHANG

**UNIVERSITI MALAYSIA PAHANG**
**FACULTY OF MECHANICAL ENGINEERING**

I certify that the project entitled "Optimization of Tool Life in Milling using Radial Basis Function" is written by Mohd Faizal Bin Aziz. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

DR. ABDUL ADAM BIN ABDULLAH
Examiner Signature

OPTIMIZATION OF TOOL LIFE USING IN MILLING USING RADIAL BASIS FUNCTION NETWORK

MOHD FAIZAL BIN AZIZ

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

DECEMBER 2010

## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering *with Manufacturing Engineering.

Signature
Name of Supervisor: MR KUMARAN A/L KADIRGAMA
Position: LECTURER
Date: 6th DECEMBER 2010

## STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

Signature
Name: MOHD FAIZAL BIN AZIZ
ID Number: ME05044
Date: 6th DECEMBER 2010

***Specially dedicated to***

***My beloved family, and those who have guided and inspired me***

***Throughout my journey of learning***

## ACKNOWLEDGEMENTS

First and foremost, I wish to express my sincere appreciation to my project supervisor, Mr. Kumaran A/L Kadirgama, for constantly guiding and encouraging me throughout this study. Thanks a lot for giving me a professional training, advice and suggestion to bring this thesis to its final form. Without his support and interest, this thesis would not have been the same as presented here. I am very grateful to him for his patience and his constructive comments that enriched this research project.

I would also like to acknowledge with much appreciation the crucial role of the staff in Mechanical Laboratory, for their valuable comments, sharing their time and knowledge on this research project during the project was carried out and giving a permission to use all the necessary tools in the laboratory. They have contributed towards my understanding and thoughts.

In particular, my sincere thankful is also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. And last, but not least thanks to my family for their continuous support and confidence in my efforts.

# ABSTRACT

This paper discuss of the Optimization of tool life in milling using Radial basis Function Network (RBFN).Response Surface Methodology (RSM) and Neural Network implemented to model the end milling process that are using high speed steel coated HS-Co as the cutting tool and aluminium alloy T6061 as material due to predict the resulting of flank wear. Data is collected from RoboDrill T14i CNC milling machines were run by 15 samples of experiments using DOE approach that generate by Box-Behnkin method due to table design in MINITAB packages. The inputs of the model consist of feed, cutting speed and depth of cut while the output from the model is Flank wear occur on the tool surface. The model is validated through a comparison of the experimental values with their predicted counterparts. The analysis of the flank wear is using IM1700 Inverted Metallograph microscope for examine the minimum size of the flank wear within 0.3mm. The optimization of the tool life is studied to compare the relationship of the parameters involve. Cutting speed is the greater influence to the tool fatigue criterion which is result the performance of the cutting tool. The proved technique opens the door for a new, simple and efficient approach that could be applied to the calibration of other empirical models of machining.

# ABSTRAK

Kertas kajian ini membincangkan tentang mengoptimum kekasaran permukaan dalam proses pengilingan manggunakan pendekatan dari Fungsi Asas Rangkaian Berpusat(RBFN). Pendekatan RSM dan NN digunakan dalam menganalisis nilai kerosakan berlaku pada permukaan mata pemotong iaitu besi ketahanan tinggi bersalut untuk memotong campuran aluminium T6061 iaitu bahan kerja bagi eksperimen ini. Data dikumpul dari 15 sample eksperimen yang direka dari kaedah Box-Behnkin di dalam perisian MINITAB mengunakan pendekatan DOE dan mesin pengiling RoboDrill T14i CNC. Data masuk adalah kelajuan memotong, kedalaman memotong dan kadar pergerakan pemotong dan data yang dinilai adalah kadar kehausan pada permukaan alat pemotong. Model ini diaktifkan melalui perbandingan nilai eksperimental dengan ramalan telah dijangka. Analisis kehausan permukaan alat pemotong menggunakan mikroskop terbalik iaitu IM1700 Metallograph untuk menyemak saiz minimum kehausan sisi minimum sebanyak 0.3mm mengikut kadar kajian ditetapkan. Penentuan jangka hayat optima bagi alat pemotong adalah melalui perbandingan di antara hubungan parameter yang terlibat. Hasil kajian menunjukkan kadar kelajuan sesuatu alat pemotong adalah pengaruh yang lebih besar untuk kriteria kerosakan alat. Melalui kajian ini adalah terbukti bahawa teknik dan pendekatan ini telah memberikan satu pendekatan baru, mudah dan efisien yang boleh diterapkan dalam mendapatkan kadar purata untuk jangka hayat sesuatu alat pemotong.

# TABLE OF CONTENTS

# LIST OF TABLE

# LIST OF FIGURES

# LIST OF SYMBOLS

| | | |
|---|---|---|
| mm | - | Millimeter |
| MPa | - | Megapascal |
| $GPa$ | - | Gigapascal |
| % | - | Percent |
| $HB$ | - | Hardness |
| $kN$ | - | Kilo Newton |
| $lbf$ | - | Pound of force |
| $\sigma$ | - | Stress |
| $P$ | - | Load |
| $A_o$ | - | Cross sectional area |
| $A_f$ | - | Final crosses sectional area |
| $e$ | - | Strain |
| $l$ | - | Instantaneous length |
| $l_o$ | - | Original length |
| $E$ | - | Modulus of elasticity |
| $UTS$ | - | Ultimate tensile strength |
| $Y$ | - | Yield strength |

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AISI | - | American Iron and Steel Institute |
| ASTM | - | American Society for Testing and Material |
| CCD | - | Camera Charging Device |
| CMOS | - | Computer Minimum Operating System |
| CNC | - | Computer Numerical Control |
| DOE | - | Design of Experiment |
| FKM | - | Fakulti Kejuruteraan Mekanikal |
| HS-Co | - | High Speed Coated |
| HSS | - | High Speed Steel |
| ISO | - | International Organization for Standardization |
| IPM | - | Inches per Minute |
| MRR | - | Material Removal Rate |
| NDT | - | Nondestructive Testing |
| PC | - | Personal Computer |
| RBFN | - | Radial Basis Function Network |
| RPM | - | Revolution per Minute |
| SFM | - | Surface Feet per Minute |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT BACKGROUND

The development of manufacturing have been acknowledge and well developed with the race of time. Manufacturing started with act of commercializing product in market with a high volume of product created. To fulfill the demand of market, conventional machines have been developed throughout the years. One of these so call machines is milling machine, lathe machine and etc. today’s leading manufacturing and companies compete on the basis of time, product cost, quality and quantity. Therefore, machine such as milling machine are beneficial asset as the manufacturing process become easier and effective.

A milling machine is a machine tool used for the complex shaping of material and other solid materials. Its basic form is that of a rotating cutter or endmill which rotates about the spindle axis, and a movable table to which the workpiece is affixed. That is to say the cutting tool generally remains stationary (except for its rotation) while the workpiece moves to accomplish the cutting action.

The milling process is most efficient if the material removal rate is large as possible, while maintaining a high quality level. But, the material removal rate is often limited due to tool wear and failure. These will effect the condition of the tool thus bring lots of problem in productivity, quality, also the economical aspect in machining process. To verify this problem we need to consider the improvement of the tool long term usage which is it life that able to withstand higher fatigue, wear and so on. The tool life improvement is very crucial factor in the manufacturing that needs to have lots of study on to development of new research of the tool itself.

This project are focusing on how to improve the tool life in milling machine through a method using artificial neural network ANN call Radial Basis Function Network. The project is related the practical and theoretical evaluation onto the wear that occur to the tool mainly for flank wear and the crater wear data analysis base on the revision on the subject related to this approach.

## 1.2 PROBLEM STATEMENT

Milling machine process is base on a rotating cutter that removes material while travelling along various axes with respect to the workpiece that produce waste call chips. Lots of various shapes can be machining by milling machine and it is one of the most common machining processes that capable of economically producing a variety of shape on workpieces.

The process is similar to other machining process such as turning, drilling, and boring, but most of the other latter process is need to utilize multitooth tools and cutter axes with respect to the shape of the product design. Most of it process is on the cutting tools that subjected to high localized stresses at the tip of the tool, high temperature, sliding chip on the rake face, and sliding of the tool on the surface.

The other factor is workpiece material microstructure all these conditions induce tool wear that will adversely affect tool life. To find a good solution to this factor a development of new research has been made to cope with the economically aspect to reduce tool change and it cost, one of it is to improve the tool life using Radial Basis Function Network method. This method is providing the user to gain specific information about the characteristic of the whole structure of a certain suface on the tool material.

## 1.3 PROJECT OBJECTIVES

The objective of this project is:

a) To understand the behavior of the tool life under the maximum machining process.
b) To optimized the tool life in the milling machine using HSS T6061 tool.
c) Generated knowledge toward the practical lesson and applying the theoretical aspect.

## 1.4 PROJECT SCOPE

a) Tool life analysis on flank wear using IM 1700 microscope
b) Analyzing the method involved to opyimize the tool life
c) Conduct an experiment for machining using milling machine (CNC or conventional milling)

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

The tool life criterion to be used is a basic problem in tool condition monitoring. On-line tool condition monitoring is important to prevent workpieces and tools from damage, and to increase the effective machining time of a machine tool. After Taylor published his famous tool-life equation, numerous techniques and methods of monitoring tool wear have been developed over the years.1 Figure 1 shows the state of tool wear characterized by flank wear, crater wear, nose wear and outer diameter groove. These types of wear, flank wear and crater wear have a dominant influence on the tool life. Depending upon the machining conditions, one of the two types of wear may dominate over the other.

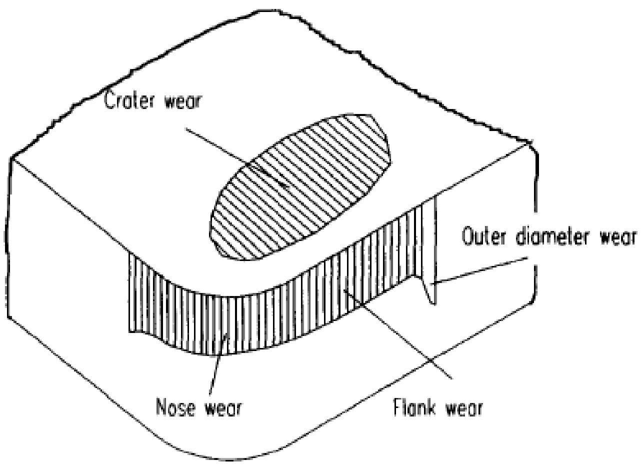



**Figure 2.1** Wear characteristic

Generally, the flank wear develops under almost any cutting conditions and its development usually includes three stages. The first stage is a rapid initial wear stage in which the wear develops rapidly to a certain point, within a relatively short time. In the second stage, the wear progresses linearly for a comparatively longer period of time. Most of the useful tool life lies within this stage. The last stage is a rapid, accelerated wearing period. In this stage, the wear rate increases rapidly and it is usually recommended that the tool be replaced before this stage. Flank wear phenomena predominate under low cutting speeds (low cutting temperatures), whereas at high cutting speeds or high feed rates, crater wear is usually more significant. The crater wear is manifested in the form of a dish-shaped hollow on the tool face. The development of crater wear is closely related to the cutting temperature and pressure. The maximum crater depth is generally at a substantial distance from the cutting edge, where the cutting temperature and pressure are high. The crater curvature corresponds to radius of curvature of the chip (the removed workpiece material).

In general, as the crater grows, it will eventually intersect the wear land. 1 Thus, as wear progresses, the general tool geometry can vary considerably. There are many tool-life criteria that depend on various considerations. Basically these criteria can be defined by tool failure (including fracture or chipping, accelerated wear and tool softening), workpiece dimensional tolerance, surface finishing degradation and economic considerations. 2 Under normal machining conditions the flank wear is usually chosen as the basis for tool life criterion. One of the main reasons is that the mechanisms of tool wear have a complex relationship with the properties of the materials of the cutting tool and the workpiece, as well as the variation in cutting conditions.

In a manufacturing system, in order to improve machining efficiency, it is necessary to select the most appropriate from a collection of cutting tools, each with their own history of use. At the time of making this selection, one of the most important tasks is to estimate as accurately as possible the rest of life under given cutting conditions. A multitude of tool information, such as tool wear and cutting force, is proposed to predict tool life. But the applicability of each piece of information in itself is limited to the particular situation for which it was devised. Therefore, a monitoring system processing such information does not always estimate the grade of machinability and/or state of the cutting tool accurately. This is due to the complexity of the cutting process. Tool life is affected by the tool materials, cutting conditions and work materials involved, and depend on the machine tool used. Thus, the prediction of tool life is a kind of ill-structured problem.

## 2.2 MILLING MACHINE

A milling machine is a machine tool used to machine solid materials. Milling machines are often classed in two basic forms, horizontal and vertical, which refer to the orientation of the main spindle. Both types range in size from small, bench-mounted devices to room-sized machines. Unlike a drill press, which holds the workpiece stationary as the drill moves axially to penetrate the material, milling machines move the workpiece radially against the rotating milling cutter, which cuts on its sides as well as its tip. Workpiece and cutter movement are precisely controlled to less than 0.001 in (0.025 mm).


**Figure 2.2** CNC milling machine

Milling machines may be manually operated, mechanically automated, or digitally automated via computer numerical control (CNC). Milling machines can perform a vast number of operations, from simple (e.g., slot and keyway cutting, planning, drilling) to complex (e.g., contouring, die sinking). Cutting fluid is often pumped to the cutting site to cool and lubricate the cut and to wash away the resulting swarf. For CNC milling machine there is a 3 axes which is X, Y, and Z axis for the cutting direction as shown in the figure 2.2.

Refer to figure 2.3 the milling machine that had been use is Fanuc RoboDrill T14i which is has a high performance, compact machine center focused on reliability and speed. At over 1.5G and 2,125 IPM, these compact machines make quick work of any milling, drilling or tapping jobs. Reliability has also been addressed with less than 4 moving parts in its tool changer.


| FANUC ROBODRILL T14IA BASIC SPEC | |
|---|---|
| Machine Type : | VERTICAL |
| Control : | Fanuc |
| Number of Axes : | 3 |
| X Axis Travel : | 500 mm |
| Y Axis Travel : | 380 mm |
| Z Axis Travel : | 300 mm |
| Tool Stations : | 14 |
| Spindles : | 1 |
| Motor Power : | 0 kw |
| Spindle Speed : | 8000 rpm |
| Extra Functions : | None |

**Figure 2.3** The specification of the Fanuc Robodrill T14i

### 2.2.1 End Milling

In a milling operation, the workpiece is moved around the stationary cutting tool, the tool is moved across the stationary material, or some combination of the two. In any case, material is removed from the workpiece by the rotating tool. The tool is mounted to a chuck or collet and the workpiece is held in place by some sort of vise or other workholding device such as a strap clamp. Vises are good for a horizontal hold while strap clamps are used for vertical. Vertical milling machines, in which the workpiece is moved through two horizontal axes and the cutting tool is moved vertically, are common.

Feed rate and spindle speed for a milling operation can be calculated to optimize for tool wear and surface finish, and depend on several variables, such as tool size, material, and geometry, use of coolant, workpiece material, width and depth of cut, and type of milling operation. Cutting tool manufactures typically supply such information along with the cutting tools.

New cutting geometries as well as coatings are constantly being developed to increase the cutting speed as well as improve surface finish on all types of materials. Programming software is changing the way features are machined into parts. The types of features which used to require a specially ground form tool are now being created using new surfacing and multi-axis technology. However, in some instances it is more cost effective to have a form tool made for large production runs.

### 2.2.2 Cutting Tool

The two basic cutting tool types used in metalworking are the single-point and multi-point designs. Fundamentally, they are similar. By grouping a number of single point tools in a circular holder, the milling cutter is created. Milling is a process of generating machined surfaces by progressively removing a predetermined amount of material from the workpiece, which is advanced at a relatively slow feedrate to a milling cutter rotating at a comparatively high speed. The characteristic feature of the milling process is that each milling cutter tooth removes its share of the stock in the form of small individual chips.

### 2.2.3 End-Milling Cutters

End mills can be used on vertical and horizontal milling machines for a variety of facing, slotting and profiling operations. Solid end mills are made from high-speed steel or sintered carbide see figure 2.1. Other types, such as shell end mills and fly cutters, consist of cutting tools that are bolted or otherwise fastened to adapters.

**Figure 2.4** End tools for milling machine

Solid end mills — Solid end mills have two, three, four, or more flutes and cutting edges on the end and the periphery. Two flute end mills can be fed directly along their longitudinal axis into solid material because the cutting faces on the end meet. Three and four fluted cutters with one end cutting edge that extends past the center of the cutter can also be fed directly into solid material.

Solid end mills are double or single ended, with straight or tapered shanks. The end mill can be of the stub type, with short cutting flutes, or of the extra long type for reaching into deep cavities. On end mills designed for effective cutting of aluminum, the helix angle is increased for improved shearing action and chip removal, and the flutes may be polished.

### 2.2.4 High Speed End Mill

End mills (middle row in image) are those tools which have cutting teeth at one end, as well as on the sides. The words end mill is generally used to refer to flat bottomed cutters, but also include rounded cutters (referred to as ball nosed) and radiused cutters (referred to as bull nose, or torus). They are usually made from high speed steel (HSS) or carbide, and have one or more flutes. They are the most common tool used in a vertical mill.

**Figure 2.5** 4 flute flat end mill HSS

High speed steel (HSS or HS) is a subset of tool steels, usually used in tool bits and cutting tools. It is often used in power saw blades and drill bits. It is superior to the older high carbon steel tools used extensively through the 1940s in that it can withstand higher temperatures without losing its temper (hardness). This property allows HSS to cut faster than high carbon steel, hence the name high speed steel. At room temperature, in their generally recommended heat treatment, HSS grades generally display high hardness (above HRC60) and a high abrasion resistance (generally linked to tungsten content often used in HSS) compared to common carbon and tool steels

High speed steel contains about 7% carbon, 4% chromium plus addition of tungsten, vanadium, molybdenum, and cobalt. These metals maintain their hardness at temperature up to about $600^o$, but soften rapidly at higher temperatures. These materials are suitable for cutting mild steel at speed up maximum rate of 0.8 m/s to 1.8 m/s.

## 2.3 CUTTING PARAMETER

As the milling cutter rotates, the material to be cut is fed into it, and each tooth of the cutter cuts away small chip of material. Achieving the correct size of chip is of critical importance. The size of this chip depends on several variables.

First surface cutting speed this is the speed at which each tooth cuts through the material as the tool spins. This is measured either in meters per minute in metric countries, or surface feet per minute (SFM) in America. Typical values for cutting speed are 10m/min to 60m/min for some steels, and 100m/min and 600m/min for aluminum. This should not be confused with the feed rate.

Spindle speed this is the rotation speed of the tool, and is measured in revolutions per minute (rpm). Typical values are from hundreds of rpm, up to tens of thousands of rpm, diameter of the tool (D), and then the feed rate is the speed at which the material is fed into the cutter. Typical values are from 20mm/min to 5000mm/min, Depth of cut is how deep the tool is under the surface of the material being cut (not shown on the diagram). This will be the height of the chip produced.

Typically, the depth of cut will be less than or equal to the diameter of the cutting tool. The operator needs three values: S, F and Depth when deciding how to cut a new material with a new tool. However, he will probably be given values of $V_c$ and $F_z$ from the tool manufacturer. S and F can be calculated from them:

**Table 1** Spindle Speed and Feed Rate

| Spindle Speed | Feed rate |
|---|---|
| $s = \frac{1000Vc}{\pi D}$ | $F = zSFz$ |

## 2.4 TOOL WEAR

Cutting tool is subjected to extremely severe cutting condition such as metal to metal contact with chip and work, very high stress, very high temperature, very high temperature gradients, and also the very high stress gradients that subjected to the tool surface.

Because of all above mentioned factors, the tool chip interface exhibit the type of wears found. As tool wear progresses, cutting forces increase and vibration increase. Tool tip softens and flows plastically and get blunt edge which will result in further progressing of plastic deformation from the tool tip to the interior. Cutting tool life is one of the most important economic considerations in metal cutting. Conditions giving a very short tool life will not be economical because of the low production rate. Efforts are made to understand the behavior of the tool, how it physically wears, the wear mechanisms, and form of tool failure.

### 2.4.1 Effect Of Tool Wear

Tool wear are most important factors in many machining operation especially for roughing or cutting. There are some general effects of tool wear in machining operation which is included the increased of the cutting force, the increase of the cutting temperature, poor surface finish, and decreased accuracy of finish part.

Reduction in tool wear can accomplished by using lubricants and coolants while machining. These reduce friction and temperature, thus reducing the tool wears.

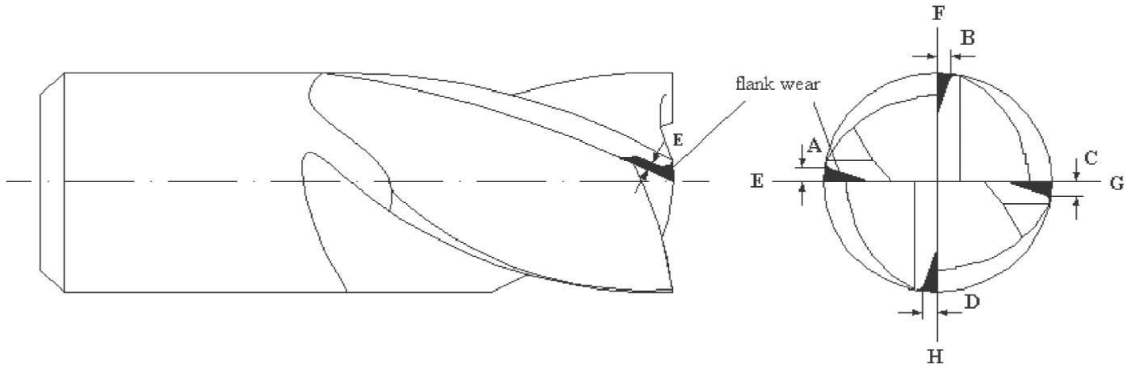



**Figure 2.6** Features of the flank wear land on the end mill

### 2.4.2 Tool Wear and Failure

In the milling process, the end of tool life is more frequently caused by chipping, cracks and breakage of the edge_rather than regular tool wear.than in other machining processes, such as turning and drilling. This occurs because milling is an interrupted operation, where the tool edge enters and exits the workpiece several times per second. In addition, chip thickness varies while the edge penetrates the workpiece. Regular tool wear will be predominant only if the tool is tough enough to resist the mechanical and thermal shocks of the process.

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact between the chip and workpiece, under conditions of very high stress at high temperature. The situation is further aggravated (worsened) due to the existence of extreme stress and temperature gradients near the surface of the tool.

During machining, cutting tools remove material from the component to achieve the required shape, dimension and surface roughness (finish). However, wear occurrs during the cutting action, and it will ultimately result in the failure of the cutting tool. When the tool wear reaches a certain extent, the tool or active edge has to be replaced to guarantee the desired cutting action.

Flank wear of an end mill is common in a material-cutting operation, hence in this work the tool-life end-point criteria is considered on the basis of the effective cutting time to reach a particular width of flank wear.

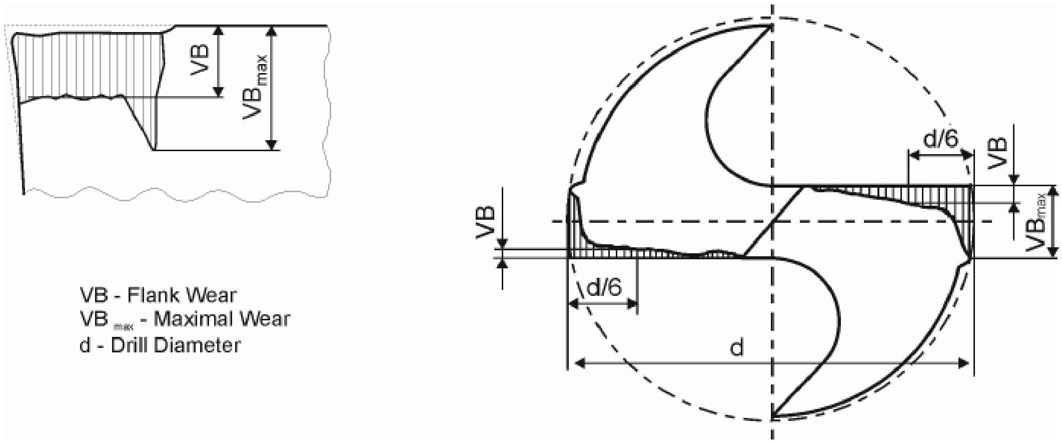



**Figure 2.7** Flank wear parameter

## 2.5 TOOL LIFE

The performance of a cutting tool is normally assessed in terms of its life. Wear criteria are usually used in assessing tool life. Mostly, flank wear is considered, since it largely affects the stability of the cutting wedge and consequently the dimensional tolerance of the machined work surface Tool life is usually defined as the period of time that tool cutting edges lose their usefulness through wear. Basically, the tool wear curve consists of three stages with different slopes, that is, an initial wear stage, a progressive wear stage, and a rapid wear stage.

It is very difficult to predict tool life in end milling with sufficient accuracy on the basis of controllable process parameters. However, on the other hand, it is an essential part of a machining system in the automated factory to change tools automatically due to wear or damage. In general, a cutting tool fails either by gradual wear or by fracturing.

### 2.5.1 Tool Life Criteria

Tool life has a relationship with a cutting speed that has it specific parameter that should be considered to apply in a wide range of materials and cutting conditions. The tool life can be expressed generally in time units from the start of a cut to some end point defined by failure criterion. The common method of forecasting tool wear is to use Taylor's equation (Frederick Winslow Taylor, 1911).

Taylor tool life equation (1):

$$VT^{c} = C \tag{1}$$

Where, T = tool lifetime, min

V = cutting speed, m/min

C = constant

n = tool life index

### 2.5.2 Tool Life Based On Volume of Work Material Cut to Failure

The tool life in terms of volume of material cut to failure, *M* can also be estimated from equation (1) provided sufficient information given. Hence for a single pass milling operation using cutting speed *V*, feed rate *f* and depth of cut *d* the tool life *M* is:

*M* = (tool life in actual cutting time to failure) × (rate of volume of workpiece cut) $M = T \times Vfd$

Tool life equation are found by expensive and time consuming tests it is not always possible to repeat the testing to obtain tool life based in different measure. The above equations are useful for relating the tool life equations based on the different measures of tool life. Assuming one equation is known fully the tool life equation for the other tool life measures can be estimated.

### 2.5.3 Tool Life Estimation Model Based On Simulated Flank Wear

This is a new model for estimating tool life based on the relationship between the flank wear progress and time. The dominating basic wears in the flank land are abrasive, adhesive, and diffusive. For that reasons the estimation of tool life should be based on these three basic wears. A direct estimation method was used for modeling the flank wear based on the volume loss due to abrasive, adhesive and diffusive wears in milling workpiece materials with higher cutting speed by using HSS cutting tool. A Matlab simulink model was developed to simulate the tool life based on the flank wear rate.

Tool life has to be estimated according to the wear rate progress on the cutting tool and the surface roughness of the work piece. (Erry Yulian T. Adesta, 2010) These two elements are affected directly or indirectly by cutting forces and cutting temperatures which are the results of machining (i.e. feed rate, depth of cut, cutting speed, cutting tool material and geometry, and work piece material). Estimating the tool life with flank wears progress can be estimated through a direct method. Fig 2.8 illustrates the estimating methods that can be used in estimating flank wear progress.

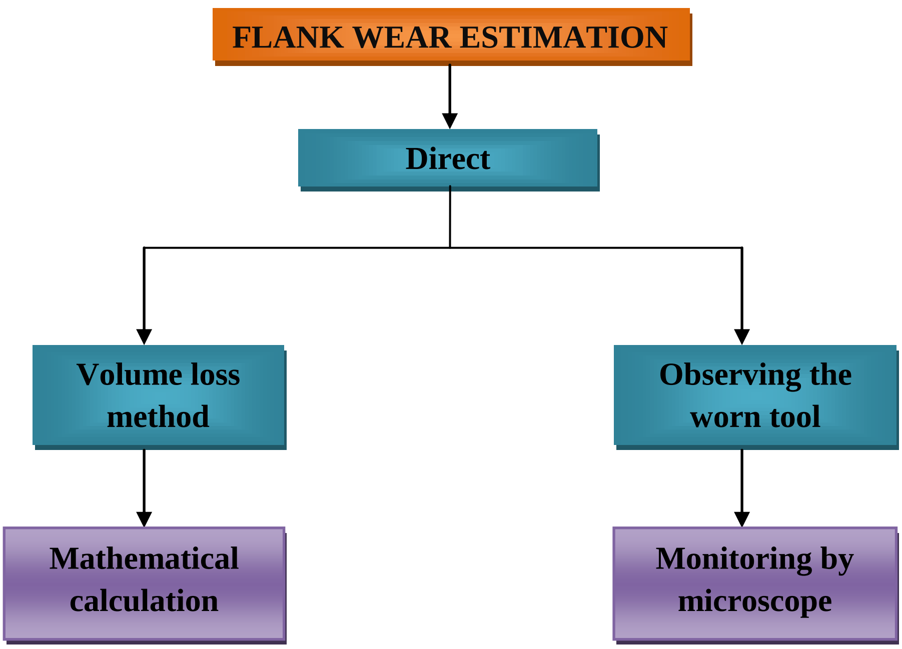



**Figure 2.8** Flank wear estimation methods

In this research the flank wear rate will be estimated based on the volume loss method due to the machining operation on the tool tip. It appears that flank wear rate in high speed steel in milling depends on following parameters that is tool material hardness, the work piece hardness, tool geometry (rake angle, nose radius, etc), and cutting condition (feed rate, depth of cut, cutting velocity).

## 2.6 ARTIFICIAL NEURAL NETWORK (ANN)

Artificial neural networks are artificial intelligence paradigms; they are machine learning tools which are loosely modelled after biological neural systems. They learn by training from past experience data and make generalization on unseen data.

Neural networks are characterized into feed forward and recurrent neural networks. Neural networks are capable of performing tasks that include pattern classification, function approximation, prediction or forecasting, clustering or categorization, time series prediction, optimization, and control.

The potential of the artificial neural networks in the field of wear and manufacturing processes are most important research for prediction and optimization. Their properties of learning and nonlinear behavior make them useful to model complex nonlinear processes, better than the analytical methods.

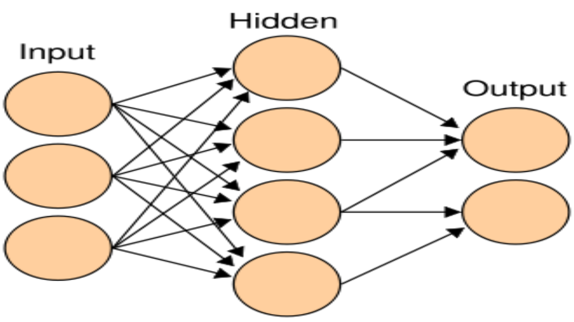



**Figure 2.9** Neural Network structure

The neural structures, considered appropriate for such models. The applications found in the referenced papers mainly consist of prediction and classification. They present some common points, specific to the field: wear processes and particles, manufacturing processes, friction parameters, faults in mechanical structures. The results obtained by the quoted authors, in their interdisciplinary research are described, proving that neural networks are a useful tool during the design stage as well as the running or operation stage.

## 2.7 RADIAL BASIS FUNCTION NETWORK

A radial basis function network is a neural network approached by viewing the design as a curve-fitting (approximation) problem in a high dimensional space. Learning is equivalent to finding a multidimensional function that provides a best fit to the training data, with the criterion for "best fit" being measured in some statistical sense.

Correspondingly, regularization is equivalent to the use of this multidimensional surface to interpolate the test data. This viewpoint is the real motivation behind the RBF method in the sense that it draws upon research work on traditional strict interpolations in a multidimensional space. In a neural network, the hidden units form a set of "functions" that compose a random "basis" for the input patterns (vectors).

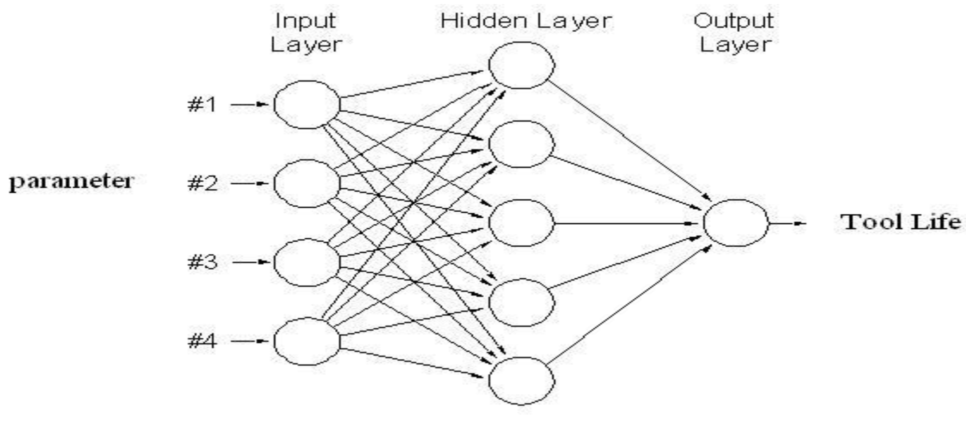



**Figure 2.10** The structure of the function in the radial basis function

These functions are called radial basis functions. Radial basis functions were first introduced by (Powell) to solve the real multivariate interpolation problem. This problem is currently one of the principal fields of research in numerical analysis. In the field of neural networks, radial basis functions were first used by (Broomhead and Lowe). Other major contributions to the theory, design, and applications of RBFNs can be found in papers by (Moody and Darken, Renals, and Poggio and Girosi). The paper by (Poggio and Girosi) explains the use of regularization theory applied to this class of neural networks as a method for improved generalization to new data.

The design of a RBFN in its most basic form consists of three separate layers. The input layer is the set of source nodes (sensory units). The second layer is a hidden layer of high dimension. The output layer gives the response of the network to the activation patterns applied to the input layer. The transformation from the input space to the hidden-unit space is nonlinear. On the other hand, the transformation from the hidden space to the output space is linear.

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

This chapter will describe about the overall process of methodology in this project from beginning until end of the project. There are four main processes that start with experimental, collecting the data, result analysis and confirmation test. All the processes will be described in this chapter by following the chart. During this part, every information and data will be gathered together and concluded according to the objectives and scope of the project.

The method are basically refers to the design of experiment (DOE) methodology and the procedure. The DOE is not a simple step process since it requires many procedure and steps to follow. Actually, a series which must follow certain sequence for the experiment to yield an improve understanding of the outcome or product.

## 3.2 PROJECT DESIGN PROCEDURE

In this project, main goal is to study the general characteristics of tool wear, understand the causes of tool wear and understand the meaning of tool-life. In order to develop this study, a design of experiment need to carry out, so the knowledge about tool life can be generated through the whole project. Before running the experiment all apparatus and the machining must go on a research. This is an important act on how the experiment should be taken and provides enough information about any related fact and procedure for develop the whole experiment.

The procedure taken is base on step by step process which is gather enough data on what the research main focus and the task that need to elaborated. In this experiment the workpiece is a (100mm x 100mm x 100mm) aluminum alloy T-6061 that has been selected from the FKM material lab. The workpiece cut into the dimension required using Bendsaw. Then for the machining process the milling machine is using Fanuc RoboDrill T14i that requires the machining guideline to operate the machine. Next task should be taken are base from below procedure:

1. Machining parameters
2. Machining procedure
3. Tools involve
4. Generate machining coding(G code)
5. Graphical analyzing of the tool
6. Gathering the data(flank wear)
7. Interprets the data using graph and software

## 3.3 MACHINING PARAMETER

The machining parameter and material properties must be generate to obtain the suitable value required when running the experiment. The Physical Properties for aluminum alloy T-6061 is Density: 2.7 g/cm$^3$, Melting Point: Approx 580°C, Modulus of Elasticity: 70-80 GPa. The machining parameter for RoboDrill is RPM is 3600 rev/min, feed rate is 1440mm/min and the depth of cut is 2mm.

### 3.3.1 Spindle Speeds

The spindle speeds may be calculated for all machining operations once the SFM or MPM is known. In most cases we are dealing with a cylindrical object such as a milling cutter or a workpiece turning in a lathe so we need to determine the speed at the periphery of this round object. This speed at the periphery (of a point on the circumference, moving past a stationary point) will depend on the rotational speed (RPM) and diameter of the object.

$$RPM = \frac{Speed}{Circumference} = \frac{Speed}{\pi \times Diameter}$$

### 3.3.2 Feed Rate

Feed rate is the velocity at which the cutter is fed, that is, advanced against the workpiece. It is expressed in units of distance per revolution for turning and boring (typically inches per revolution [ipr] or millimeters per revolution). It can be expressed thus for milling also, but it is often expressed in units of distance per time for milling (typically inches per minute [ipm] or millimeters per minute), with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth.

### 3.3.3 Depth of Cut

Cutting speed and feed rate come together with depth of cut to determine the material removal rate, which is the volume of workpiece material (metal, wood, plastic, etc.) that can be removed per time unit.

## 3.4 MILLING MACHINE

The type of milling machine that will be use in my project is Fanuc RoboDrill milling machine. CNC machine is most suitable to use in this project instead of using the conventional because the parameter can be set into a program create into the coding. Figure 3.1 show the Fanuc RoboDrill machine:


**Figure 3.1** Fanuc RoboDrill T14i

## 3.5 DESIGN OF EXPERIMENT

In identifying the effects of machining parameters to the tool wear in milling process, the Design of Experiment (DOE) is applicable to determine the possible effect of the variable during machining. This method also can be developed for experiment a ranges from uncontrollable factor, which will be introduced randomly to carefully controlled parameters. The factor consists of quantitative and qualitative. The range of value for quantitative factor must be decide on how they are going to be measured and the level at which they will controlled during this experiment. In the meantime, the qualitative factors are parameter that will be determined unconnectedly.

This method has found to be applied in many orders activities, where new products are produced and the some improvement in a production. Some application of experimental design in engineering are comprise the evaluation of basic design parameter, hence the product will work under a wide variety of machining conditions and finally is determination of the solution of design parameters that effect performance.

### 3.5.1 Variables

Machining parameters and machining characteristics are the group of variables that are going to study. Machining parameters are the classified as the data or measurable quantity that belongs to such machines involve for this experimental study. Machining parameters are grouped into two types of variables which are dependent and independent variables. During this experimental study, the independent variables will be depth of cut and table of speed. The dependent variable will be the tool wear which is considered as tool life.

**Figure 3.2** Flat endmill Tool with 4 flutes

### 3.5.2 Preliminary Finding of Research

The machining process of the milling machine using Fanuc RoboDrill is using 16mm HS-Co flat end mill with 4 flute cut the surface of the workpiece each run with depth of cut 2mm on the whole surface of the workpiece. The cutter cut a smooth direction on the X-Y axis and every cut produce one layer and until finish approximate 6 layers for every 2mm depth of cut.

Cutting process is carried out by an automatic machining operation on the Fanuc RoboDrill milling machine. The operation is been handle with caution from any accident while running the experiment. all the setup need to be double check if there have any error occur in the simulation (figure 4.2) and if all the parameter and coordinate also the coding are clear to be execute then the experiment will proceed automatically. After each run the tool then need to be examine to the material laboratory by using the microscope.

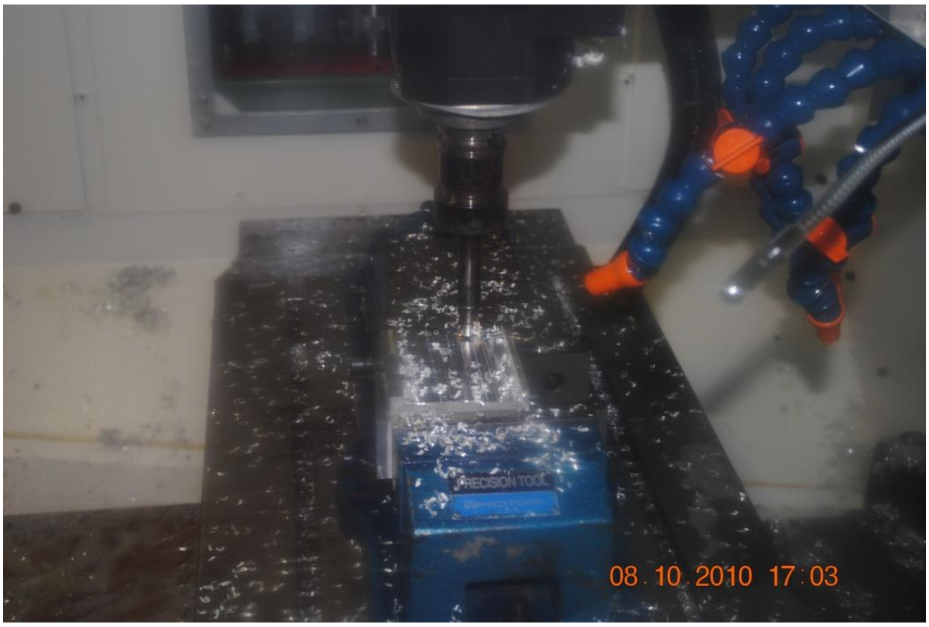



**Figure 3.3** Cutting process on the workpiece

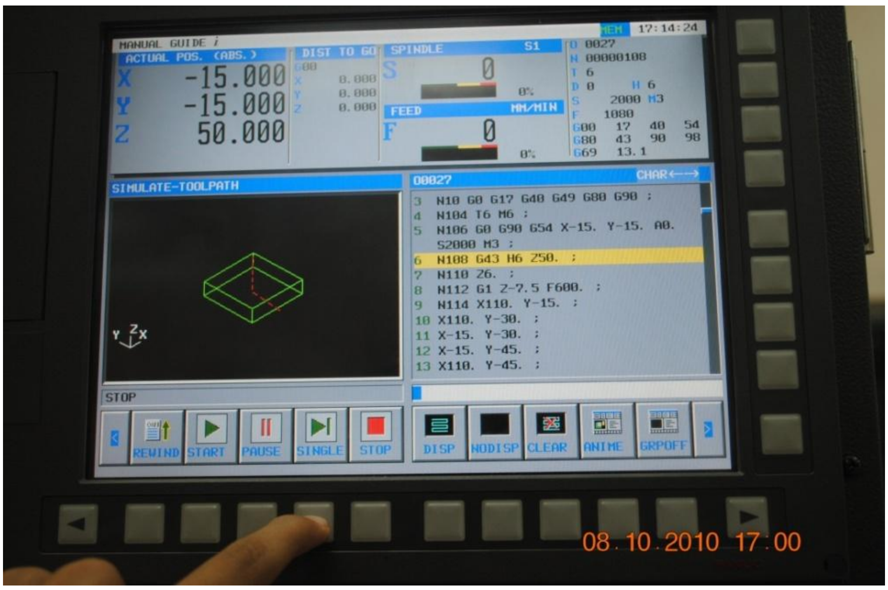



**Figure 3.4** Program coding Simulation

Program coding is an important part in the machining process especially in a milling machine that is using computerized system such as CNC system. To perform the cutting the coding need to be generated according to the experiment design operation. Figure 3.3 above is the coding to perform the cutting as shown in the figure 3.4.

## 3.6 EXPERIMENT SETUP

The overall condition of the experiment is mainly done on the milling machine using the appropriate setup. In this case the whole procedure need to be understand before designing the experiment setup shown in the figure 3.5. The objective is to gain the ability to analyze and solve of a problem in running an experiment.

Setup of this experiment is arranged with a suitable procedure, the setup is done on the milling machines which need to set the coding base on the experiment design. The coding then analyze by the CNC operator to convert it into a signal that read by the main spindle. The cutting process is followed the zigzag path start from the left to right at the X- axis and then move in front at the Y- axis to continued the whole cutting repeatedly.

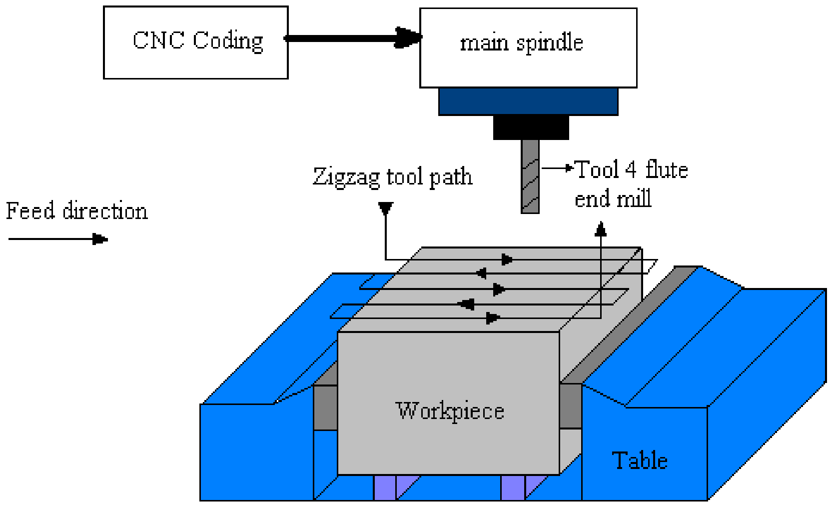



**Figure 3.5** A schematic of the experimental setup of high-speed cutting


**Figure 3.6** Aluminum Alloy T-6061 workpiece on the clamping devise

## 3.7 EXPERIMENT ANALYSIS

**Figure 3.7** IM1700 Inverted Metallograph

The IM1700 delivers an excellent performance-to-cost ratio because it has the features and versatility that one would expect to find in more expensive instruments. The IM1700 has an integrated front mounted camera port with adapters available for 35mm, CCD, CMOS and other cameras. The binocular model, the IM1700, incorporates the MA814 Siedentopf-type binocular head while the trinocular model, the IM1700 has the MA816/10 Siedentopf-type trinocular head. The MA816/10 uses an 80/20 beamsplitter that can be engaged for photomicroscopy. Each microscope head has the eyetubes inclined at 30 degrees with the left eyetube having graduated diopter settings. The interpupillary distance on the viewing heads is adjustable between 53mm - 75mm.

IM1700 Inverted Metallograph microscopes in FKM material Lab as in figure 3.2 below are the most efficient apparatus that need to be operate under the supervise by the trainer. Any error or mistake could cause lot of damage to the apparatus. The microscope is using four difference magnification lenses from 10x, 20x, 50x, and 100x lens. The specimen is place on the sliding table that clamps to hold it in a place.

**Figure 3.8** IM1700 Inverted Metallograph microscopes in FKM material Lab

## 3.8 DATA ANALYSIS

Response surface method was carried out to find the dependent variables that effect the machining parameter and machining characteristics by using Minitab software.  The software will then calculate the relations of two factors to response supported by.

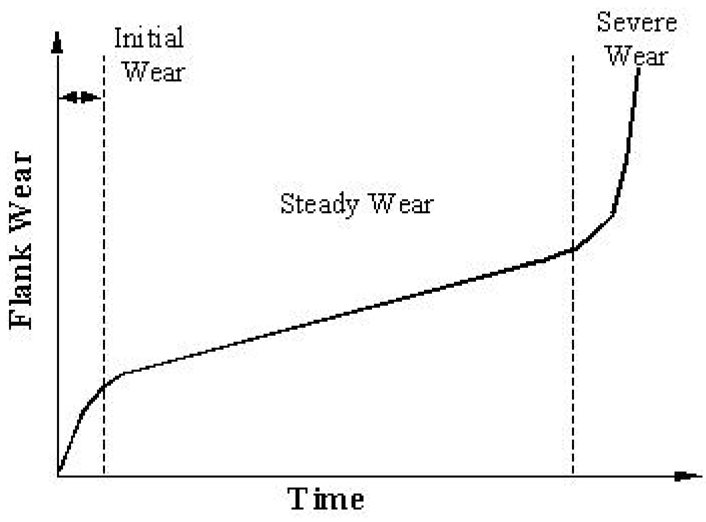



**Figure 3.9** Flank Wear Vs Machining Time

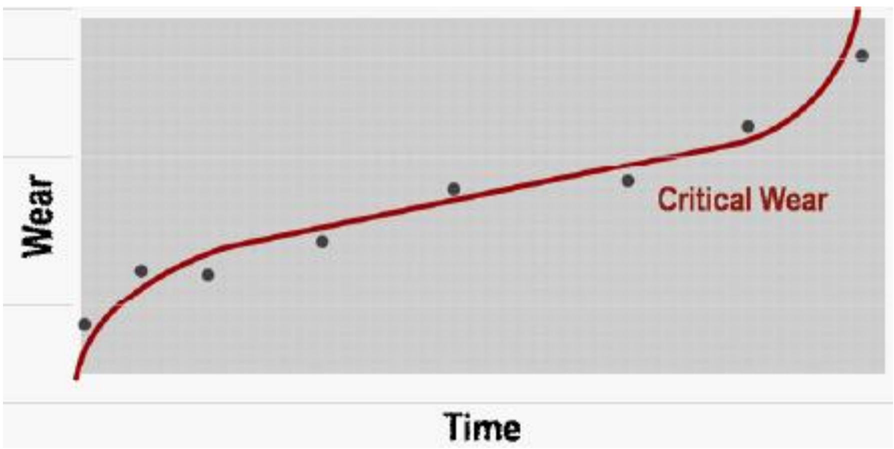



**Figure 3.10** Wear Vs Machining Time

The analysis of the wear toward the time taken for the tool to failure is conducted on how it produces the typical data about the wear. Then the analysis plot into a graph to compare the result between the flank and the time itself. It will show the pattern of what is happen to the wear if the time of cutting operation is increase. From fig 3.9 and 3.10 the graph show the curve of the relationship between wear and time. From that the critical value of wear can be generated and the pattern shown the life time of any cutting tool in a certain machining process.

## 3.9 CONCLUSION

The DOE is not a simple step process since it requires many procedure and steps to follow. Actually, a series which must follow certain sequence for the experiment to yield an improve understanding of the outcome or product. In this experiment everything need to be aware in term of a good procedure while doing the right operation to make sure the process is running on the right track. These are very crucial for the next step toward the excellent project.

# CHAPTER 4

# RESULT AND DISCUSION

## 4.1 INTRODUCTION

This chapter presents about the final results of temperature value obtained from the previous experiments. The process involved in attaining those results has been discussed thoroughly by the prior chapter. The objective of this chapter is to determine the significant factor and non-significant factor among the machining parameters using the analysis of variance. From those analyses, stable and chatter-free combination of *spindle speed*, *feed rate* and *depth of cut* can be identified. With these main finding, it is possible for machinists and engineers to use as a guideline which result in maximum chatter-free material removal rate (MRR). The outcome of this research will be discussed in detail by the next topic.

## 4.2 RESULT ANALYSIS

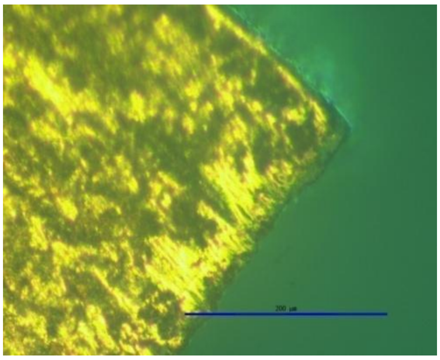
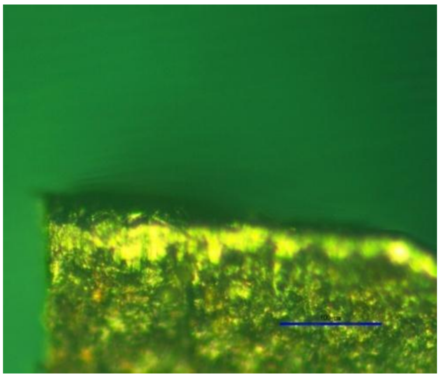
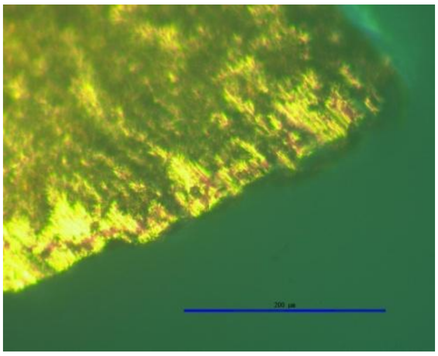
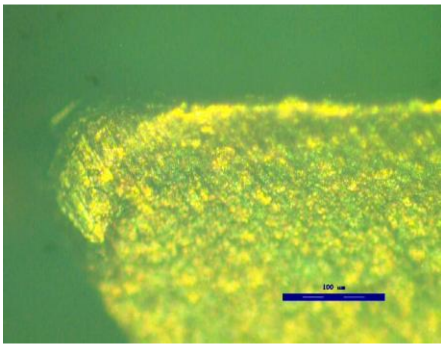
The input of the experiment is the state of crater and flank wear on the cutting tool (grade of brightness caused by surface roughness, profile and value of wear) obtained as image data, and the cutting conditions (work material, tool material, depth of cut, feed and cutting speed). The output for the associated input is an estimation of the rest of life and the wear type. It consists of a microscope, and color data control device, color image processing board, personal computer and color display.

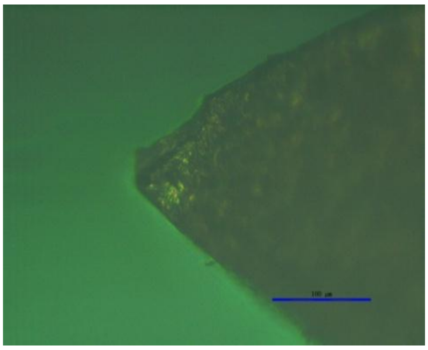
The image information on the state of tool wear is expressed by these devices. The lens and light are fixed at a position which reveals the states of flank and crater wear as clearly as possible. The grade of brightness caused by surface roughness is transmitted to the color data control device from the microscope, and is divided into 12 colors in order of brightness; White, and Cyan.

The measurement value of crater wear is represented by a ratio of its area to the display area. Tool life was judged on the basis of observations of factors such as cutting sound, form of chip, color of chip and roughness of cutting surface. From the analysis that can be made the measure of the tool life is then generated from the graph plotted between flank wear vs. time of machining and then support with a second graph which is length of cut vs. time of machining.

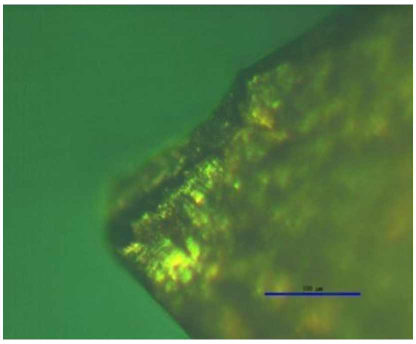
The experiments were carried out in 3 sets. Depth of cut was kept constant throughout the whole range of experiments. In the first set, velocity and feed were kept constant and the flank wear height *hf*, and the cutting force due to wear, were measured at appropriate intervals. A metallurgical microscope with a gratitude eye piece was used to measure the flank wear height. In the second set, feed was kept constant and cutting force due to wear and flank wear height, *hf*, were measured at different intervals and velocities. In the third set, velocity was kept constant and the values of cutting force due to wear *Fcf*, and flank wear height *hf* were measured for various feed values.

**Table 4.1** Microscope picture at the tip of cutting tool

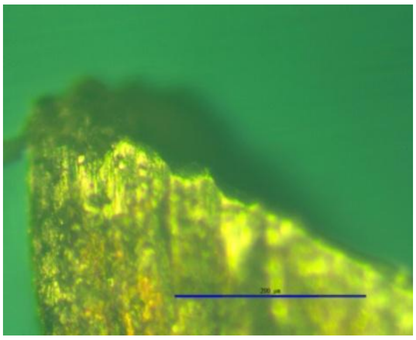
| Tool wear on the tip | Description |
|---|---|
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.2 mm/rev, axial depth of cut = 2.0 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.15 mm/rev, axial depth of cut = 1.0 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.1 mm/rev, axial depth of cut = 1.5 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed rate = 0.2 mm/rev, axial depth of cut = 2.0 mm. |



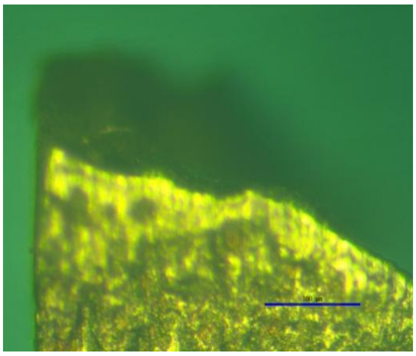
Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed rate = 0.15 mm/rev, axial depth of cut = 1.0 mm.



Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed rate = 0.1 mm/rev, axial depth of cut = 1.5 mm.

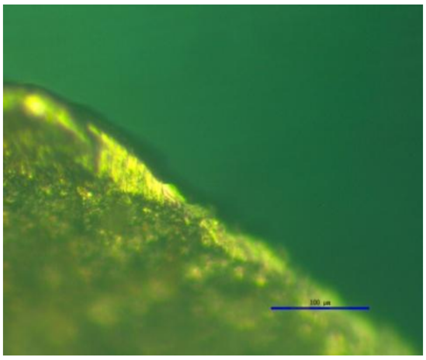
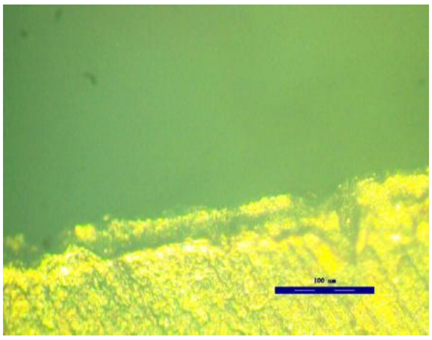
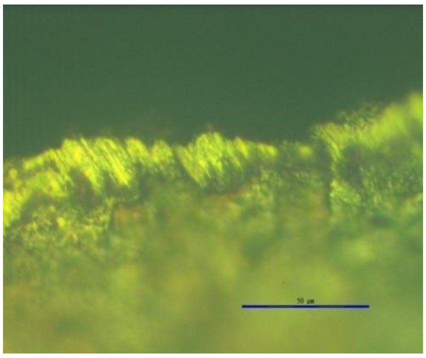
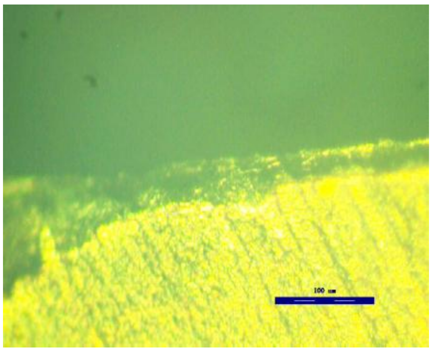


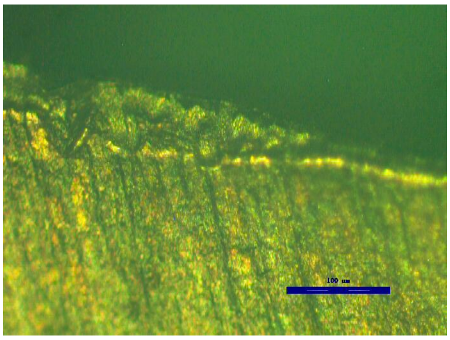
Microscope picture of cutting tool at the following conditions: cutting speed = 100 mm/min, feed rate = 0.2 mm/rev, axial depth of cut = 1.5 mm.



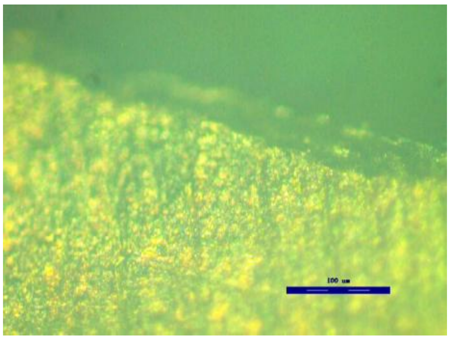
Microscope picture of cutting tool at the following conditions: cutting speed = 100 mm/min, feed rate = 0.1 mm/rev, axial depth of cut = 1.0 mm.

**Table 4.2** Microscope picture at the side of cutting tool

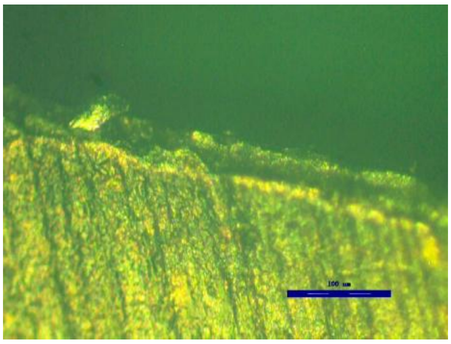
| Tool wear on the side | Description |
|---|---|
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.2 mm/rev, axial depth of cut = 2.0 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.15 mm/rev, axial depth of cut = 1.0 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 180 mm/min, feed rate = 0.1 mm/rev, axial depth of cut = 1.5 mm. |
|  | Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed ate = 0.2 mm/rev, axial depth of cut = 2.0 mm. |



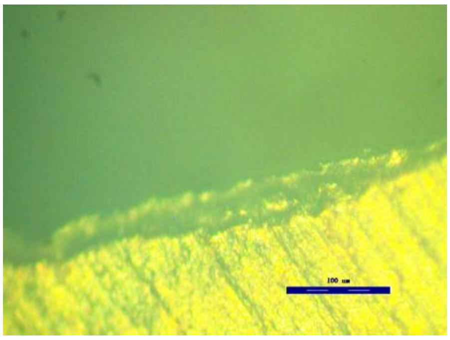
Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed rate = 0.15 mm/rev, depth of cut = 1.0 mm.



Microscope picture of cutting tool at the following conditions: cutting speed = 140 mm/min, feed rate = 0.1 mm/rev, depth of cut = 1.5 mm.



Microscope picture of cutting tool at the following conditions: cutting speed = 100 mm/min, feed rate = 0.2 mm/rev, depth of cut = 1.5 mm.



Microscope picture of cutting tool at the following conditions: cutting speed = 100 mm/min, feed rate = 0.1 mm/rev, depth of cut = 1.0 mm.

**Table 4.3** Experiment result

| flank wear, mm | times, s | volume, $mm^3$ | feed rate, mm/rev | depth of cut, mm | tool life, s |
|---|---|---|---|---|---|
| 0.045 | 45 | $16.2x10^3$ | 0.2 | 2.0 | 2916 |
| 0.055 | 95 | $12.15x10^3$ | 0.15 | 1.0 | 1731.37 |
| 0.065 | 180 | $16.2x10^3$ | 0.1 | 1.5 | 4374 |
| 0.078 | 270 | $8.10x10^3$ | 0.2 | 2.0 | 8748 |
| 0.094 | 400 | $12.15x10^3$ | 0.15 | 1.0 | 7260 |
| 0.103 | 600 | $16.2x10^3$ | 0.1 | 1.5 | 14580 |
| 0.117 | 900 | $8.10x10^3$ | 0.2 | 1.5 | 21870 |
| 0.140 | 1200 | $12.15x10^3$ | 0.1 | 1.0 | 15480 |
| 0.183 | 1500 | $12.15x10^3$ | 0.15 | 2.0 | 54675 |
| 0.218 | 1800 | $8.10x10^3$ | 0.2 | 2.0 | 54320 |

The experiment is generally focused on the flank wear at the tool side which is on the contact area of the cutting surface between the cutter tool and the workpiece. The procedure of examine the flank wear is very difficult due to lot of operation that need to be undergoes step by step to make sure the data is correct for evaluate and analyze. Twenty groups of tool wear experiments have been carried out under the 10 groups of cutting conditions shown in Table 4.1 and 4.2. A CNC milling machine that is Fanuc Robodrill T14i was used to perform the milling operation in the experiments.

From the fig. 4.1 the pattern of the graph shown a significant figure of an increasing numbers of the tool life in the unit second were at the highest peak tool life become more accurate this type of pattern happen when the values of the parameters is in the optimize state. In the other case the flank wear is higher due to the machining operation of the cutter on the workpiece is generating heat that causing the fatigue to the tool surface.

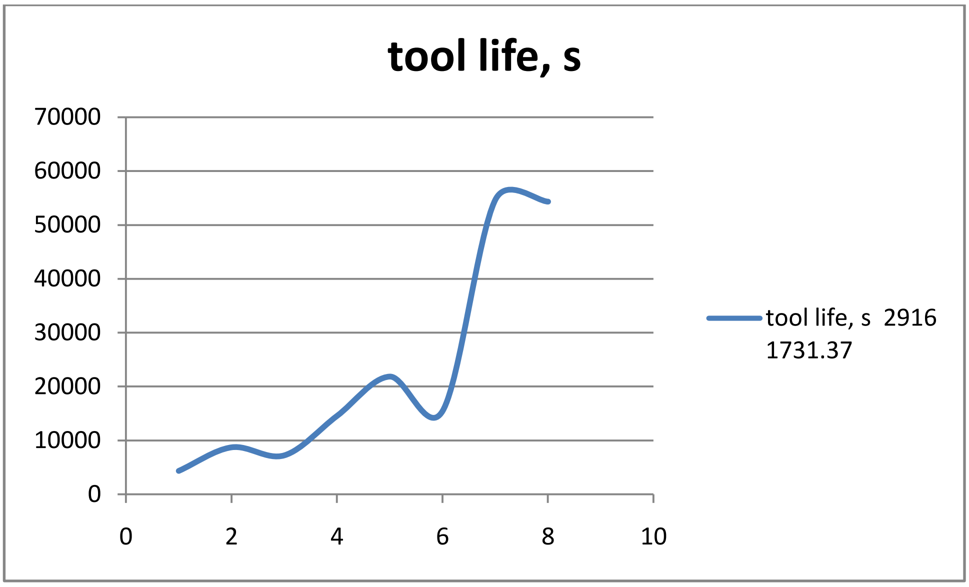



**Figure 4.1** Tool Life versus the Parameter Involve

The material of the solid cubic workpiece was Aluminum Alloy with size ~900x 900x 1000 mm. A microscope IM1700 Inverted Metallograph was used to examine the flank wear on the end mill tool with 50x magnification lens. The image then analyzes and directly collected by a computer and converted it on the computer monitor. The image of the flank wear then captured and store into a JPEG format. Flank wear and crater wear were studied on a tool-maker's microscope, respectively. Figure 4.1 show the result of a flank wear size in the JPEG format.

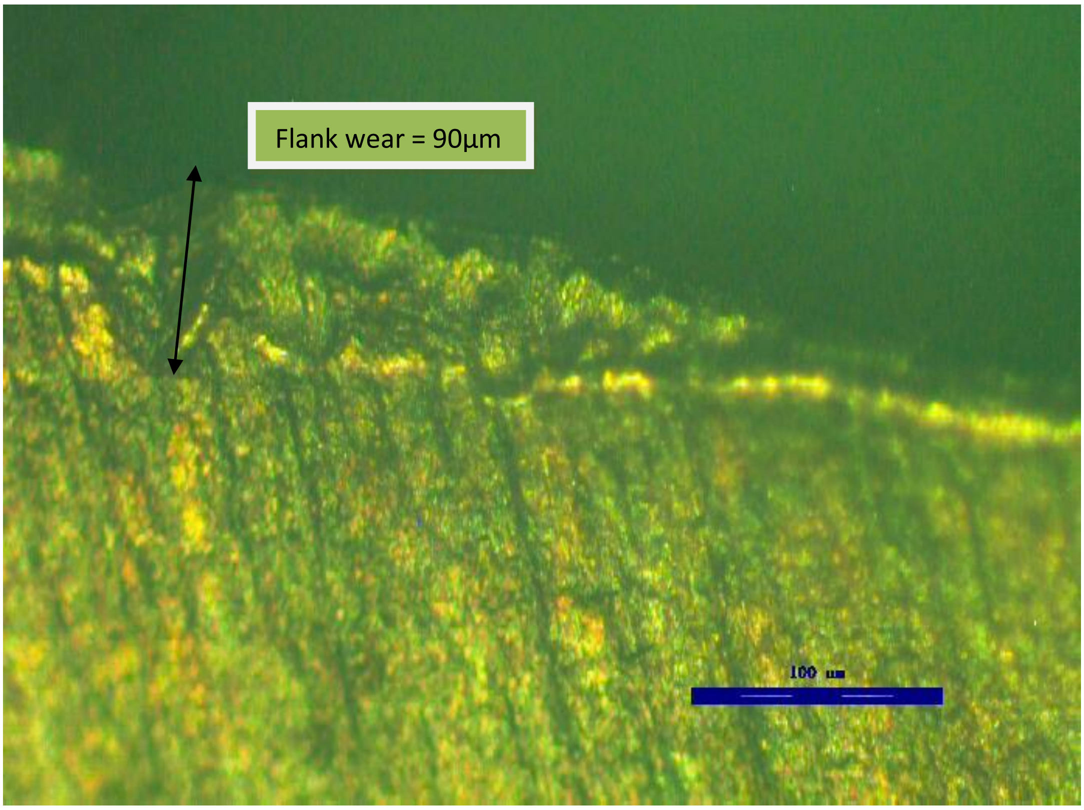



**Figure 4.2** Flank Wear Size at Magnification 100 Micrometer.

**Table 4.4** calculation from Taylor's equation

| cutting speed, mm/min | feed rate, mm/rev | depth of cut, mm | tool life, s |
|---|---|---|---|
| 180 | 0.2 | 2.0 | 3.657 |
| 140 | 0.15 | 1.5 | 4.133 |
| 100 | 0.1 | 1.0 | 4.787 |

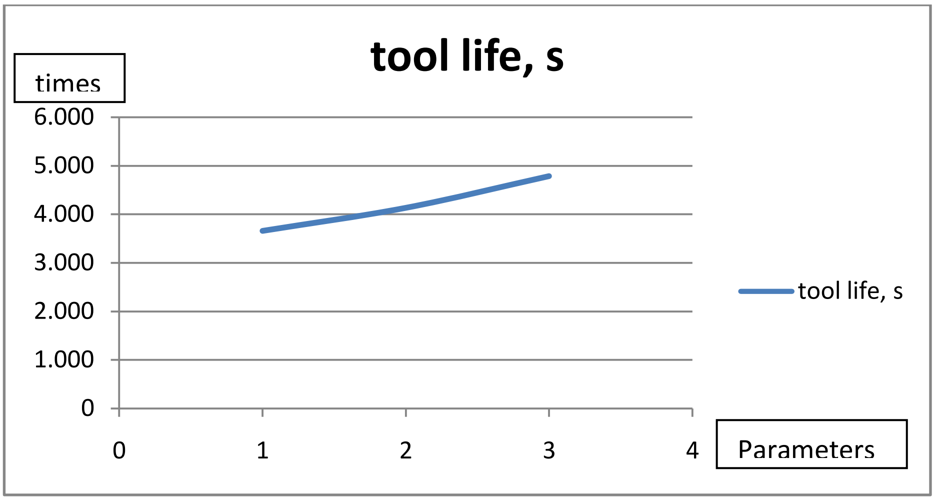



**Figure 4.3** tool life graphs for 3 different parameters.

Tool life result in Talylor's Equation have been discover to be the better factor to evaluate the life range of any tool in the wide scope of parameters. The parameters involve in this experiment are feed rate, spindle speed, and the depth of cut. For the first experiment the parameter are as shown in the table 4.4 and the result then calculated by using the Taylor's equation resulting the tool life is terms of time unit which is in second, s.

## 4.3 RESULT EVALUATION

Tool life can be predicted using lot of method but it needs to be conduct in a more conducive and friendly environment in the other word for running the experiment one must concentrate the procedure in finding the information about the tool life that must consider the parameter involve which is the main factor of the tool life itself. The experiment must have a lot of data especially for analyzing the tool life, for example the cutter tool that use in the experiment must consist at least two or more the same type of cutter in order to obtain the optimum data evaluation. Overall analysis of this experiment the conclusion that can be made is tool life can be optimize using the parameters and analyze with the software that related that is Mathlab, Statistica, and many more.

# CHAPTER 5

# CONCLUSION

## 5.1 INTRODUCTION

This chapter provides conclusion of finding for this project and summarization by of overall progress taken and discussion of the project. For future reference, some recommendations are enlisted as a topic in this chapter for enhancement of knowledge in continuing this research of tool life in end mill tool.

## 5.2 SUMMARY

At the beginning of this research, there was an uncertainty on how an optimum performance of parameter could be attained and the most suitable characteristic wear of end-mill cutters is caused by of the fact that the cutting speed is no longer the main influential factor on wear, but more likely wear is the  onsequence of the high-speed of the tool movements (feed rate), the tool is worn out when it can no longer generate a prescribed surface quality or assure required workpiece properties. Then, experimental approaches on measurement of all observed parameters, which are difficult to predict, are closely connected with the appearance of favorable wear at the tool tip of the end mill cutter.

The research continued at the beginning of the milling process the wear of the sharp edges is intensive, but after some time (e.g. 30 minutes of milling), the cutting process becomes stabilized and the surface roughness even improves. Further wear at the flank continues as usual, however it is strongly related to the wear magnitude at the centre of the mill or so called central wear.

The optimization of the cutting parameters in HSC is thus not made with respect to the maximum removal rate, but rather to the low level of the cutting forces and better surface quality. All these parameters, which are difficult to predict, are closely connected with the appearance of favorable wear at the tool tip of the end mill cutter.

## 5.3 CONCLUSION

This project is 100 % successfully completed and all of the notified objectives already been achieved which are to investigate the tool life of end milling machining via experimental. It obviously showed from the finding that, the most significant factor for the producing cutting forces in x-direction is the depth-of-cut. As for force in y-direction, significant factors are the depth-of-cut and cutting speed.

Number of flutes only influenced a lot in producing z-direction cutting force. Feed rate also gave impact in accumulating cutting forces, in term of increasing the chip formation thickness can also increase the cutting forces. From the plotted graph, it can be concluded that for the most of cutting speeds recommended, the ideal setting of depth-of-cut is at 0.6 mm. Finding also proved that the 4-flute cutter tools performed better than 2-flute for most of milling method. By applying these results in aluminum milling operation, one can even predict and avoid wear occurrence and thus, elongates the tool life span and increased the production rate with less distortion.

The characteristic wear of such tools is caused by of the fact that the cutting speed is no longer the main influential factor on wear, but more likely wear is the consequence of the high-speed of the tool movements (feed rate). In machining at high cutting speeds the tool actually slides on the workpiece surface, and the wear mechanisms are consequently different. In high-speed-cutting of hardened steel the increased speed significantly increases the temperature at the contact zone, which even exceeds the limit of the allowed thermal stability of the cutting material.

Consequently this leads to drastic reduction of the tool life. With simultaneously increasing feed rate, and speed of the deformation, the forces, heat generation and consequently the temperature at the contact zone are increased. All these processes can cause the shifting of the flank wear of the tool into crater wear, due to the higher influence of the diffusion process. Additionally, the larger cross-section of the chip causes higher cutting forces which lead more and more to the subsequent chipping of the cutting tool edges.

## 5.4 SUGGESTION FOR IMPROVEMENT

From the previous experiment, there are several suggestions that could be implanted as to improve results and obtained more accurate finding. The recommendations are as enlisted below:

1. Experiment repetitions are necessary: the data of tool wear should be taken repeatedly and plenty of experiment in order to gain a more accurate value in plotting the graph.
2. Advanced technology provides better: A CNC milling machine are much better for chatter vibration instead of a conventional milling machine as the conventional milling machine has less performance in term of poor accuracy and poor stability compared to a CNC milling machine.
3. Vary cutter tools for each experiment: the cutting tool use in the experiment should be change for each experiment as to maintain a constant performance reading and avoid tool wear which can influence the reading of the data.

## REFERENCES:

This guide is prepared based on the following references;

B. Mills, A.H. Redford, Machinability of Engineering Materials, Applied Science, London, 1983, 20.

B.V. Niebel, A.B. Draper, R.A. Wysk, Modern Manufacturing Process Engineering, McGraw-Hill, New York, 487, 1989.

C.Y.H. Lim, P.P.T. Lau, S.C. Lim, 2001, The Effects Of Work Material On Tool Wear, Elsevier, Wear 250 (2001) 344-348.

Erry Yulian T. Adesta, Muataz Al Hazza, Muhammad Riza, Delvis Agusman and Rosehan., 2010. "Tool Life Estimation Model Based on Simulated Flank Wear during High Speed Hard Turning". European Journal of Scientific Research. ISSN 1450-216X Vol.39 No.2 (2010), pp.265-278.

K. Mondalski, Study of Influence of Feed Variations on Tool Wear, J. Engng Ind. 43 (1990) 115–122.

K.V.B.S. Kalyan Kumar, S.K. Choudhury, 2007, Investigation of Tool Wear And Cutting Force In Cryogenic Machining Using Design of Experiments,Elsevier, Journal of Materials Processing Technology 203 (2008) 95-101.

K. Nagasaka, F. Hashimoto, The establishment of a tool life equation considering the amount of tool wear, Wear 81 (1982) 21–31.

M. Balazinski, E. Ennajimi, Influence of Feed Variation on Tool Wear when Milling Stainless Steel 17-4 Ph, J.Engng Ind. 116 (1984) 516–520.

M. Balazinski, V. Songmene, Tool life improvement through variable feed milling of Inconel 600, Ann. CIRP 44 (1) (1995) 55–58.

N.H. Cook, Tool Wear and Tool Life, J. Engng Ind. 95 (4) (1973) 931–937.

Pei-Lum Tso, Yan-Gang Liu, 2001, Study on Machining, Pergamon, International Journal Of Machine Tools & Manufacture 42 (2002) 331-334
Prentice Hall, p 677-697.

S.C. Lim, C.Y.H. Lim, K.S. Lee, "The effect of machining conditions on the flank wear of TiN-coated high speed steel tool inserts". Wear 181r183_1995.901–912.

S. Kalpakjian, Manufacturing Engineering and Technology, Addison- Wesley, New York, 1989.

# APPENDIX A

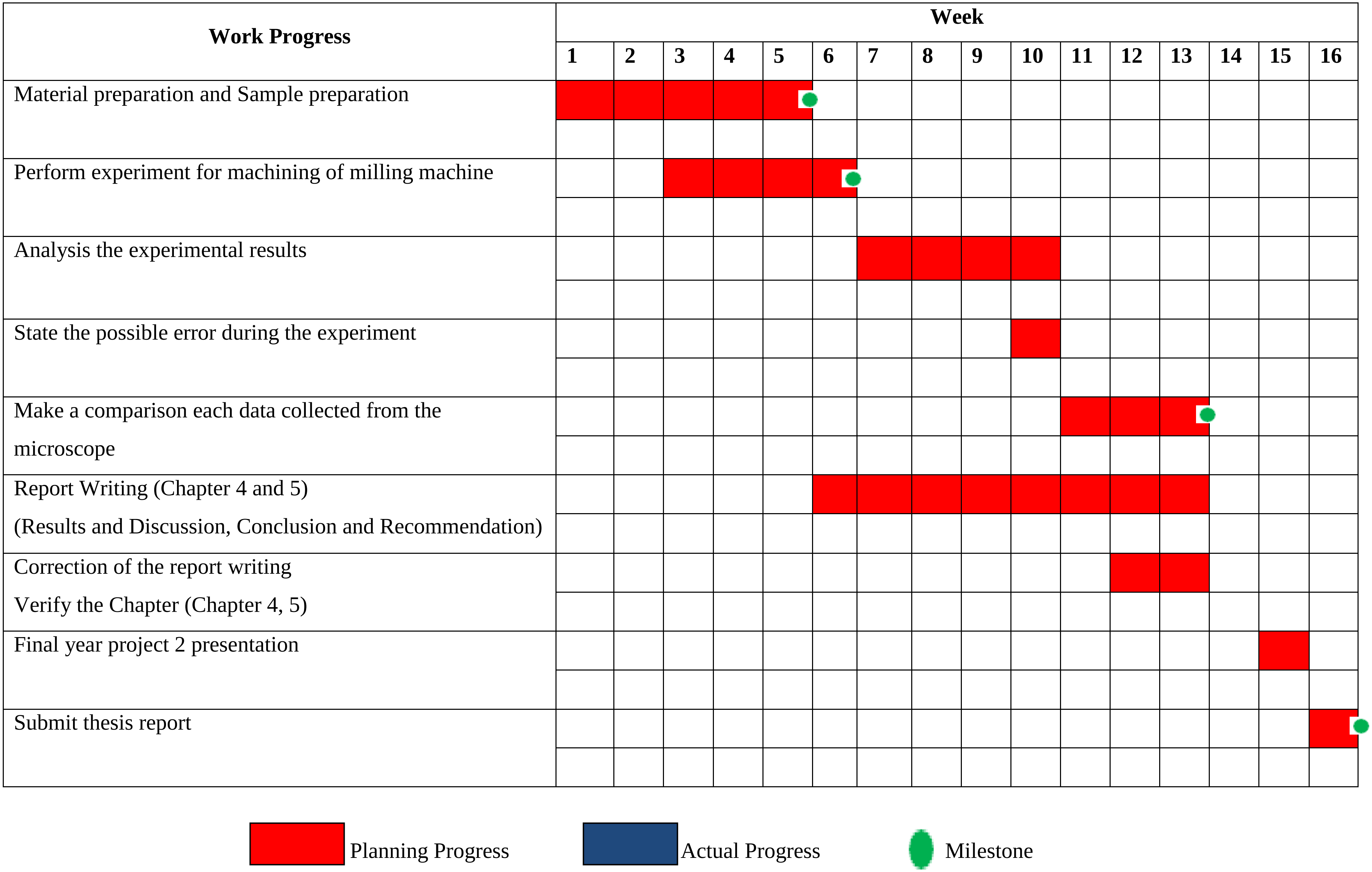
**Project Planning (Gantt chart): Final Year Project 1**

| Work Progress | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Get the project title and arrange discussion time with supervisor | | | | | | | | | | | | | | | |
| Find the problem statement and project objectives | | | | | | | | | | | | | | | |
| Find the scope of the project, hypothesis. Verify the problem statement, project objectives, scope of work and hypothesis. | | | | | | | | | | | | | | | |
| Do research and collect the information (Milling machine process, tool life, material parameter) | | | | | | | | | | | | | | | |
| Study and Learning the theory about tool life and it wear mechanisme | | | | | | | | | | | | | | | |
| Do the design of the experiment and state the experimental procedure | | | | | | | | | | | | | | | |
| Report Writing (Chapter 1, 2, 3) (Introduction, Literature review, Methodology) | | | | | | | | | | | | | | | |
| Submit draft thesis and slide presentation | | | | | | | | | | | | | | | |
| Final year project 1 presentation | | | | | | | | | | | | | | | |

Planning Progress Actual Progress Milestone

# APPENDIX B

**Project Planning (Gantt chart): Final Year Project 2**



## APPENDIX C

# FANUC ROBODRILL α-iF series

| Item | | α-T21iFsa / α-T14iFsa | α-T21iFa / α-T14iFa | α-T21iFLa / α-T14iFLa |
|---|---|---|---|---|
| Machine (Standard) | | | | |
| Capacity | X-axis travel (Longitudinal movement of table) | 300mm | 500mm | 700mm |
| | Y-axis travel (Cross movement of saddle) | 300mm + 100mm | 400mm | |
| | Z-axis travel (Vertical movement of spindle head) | 330mm | | |
| | Distance from table surface to spindle gage plane | 150 to 480mm (When no high column is specified) | | |
| Table | Working space (X-axis × Y-axis) | 630×330mm | 650×400mm | 850×410mm |
| | Capacity of workpiece mass | 200kg (uniform load) | 300kg (uniform load) | |
| | Working surface configration | 3T-slots, size 14mm pitch 125mm | | |
| Spindle | Speed range | 100～10,000min$^{-1}$ | | |
| | Spindle gage (Call number) | 7/24 taper No.30 (with air blow) | | |
| Feedrate | Rapid traverse rate | 54m/min(X,Y,Z) | | |
| | Feedrate | 1 to 30,000mm/min | | |
| Turret | Tool change system | Turret type | | |
| | Type of tooling | JIS B 6339-1998 BT30, MAS 403-1982 P30T-1(45°) | | |
| | Tool storage capacity | 21tools : α-T21iFsa/T21iFa/T21iFLa<br>14tools : α-T14iFsa/T14iFa/T14iFLa | | |
| | Maximum tool diameter | 80mm | | |
| | Maximum tool length | 200mm : α-T14iFsa<br>190mm (Changed by specifications)<br>: α-T21iFsa | 250mm (Changed by specifications) | |
| | Method of tool selection | Random shortest path | | |
| | Maximum tool mass | 2kg/tool(total mass : 23kg)/3kg/tool(total mass : 33kg): α-T21iFsa/T21iFa/T21iFLa<br>2kg/tool(total mass : 15kg)/3kg/tool(total mass : 22kg): α-T14iFsa/T14iFa/T14iFLa | | |
| | Tool changing time (Cut To Cut) | 1.4 sec. α-T14iFsa/T14iFa/T14iFLa (When 2kg/tool is specified) 1.6 sec. α-T21iFsa/T21iFa/T21iFLa (When 2kg/tool is specified) | | |
| Motors | Spindle drive motor | 11.0kW (1min rating) / 3.7kW (continuous rating) | | |
| Accuracy *1 | Bidirectional accuracy of positioning of an axis (ISO230-2:1997) | Less than 0.006mm | | |
| | Bidirectional repeatability of positioning of an axis (ISO230-2:1997) | Less than 0.004mm | | |
| Sound pressure level | | Less than 70dB *7 | | |
| Numerical control (Standard) | | | | |

**Table C- 1** Standard Specification of the Milling Machine

# APPENDIX D

| G codes | Description |
|---|---|
| G0 | rapid positioning |
| G1 | linear interpolation |
| G2 | circular/helical interpolation (clockwise) |
| G3 | circular/helical interpolation (c-clockwise) |
| G10 | coordinate system origin setting |
| G17 | xy plane selection |
| G18 | xz plane selection |
| G40 | cancel cutter diameter compensation |
| G41 | start cutter diameter compensation left |
| G42 | start cutter diameter compensation right |
| G53 | motion in machine coordinate system |
| G80 | cancel motion mode (includes canned) |
| G90 | absolute distance mode |
| G91 | incremental distance mode |

| M codes | Description |
|---|---|
| M0 | program stop |
| M1 | optional program stop |
| M2 | program end |
| M3 | turn spindle clockwise |
| M4 | turn spindle counterclockwise |
| M5 | stop spindle turning |
| M6 | tool change |
| M7 | mist coolant on |
| M8 | flood coolant on |
| M9 | mist and flood coolant off |
| M26 | enable automatic b-axis clamping |
| M27 | disable automatic b-axis clamping |
| M30 | program end, pallet shuttle, and reset |
| M48 | enable speed and feed overrides |
| M49 | disable speed and feed overrides |

**Table D-1** Machining operation codes milling machine