UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY ON WEAR RATE OF TiAlN BALL NOSE DURING MILLING INCONEL 718 UNDER FLOODED LUBRICATION

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Manufacturing Process) (Hons.)

by

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2015

DECLARATION

I hereby, declare this report entitled "STUDY ON WEAR RATE OF TiAlN BALL NOSE DURING MILLING INCONEL 718 UNDER FLOODED LUBRICATION" is the results of my own research except as cited in the reference.

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Date : 25TH JUNE 2015 ……………………………………………

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Process) (Hons.). The member of the supervisory is as follow:

………………………………

(DR. MOHD SHAHIR BIN KASIM)

ABSTRAK

Inkonel 718 merupakan aloi berasaskan nikel yang digunakan secara meluas di dalam industry aeroangkasa dan merupakan bahan yang sukar dimesin disebabkan oleh kekerasan yang tinggi dan konduksi haba yang rendah. Ini menyebabkan berlakunya perubahan bentuk mata alat semasa pemesinan Inkonel 718 yang memberi kesan kepada kadar haus mata alat. Untuk memahami keadaan ini, suatu penyelidikan telah dijalankan untuk mengkaji objektif berikut; mengkaji kesan setiap parameter permesinan terhadap kadar haus mata alat semasa pemesinan Inkonel 718 di dalam pelinciran banjir, membina model matematik bagi mengjangkakan kadar haus mata alat semasa pemesinan Inkonel 718 di dalam pelinciran banjir dan menentukan set parameter yang optimum bagi mengurangkan kadar haus mata alat semasa pemesinan Inkonel 718 di dalam pelinciran banjir. RSM digunakan untuk menganalisis hubungan antara input dan output. Sebanyak 17 eksperimen telah dijalankan. Parameter pemesinan adalah laju pemotongan, Vc (100 m/min - 140 m/min), kadar suapan, fz (0.1 mm/gigi – 0.2 mm/gigi) dan kedalaman pemotongan , a_p (0.5 mm – 1 mm). Dalam kajian ini, bebola mata alat bersalut TiAlN dengan diameter 10 mm diuji kerana kekerasanya yang meningkat sebanyak 40% berbanding mata yang tidak bersalut. Semasa oeprasi pemesinan, haus rusuk Vb_1 dan haus takuk Vb_3 diukur menggunakan mikroskop. Berdasarkan kepada hasil analisis, laju pemotongan sangat memberi kesan terhadap kadar haus mata alat semasa pemesinan Inkonel 718. Kadar haus meningkat dengan peningkatan laju pemotongan. Namun, a_p dan juga fz turut memberi kesan kepada kadar haus mata alat. Selain itu, model matematik untuk mengjangkakan kadar haus mata alat turut berjaya dibina. Akhir sekali, parameter optimum berjaya ditentukan iaitu Vc (100 m/min), fz (0.10 mm/gig) and a_p (0.81 mm). Ralat antara nilai jangkaan dari model dan nilai sebenar hanya 2.21%.

ABSTRACT

Inconel 718 is a nickel-based alloy that is widely used in the aerospace industry and prominently known as a hard to machine material due to abrasiveness, high hardness and low thermal conductivity. These characteristics contribute to the changes in the shape of the cutting tool during machining Inconel 718 material which affects the wear rate of the cutting tool itself. To understand this situation, this research is conducted to meet the following objectives; to study the effect of machining parameters on the wear rate of ball nose TiAlN during end milling of Inconel 718 under flooded lubrication, to develop a mathematical model to predict the wear rate by using Response Surface Methodology (RSM) analysis and to determine optimum process parameters to minimize the wear rate of ball nose TiAlN during end milling of Inconel 718 under flooded lubrication. RSM through Box-Behnken was used to analyze the relationship between the input and output specifications. A total of 17 experiments was conducted. The machining parameters were cutting speed,Vc, (100 m/min to 140 m/min), feed rate,fz, (0.1 mm/tooth to 0.2 mm/tooth) and depth of cut,a_p, (0.5 mm to 1.0 mm). Meanwhile, width of cut was set as a fixed parameter at 1.0 mm. In this research, TiAlN ball nose of diameter 10 mm was tested due to its hardness which increases by 40% compared to uncoated tool. During machining operation, flank wears VB_1 and notch wear VB_3 were measured by using tools maker microscope. Based on the results, it showed that the cutting speed affects the rapid wear rate. It was found that as the cutting speed increase, the wear rate will increase. Meanwhile, a_p and fz affect also significantly affect the wear rate of the tool. Besides, a mathematical model to predict the wear rate was developed. Lastly, the optimum parameter was determined which the Vc (100 m/min), fz (0.10 mm/tooth) and a_p (0.81 mm). The error between predicted wear rate using this model and actual wear rate was only 2.21%.

DEDICATION

For my beloved family:

Muhammad Rafie Empari Bin Abdullah

Salina Binti Razali

Mazlan bin Razali

Nurul Najwa Binti Muhammad Rafie Empari

Muhammad Mustaqim Bin Muhammad Rafie Empari

And

FKP’s Students

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim. With the name of Allah the most Gracious and the most Merciful.

I would like to express my utmost appreciation to my final year project supervisor **Dr. Mohd Shahir Bin Kasim** for his guidance during the whole duration of *Projek Sarjana Muda (PSM)*. The supervision and support that he gave truly help the progression and smoothness of completing my final year project. He also always gives advices and motivates me to work harder and smarter.

Besides, I would like to thank Assistant Engineer of FKP"s CNC lab, En. Mohd Hanafiah bin Mohd Isa for his help during completing my final year project.

Above all, I heartily thankful to my parents, Muhammad Rafie Empari bin Abdullah and Salina binti Razali, my siblings; Nurul Najwa and Muhammad Mustaqim and my uncle who raised me up, Mazlan bin Razali for their continuous support and encouragement. They made me agree that verily with every hardship, there is relief.

Last but not least, I would like to thank all my friends, especially Nur Hazhim, Noorhanani, Alia Najwa, Noraini, Siti Sara, Nurul Bazilah, Nurul Ermiera and 4 BMFP"s colleagues for their help and support. Also, to those who are directly or indirectly involved in completing this final year project.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

a_e - Width of cut
Al - Aluminium
ANOVA - Analysis of variance
a_p - Depth of cut
BUE - Build up edge
C - Carbon
CCD - Central composite design
CH - Chipping
CNC - Computer Numerical Control
Co - Cobalt
Co - Cobalt
Cr - Chromium
CR - Cracks
CrN - Chromium Nitride
Cu - Copper
CVD - Chemical vapour deposition
DOC - Design of Experiment
F - Force
FCC - Faced-centered cubic
Fe - Iron
f_z - Feed rate
H_0 - Null hypothesis
HSM - High speed machining
ISO - International Standard Organization
MDI - Manual Data Input
Mn - Manganese
Mo - Molybdenum
MQL - Minimum quantity lubrication

MRR - Material rate removal
Nb - Niobium
Ni - Nickel
O_2 - Oxygen
PCBN - Polycrystalline cubic boron nitride
PhD - Doctor of Philosophy
PVD - Physical vapour deposition
Ra - Surface roughness
RSM - Response Surface Methodology
Si - Silicone
T - Tool Travel
Ti - Titanium
TiAlN - Titanium Aluminium Nitride
TiN - Titanium Nitride
VB_1 - Flank wear
VB_3 - Non-uniform flank wear
Vc - Cutting speed
Vc_{eff} - Effective cutting speed
WC - Tungsten carbide
$\dot{w}$ - Wear Rate

CHAPTER 1

INTRODUCTION

1.1 Project Background

End milling is one of the materials removing process that widely used in manufacturing engineering component (Kalpakjian & Schmid, 2003). This process is one of the final processes in the production especially to produce high precision of mechanical products. In aerospace industry, the demand of complex shape, high accuracy and high better surface finish require for application of ball nose compare to other shapes of cutting tools (Alauddin, El Baradie, & Hashmi, 1995). Due to these scenarios, many researchers and as well as manufacturers conduct an ongoing research to meet the quality standards required.

Inconel 718 is one of high temperature alloy that is widely used in aerospace component, especially in producing of turbine blade. The ability of this material to withstand at elevated temperature cause to it was chosen with 50% of engine component(Krain, Sharman, & Ridgway, 2007). As a drawback, Inconel 718 is prominently well known as hard material to be machined (H. Z. Li, Zeng, & Chen, 2006). In term of machinability, Inconel is 16, 6 and 4 times more difficult than aluminium, mild steel and stainless steel respectively (E. O Ezugwu, Bonney, Fadare, & Sales, 2005).

Most of the problem arise during machining Inconel reported was flank wear, notch wear, crater wear (Jawaid, Che-Haron, & Abdullah, 1999). The increasing of these wear deteriorated cutting tool that will change cutting geometry. Moreover, the formation of build up edge (BUE) worsening cutting performance by increasing of flaking formation and notch wear (Liao & Shiue, 1996). The formation of these unpredictable problems lead to premature tool failure (Kasim et al., 2014).

The development of coating technology improves durability of cutting tool (Graham, 2008). During initial stage of study in 1980s, most of researchers used coated carbide rather than uncoated carbide (Trent & Wright, 2000). Taking advantage of development of coating technology, most of investigation done using coated carbide. Lee et al. (2009) done by using PVD, Krain et al. (2007) done using CVD and Koshy et al. (2002) using PCBN. However due to cost constrain, coated carbide was become more popular in market that contribute of 80-85% of market share (Krain, et al., 2007).

One of the strategies done to increase tool performance is by implementing high speed machining (HSM). HSM generally associated with end milling at rotational speed at 100,000 rpm (Ng, Lee, Dewes, & Aspinwall, 2000; Sharman, Dewes, & Aspinwall, 2001b). It was proven that the tool life can be prolong up to 7 min (Alauddin, et al., 1995).

The other approach is using Minimum Quantity Lubrication. It was done by Min et al. (2005) as to improve not only machined surface but also tool life. The exact comparison between MQL and conventional lubrication system however less to be reported. Kasim et al. (2013) only done involve MQL without comparing with dry and flooded cooling system. Therefore, this research was established to investigate the tool life during flooded condition and to be compared with the previous study.

1.2 Problem Statement

During the machining process, any changes in the shape of machining tool will directly influence the machining efficiency. Specifically, Inconel 718 possesses high strength, work hardening and dynamic shear strength at room and elevated temperatures (Bouzakis, Aichouh, & Efstathiou, 2003). However, due to metallurgical and mechanical characteristics leads to highly valued properties which also make them one of the most difficult to machine aerospace material (Bhatt, Attia, Vargas, & Thomson, 2010b).

It maintains high strength at temperatures typically encountered during cutting leading to high cutting forces and high temperatures in the shear zone which causes plastic deformation of the cutting tool edge (Krain, et al., 2007). Rapid tool wear in machining has long been recognised as a challenging problem in this industry (H. Z. Li, et al., 2006).

The tool will work efficiently in its original geometry. For milling process, the critical limit for tool life when the flank wears below 0.3 mm (Jawaid, Koksal, & Sharif, 2001). Normally, flank wear beyond this amount will affect cutting performance. The cutting force will increase as the tool geometry deteriorates (Ng, et al., 2000). This is mainly caused by the tool wear and fracture failures of the tool during the machining process (Childs, Maekawa, Obikawa, & Yamane, 2000). Apart from tool lifetime, the replacement cost of a worn tool (consumable cost) and time to replace a worn-out tool are important in machining economics.

Previous research by Alauddin et al. (1995) found that the tool life is not instigated. The tool life is only about 7 min at Vc = 19.32 m/min, fz = 0.091 mm/tooth, ap = 1.00mm. The result is shown in the Figure 1.1. Meanwhile Krain et al. (2007) only obtained an average of tool life7.60 min with 21, 406 mm^3 metals is removed.

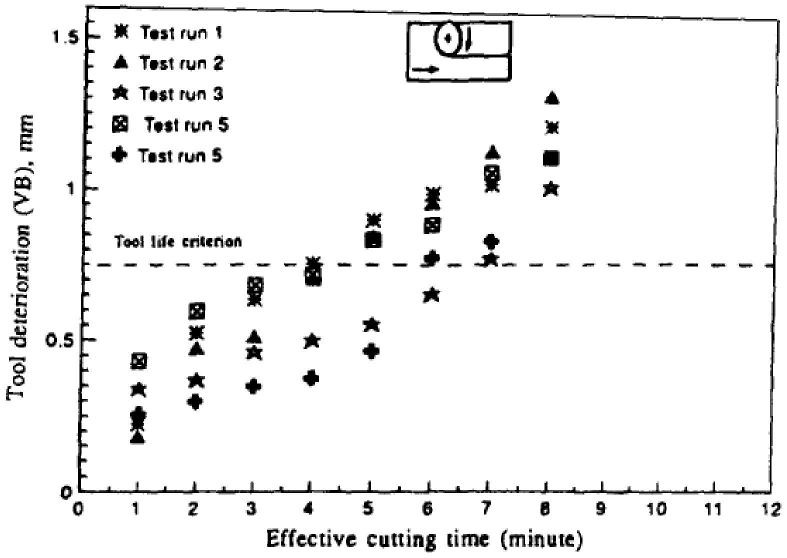

Figure 1.1: Tool Deterioration (Flank Wear) Values of End Mill (Alauddin, et al., 1995)

1.3 Objectives

During cutting operation, the changes on the shape of the cutting tool will affect the effectiveness of the cutting tool itself. To understand this scenario, a research on the workpiece and cutting parameters are required.

1. To study the effect of machining parameters on the wear rate of ball nose TiAlN during end milling of Inconel 718 under flooded lubrication.
2. To develop a mathematical model to predict wear rate by using Response Surface Methodology (RSM) analysis.
3. To determine optimum process parameters to minimize the wear rate of ball nose TiAlN during end milling of Inconel 718 under flooded lubrication.

1.4 Scope

This research will investigate the tool performance by observing wear rate of ball nose end milling. The coated carbide insert with Titanium Aluminium Nitride (TiAlN) will be used during experiment process using 3 axis CNC milling machine. The material to be used is Inconel 718. Under this research, there are 3 machining parameters that being considered namely; cutting speed (V_c), feed rate (fz) and depth of cut (a_p). Meanwhile, width of cut (a_e) is a fixed variable in this research. Response Surface Methodology (RSM) will be used as a statistical tool of design of experiment.

1.5 The Organization of Report Dissertation

This report consists of 5 chapters:

a) The first chapter describes in general about the research background and problem statement that leads to this research. Experimental objectives and scope of the research also indicated in this chapter.

b) The second chapter includes a review of previous scientific studies on machining Inconel 718. It consists of a variety failure mode and tool wear mechanisms that occur during the cutting process of this material. In addition, the application of flooded lubricant, experimental designs and data analysis, Response Surface Methodology (RSM) with Box-Behnken approach are also discussed in this chapter.

c) The third chapter describes about the methods on conducting the experiment. It includes necessary tools and experimental procedure when carry out the experiment, measurement and analysis process. All equipments that relate with this research are stated in this chapter.

d) The fourth chapter discusses in detail regarding the result obtained from the experiment regarding the tool wear. The results are shown in the form of graphs and supported by statistical data through analysis if variance (ANOVA) method. A mathematical model will be developed and compared with the results. Some of the results will be evaluated and compared with previous researcher, Kasim (2014) through his PhD thesis titled „The Performance of Coated Carbide Cutting Tool during End Milling of Inconel 718 in a Minimum Quantity Lubricant (MQL)‟. Analysis if the data regarding the tool wear is briefly discussed in this chapter.

e) The last chapter, Chapter 5, discusses the conclusion of the research and suggestions for future research.

Figure 1.2 shows the report organization for PSM I and PSM II.

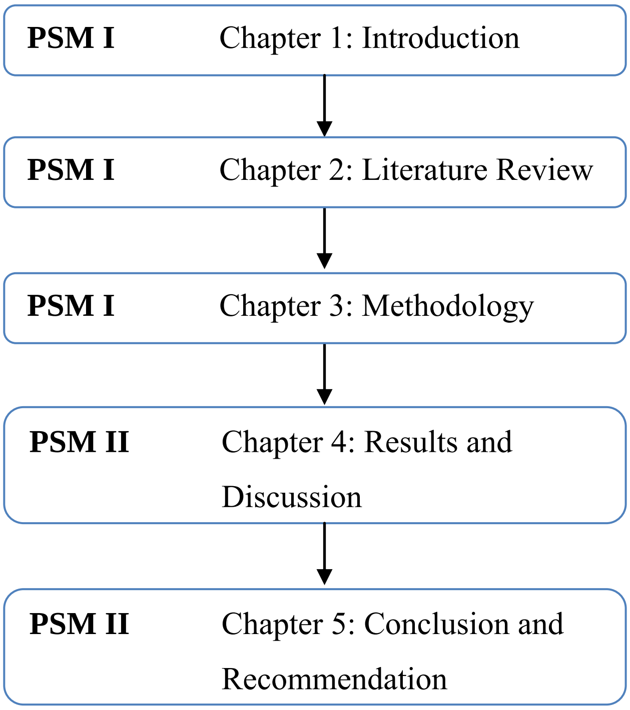

Figure 1.2: Report Organization

CHAPTER 2

LITERATURE REVIEW

This chapter discusses on the related information, previous researchers‟ findings and the current knowledge regarding this topic.

2.1 Introduction

Machining operation is the core of the manufacturing industry since the industrial revolution. Machining is a process which a raw material undergoes a material-removal process in order to get its desired shape and size by using the selected tool and machine. The manufacturers are trying to produce the maximum quantity of product through a minimum production cost and at the same time meet its quality standards (Rao, 2011).

Although the material-removal process is a technique that has been used for a long time in manufacturing process, the basic characteristics and the results of tool life, tool force, machinery and process design can only been done through researches and experimental tests (Viktor P. Astakhov, 2006b). However, these researches and experimental tests require high costs and time-consuming process. Some require the new technology equipments and experienced personnel. Therefore, the strategy and design of experiments, data acquisition and development of appropriate statistical models have been emphasized in this research. Alaudin et al. (1996a) and Rao (2011) mentioned that milling process is influenced by the input variables and output specifications. The input for machining process is independent variables and output is dependent variables. The relationship between these input and output variables is shown in the Figure 2.1.

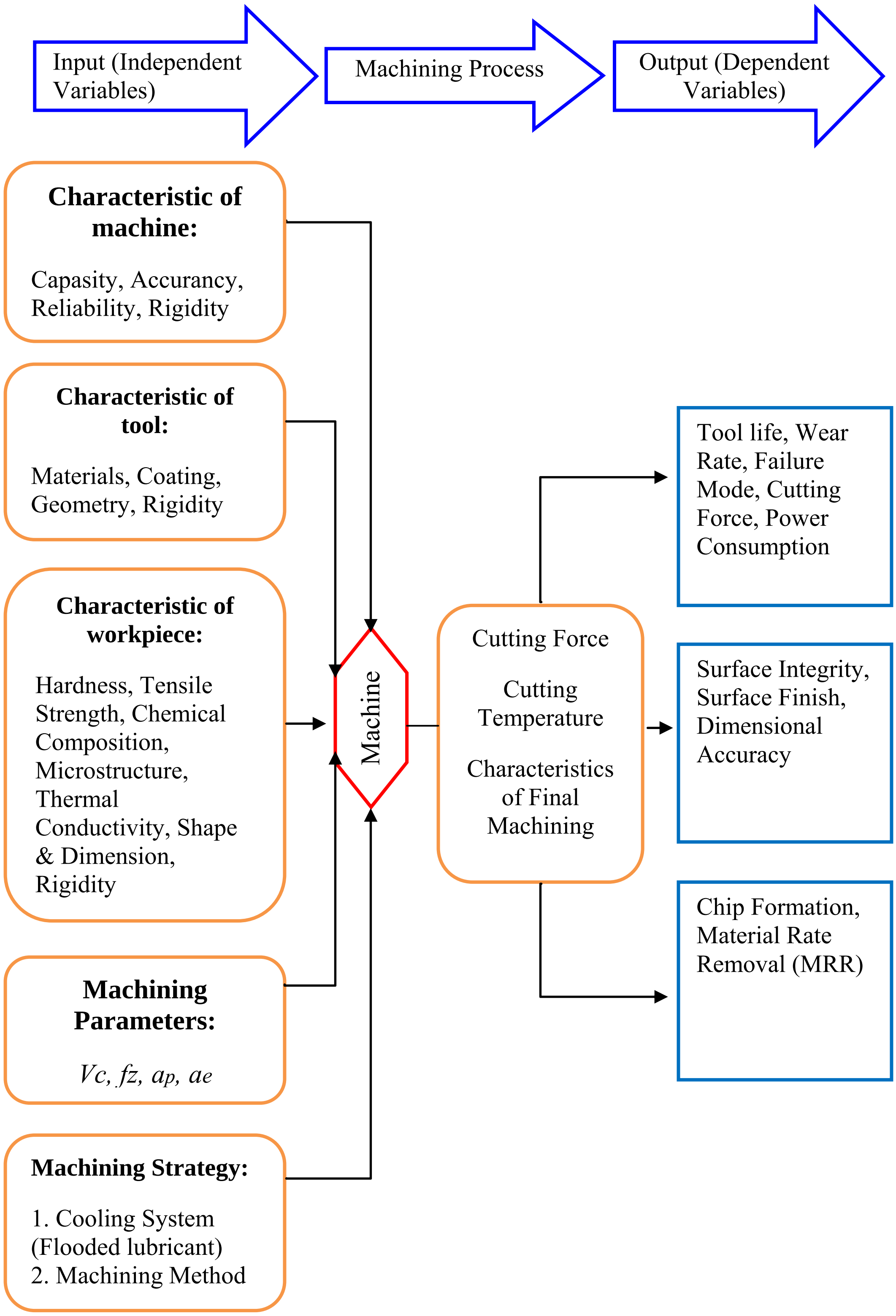

Figure 2.1: Relationship Between Independent and Dependent Variables to Machining Output (Alauddin, El Baradie, & Hashmi, 1996; Rao, 2011).

2.1.1 Fundamental of Milling Process

Milling is consider as multi tooth cutting process, the process differs with turning and grinding where the process is a single cutting tool and random cutting tool respectively (Kalpakjian & Schmid, 2003). However, some milling process uses a single cutting tool, especially for experiment purpose (Richetti, Machado, Da Silva, Ezugwu, & Bonney, 2004).

Previous researchers‟ opinions said that the cuts happened upon the formation of metallic fragments during metal-removing process. It occurs as there is plastic deformation on the workpiece caused by the opposite movement between the tool and the workpiece (Childs, et al., 2000). In addition, this metal cutting is different from the concept of cutting blade when cutting a soft material whereby a wedge-shaped tool is forced symmetrically into the material (Trent & Wright, 2000).

When the tool is in contact with the workpiece, it requires more force to overcome the opposite force from the workpiece. At an early stage, the accumulated force will cause deformation on the worpiece and push it out towards the surface of the tool which is known as chips. Such high and uniform force will cause shearing and tearing on the workpiece which eventually will push the workpiece until a chip is formed (Schrader & Elshennawy, 2000).

Rao (2011) stated that during milling process, the unwanted material from the workpiece is removed by the rotation of the tool. As the tool rotates, a linear motion occurs between the workpiece and the tool. Each tooth on the tool will remove a small amount of material due to both motions.