UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PERFORMANCE OF CVD COATED CARBIDE TOOL DURING TURNING TITANIUM ALLOY Ti-6Al-4V ELI IN DRY CONDITION

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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2014

ABSTRACT

Turning process involves the removal of material from a rotating workpiece with a single cutting tool to form of a cylinder or an intricate profile. In this research, coated carbide tools by Chemical Vapor Deposition, CVD (CNNG 120408-SGF S05F) were used in turning workpiece titanium alloy, Ti-6AL-4V ELI (extra low interstitial). Titanium alloys have been used widely in many applications especially in aerospace, automotive, medical and chemical. This is because high strength to weight ratio, high fracture resistance, and excellent corrosion resistance of titanium alloy. However, titanium alloys are difficult to machine materials even though at elevated temperatures. It has low thermal conductivity, low elastic modulus and easy to react chemically with the cutting tools material. The objective of this study was to investigate the performance of cutting tools in turning Ti-6AL-4V ELI using CVD carbide in dry condition. Experimental design of this study based on Factorial method. Two Level Factorial design was selected to arrange the cutting parameters of cutting speed with range of 100 to 140 m/min, feed rate with 0.15 to 0.20 mm/rev, and depth of cut is constant (0.35 mm). Flank wear was measured using a three axis microscope. The values were recorded for each 20 mm on the workpiece until flank wear (V_b) reached the tool life criterion followed by (International Standard ISO 3685). From the results, maximum tool life (20.68 minutes) obtained by cutting speed of 100 m/min and feed rate of 0.15 mm/rev.

ABSTRAK

Proses melarik merupakan operasi pemesinan yang menyingkirkan bahan daripada benda kerja yang berputar dengan menggunakan mata alat berpinggir tunggal bagi menghasilkan bentuk silinder atau permukaan yang berprofil. Dalam kajian ini, mata alat karbida salutan secara pengendapan wap kimia, CVD (CNNG 120408-SGF S05F) digunakan dalam pelarikan benda kerja aloi titanium Ti-6AL-4V ELI (extra low interstitial). Aloi titanium tersebut digunakan secara meluas terutamanya dalam bidang aeroangkasa, automotif, perubatan dan kimia. Ini disebabkan aloi titanium memiliki sifat nisbah kakuatan terhadap berat yang tinggi, rintangan patah yang tinggi, dan rintangan kakisan yang sangat baik. Walau bagaimanapun, aloi titanium adalah bahan yang sukar dimesin walaupun pada suhu tinggi, mempunyai keberairan terma yang rendah, modulus kenyal rendah dan mudah bertindak balas kimia dengan bahan mata alat. Tujuan kajian ini adalah untuk mengkaji prestasi mata alat semasa pelarikan bahan Ti-6AL-4V ELI menggunakan mata alat karbida (CVD) dalam keadaan kering. Reka bentuk eksperimen kajian ini adalah berdasarkan kaedah pemfaktoran. Reka bentuk Two Level Factorial digunakan untuk mengatur parameter eksperimen iaitu laju pemotongan dengan julat dari 100 hingga 140 m/min, kadar suapan dari 0.15 hingga 0.20 mm/rev dan kedalaman pemotongan adalah malar (0.35 mm). Haus rusuk diukur menggunakan mikroskop mudah alih tiga paksi. Bacaan diambil dan direkod bagi setiap 20 mm pelarikan pada benda kerja sehingga nilai haus rusuk purata (V_b) mencapai 0.3 mm mengikut Piawai Antarabangsa ISO 3685. Berdasarkan kepada result, nilai hayat maksimum dihasilkan oleh laju pemotongan (100 m/min) dan kadar suapan (0.15 mm/rev).

DEDICATION

To my beloved family, friends and that accompanying me along the difficult pathway in my university life, thanks for your help and support.

ACKNOWLEDGEMENTS

First of all, I would like to thank GOD for giving me strength and guidance to complete this project. I wish to express my sincere thanks and appreciation to my supervisor, Mr. Mohd Amri bin Sulaiman for his advice and guidance in completing this project.

Secondly, I would like to thank to Manufacturing Engineering Laboratory of Universiti Teknikal Malaysia Melaka (UTeM) for providing me the equipments and machines. Moreover, I would like to thank to Mr. Taufik and Mr. Hanafiah for giving me lot convenience in using the equipments in the Laboratory.

Furthermore, special thanks to all my friends Omar Jamaludin, Norizan Taib, Nor Izuan and Izzati Ishak. They had giving me advice, ideas, comments and sharing their time to completed my project.

Finally, I would like to extend my special thanks to my family members, all lecturers in the Department of Manufacturing Universiti Teknikal Malaysia Melaka and friends who have given me support during my studies.

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CHAPTER 1

INTRODUCTION

This chapter describes the introduction of the project and briefly explains the problem statement, objectives and scopes of the research.

1.1 Background

Nowadays in the manufacturing industry the use of cutting tool is a very important. There are a lot of researches and experiments have been made to improve the quality and usage of a cutting tool which will be discussed in Chapter 2. The different of cutting tool characteristics like types, materials and shape will give different types of application. To obtain long life in service, cutting tool should have certain aspect or criteria such as hardness, toughness and wear resistance. One of the most common cutting tools used in the industry is Chemical Vapor Deposition (CVD) carbide tool.

Most of cutting tool can be used until they reach their max tool wear which can be longer or shorter in time. Most of researchers always want to eliminate or minimize the tool wear. Effect of tool wear will result in reduction in cost and improvement in quality of machining. If the tool wear can be minimized, the tool life of cutting tool will be increased and better in durability because they are related with each other.

Coated carbide tools are widely used in the metal working industry especially in turning operations. Flank wear is one of the main causes that cutting tool fails during machining using carbides under typical cutting conditions. Kishawy *et al.* (2005) carried out tool wear investigation on some cutting tool materials. He found out that plotted tool life curves using the flank wear criterion and found out that the tool life of carbides decreased quickly at higher speed.

The tool life of cutting tool also depends on material to be machined. Some of the material is titanium which described as a difficult to machine material. Titanium and titanium alloys are used extensively in aerospace application because of their excellent combination of high specific strength (strength-to-weight ratio), which is maintained at elevated temperature, their fracture resistant characteristics and their exceptional resistance to corrosion at high temperature (Ezugwu and Wang, 1997; Ezugwu, 2005).

Some typical characteristics of aerospace super alloys are austenitic matrix which promotes rapid work hardening, reactivity with cutting tool materials under atmospheric conditions which tends to build-up edge and weld onto cutting tools, low thermal conductivity which impairs the surface quality and presence of abrasive carbide in their microstructures (Che Haron *et al.*, 2001; Ezugwu, 2005). The major requirements to the materials for the aerospace and aircraft industry are due to their ability to maintain their high strength at elevated temperature, fracture resistant characteristics and high resistance for corrosion. However, titanium alloys described as a difficult to machine materials due to their high strength at high generated temperatures, relatively low modulus of elasticity, low thermal conductivity and high chemical reactivity.

Turning is a very important machining process in which a single-point cutting tool removes material from the surface of a rotating cylindrical workpiece. The cutting tool is fed linearly in a direction parallel to the axis of rotation. It has long been recognized that conditions during cutting, such as feed rate, cutting speed and depth of cut, should be selected to optimize the economics of machining operations, as assessed by productivity, total manufacturing cost per component or some other suitable criterion.

1.2 Problem statement

CVD carbide cutting tools are frequently used during titanium machining, but the tool wear is often fast and extensive because titanium is the difficult to machine materials. Wear mechanism on the flank of a cutting tool is caused by friction between newly machined surface and the cutting tool, which plays predominant role in determining tool life. Tool wear and failure mechanisms are of great practical interest because they will affect machining costs and quality. Tools that wear slowly have comparatively long and predictable service lives, resulting in reduced production costs and more consistent dimensions and surface finish. Tools that fail rapidly and unpredictably increase costs and scrap rates.

Tool wear is inherent in machining. There are many steps and measures taken to reduce the effect of tool wear on cutting tools. One of the steps is applying surface treatment on the base cutting tool material. By studying the behavior of the tool wear with respect to machining parameters, tool life can be optimized by choosing the right machining parameters.

According to Schneider *et al.* (2005) the optimum tool is not necessarily to be expensive and not always the same tool that was used for the job last time but the best tool is the one that has been carefully chosen to get the job done quickly, efficiently and economically. This mean, it is necessary to characterize specific cutting tool and work-piece combination to understand the interaction between machining parameters and tool wear performance.

1.3 Objectives

The objectives of this study are:

i. To study the influence of machining parameters to the tool wear of CVD carbide tool during turning of Ti-6Al-4V ELI under dry condition.
ii. To define optimum process parameter settings to maximize tool life of CVD carbide tool.
iii. To develop a mathematical modeling of tool life.

1.4 Scope

This study only focuses on tool wear characterization of CVD carbide tool in turning the titanium alloy Ti-6Al-4V ELI with 32 HRC / 317 HV. The type of tool wear to be analyzed is flank wear while the machining process is a single point turning operation with medium speed cutting range and no coolant involved (dry cutting). The machining parameters evaluated are cutting speed, feed rate and depth of cut. The cutting speed and feed rate will be various while depth of cut will be constant. The value of parameters and types of cutting tool are discussed in Chapter 3.

CHAPTER 2

LITERATURE REVIEW

In this chapter, the basic theory of turning process is discussed and the some related published works will follow to prove the theory. This review covers work-piece materials (Ti-6AL-4V-ELI), turning operation, cutting condition (no coolant or dry), types of cutting tool, types of tool wear, and the design of experiment methods.

2.1 Titanium

Titanium is a metal showing a high strength-weight ratio which is maintained at elevated temperatures, and it has exceptional corrosion resistance. These characteristics are the main cause of the rapid growth of the titanium industry over the last 40 years. The major application of the material is in the aerospace industry, both in airframes and engine components. Non-aerospace applications take advantage mainly of their excellent strength properties, for example steam turbine blades, superconductors, missiles; or corrosion resistance, for example marine services, chemical, electronics industry etc.

However, despite the increased usage and production of titanium, they are expensive when compared to many other metals, because of the complexity of the extraction process, difficulty of melting and problems during fabrication. On the other hand, the longer service lives and higher property levels counterbalance the high production costs. The poor machinability of titanium has led many large companies to invest large sums of money in developing techniques to minimize machining costs. Similarly, tool makers are looking for new tool materials which could extend tool life in the presence of such a challenge.

Titanium alloys are used extensively in aerospace because of their excellent combination of high specific strength (strength-to-weight ratio), which is maintained at elevated temperature, their fracture resistant characteristics and their exceptional resistance to corrosion at high temperature (Ezugwu and Wang, 1997; Ezugwu *et al*., 2005). Some typical characteristics of aerospace super alloys are austenitic matrix which promotes rapid work hardening, reactivity with cutting tool materials under atmospheric conditions which tends to build-up-edge and weld onto cutting tools, low thermal conductivity which impairs the surface quality and presence of abrasive carbide in their microstructures (Che Haron *et al.,* 2001; Ezugwu, 2005).

One of the most commonly used titanium alloys is an alpha-beta alloy containing 6% Aluminium and 4% Vanadium. This alloy, usually referred to as Ti 6Al-4V, exhibits an excellent combination of corrosion resistance, strength and toughness. Typical uses include medical devices or implants, aerospace applications and pressure vessels. In the case of medical applications, stringent user specifications require controlled microstructures and freedom from melt imperfections. The interstitial elements of iron and oxygen are carefully controlled to improve ductility and fracture toughness. Controlled interstitial element levels are designated ELI (Extra Low Interstitials).

Ti-6Al-4V ELI is one of the most widely used Titanium alloys in the medical industry. Its properties of biocompatibility, corrosion resistance, high strength, and toughness make it especially suitable for implants and other medical devices. The main difference between Ti-6Al-4V ELI (Grade 23) and Ti-6Al-4V (Grade 5) is that in ELI (Extra Low Interstitials) the maximum oxygen content is lowered to 0.13%. Grade 23 contains 6% Aluminium, 4% Vanadium, which is also known as Ti-6AL-4V ELI or simply Ti 6-4 ELI. Grade 23 is very similar to Grade 5 except Grade 23 has lower oxygen, nitrogen and iron. This confers improved ductility and fracture toughness, with some reduction in strength. Grade 23 has been widely used in fracture critical airframe structures and for offshore tubular.

Machining of titanium alloys is as demanding as the cutting of other high-temperature materials. Titanium components are machined in the forged condition and often require removal of up to 90% of the weight of the work piece. The high-chemical reactivity of titanium alloys causes the chip to weld to the tool, leading to cratering and premature tool failure. The low thermal conductivity of these materials does not allow the heat generated during machining to dissipate from the tool edge. This cause high tool tip temperatures and excessive tool deformation and wear (Klocke *et al*., 1996).

Titanium alloys retain strength at high temperatures and exhibit low thermal conductivity. This distinctive property does not allow heat generated during machining to dissipate from the tool edge, causing high tool tip temperatures and excessive plastic deformation wear which leading to higher cutting forces. The high work hardening tendency of titanium alloys can also contribute to the high cutting forces and temperatures that may lead to depth-of-cut notching. In addition, the chip-tool contact area is relatively small, resulting in large stress concentration due to these higher cutting forces and temperatures resulting in premature failure of the cutting tool.

2.2 Turning Process

Turning machines typically referred to as lathes, can be found in a variety of sizes and designs. A manual lathe requires the operator to control the motion of the cutting tool during the turning operation. Turning machines are also able to be computer controlled, in which case they are referred to as a computer numerical control (CNC) lathe. The typical cutting tool used in the CNC machine has a replaceable cutting edge (tool insert). CNC lathes rotate the work-piece and move the cutting tool based on commands that are preprogrammed and offer very high precision. In this variety of turning machines, the main components that enable the work-piece to be rotated and the cutting tool to be fed into the workpiece remain the same.

Turning is one type of metal cutting process that is used to produce cylindrical surface. During the turning operation workpiece is rotated and the tool will travel along feed direction. The combination between workpiece rotation and tool motion will result in reducing the workpiece size or diameter of workpiece. Figure 2.1 shows the turning operation.

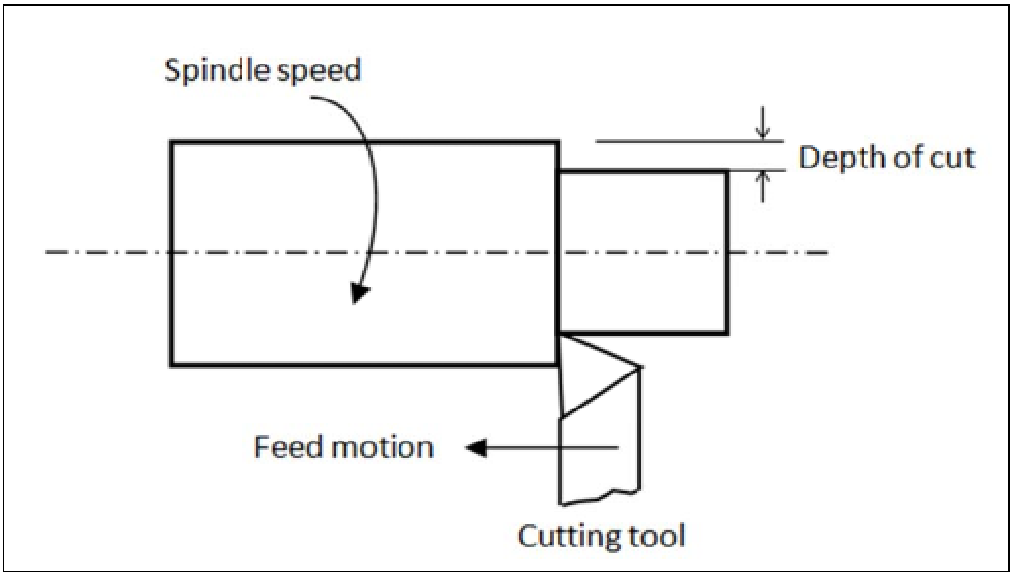

Figure 2.1: Turning operation (Ghosh and Malik, 1986)

2.2.1 Hard turning

Hard turning refers to turning of workpiece with hardness value above 45 HRC. Typical workpiece materials suitable for hard turning operations include heat treated materials examples like quenched and tempered case hardened materials (Gallopi *et al.*, 2006). Hard turning mostly need high hardness tools with negative rake angle, lower feed rate and depth of cut in order to produce better performance. However, large nose radius (generally 0.8 mm) is selected to achieve better surface finish (Kumar *et al.*, 2003). The selection of cutting tools for hard turning applications generally involve the use ceramic and CBN tools since these tools typical have high hardness, toughness, and wear resistance.

Hard turning has the potential for replacing grinding operation and hard turning significant is attained growth due to increased productivity and low production cost compared to grinding. Generally, the grinding process involves low materials removal rate, and requires large quantities of coolants that impact both the operator health and may cause environmental pollution. However, hard turning offers several advantages over grinding such as reduce machining time, high geometry flexibility, less energy required, environmental friendly, and able to obtain better surface finish quality (Kumar *et al*., 2003).

Due to increasing demand on hard turning the finished components should satisfy high quality requirements such as dimensional accuracy and quality surface finish and dry hard turning can achieve these requirements. Jiang *et al*. (2006) found that hard turning using a tool with nose radius of 0.8 mm is able to produce parts with surface finish quality equivalent to mechanical grinding process. The surface roughness in hard turning is comparable to the result obtained by grinding process (Remadna and Rigal, 2006).

2.3 Cutting Parameters

In turning process, the most important cutting parameters are cutting speed (*v*), feed rate (*f*), and depth of cut (*d*). Cutting speed is the speed of the workpiece material measured in meters per minute. Feed is the rate which the cutting tool is traveling in millimeters per each spindle revolution. The depth of cut is the amount of material removed from the workpiece measured in millimeters. The selection of these parameters influences cutting forces, power consumption, and surface roughness of the workpiece and cutting tool life. Cutting parameters are usually selected based on the workpiece, tool material, and tool geometry (Trent and Wright, 2000).

2.3.1 Cutting speed (*v*)

In general, cutting speed (*v*) was the primary cutting motion, which relates the velocity of the rotating workpiece with respect to the stationary cutting tool. The cutting speed refers to the edge speed of the rotating workpiece. It is generally given in unit of surface feet per minute (sfpm) or inches per minute (in. /min), or meters per minute (m/min).

For a given material there will be an optimum cutting speed for a certain set of machining conditions, and from this speed the spindle speed (RPM) can be calculated. Equation 2.1 shows formula of cutting speed between diameter of workpiece and spindle speed. Factors affecting the calculation of cutting speed are (Kalpakjian, 2006):

- The material being machined
- The material the cutter is made from
- The economical life of the cutter

$$V = \pi \times D \times N_S \tag{2.1}$$

Where, V = Cutting speed (m/min)

D = Diameter of material (mm)

Ns = Spindle speed (RPM)

2.3.2 Feed rate (*f*)

Feed is the amount of material removed per revolution or per pass of the tool over the workpiece. In turning, feed is in inches/revolution or millimeter/min and the tool feed parallel to the rotation axis of the workpiece (DeGarmo, 1999). Feed rate is dependent on the:

- Surface finish desired.

- Power available at the spindle (to prevent stalling of the cutter or work piece).
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the work piece (high feed rates will collapse thin wall tubing).
- Characteristics of the material being cut, chip flow depends on material type and feed rate. The idea chip shape is small and breaks free early, carrying heat away from the tool and work.

2.3.3 Depth of cut (*d*)

The depth of cut (DOC), d represents the third dimension. In turning, it is the distance the tool is plunged into the surface. In machining, the usual procedure is to first perform one or more roughing cuts at high feed rates and large depths-of-cut (DOC) (and therefore high material removal rates) but with little consideration of dimensional tolerance and surface roughness. After roughing process, finishing cut is required and a lower feed and depth of cut in order to produce a good surface finish (Kalpakjian, 2006 and DeGarmo, 1999).

2.4 Cutting Forces

Figure 2.2 shows the three forces acting on the cutting tool in the turning process. The cutting force (Fc) is the main force in the turning process and it acts downward on the cutting tool. The thrust force (Ft) or feed force acts in the direction of the feed motion of the cutting tool. The radial force (Fr) acts in the radial direction.