UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MACHINING PERFORMANCE OF TITANIUM ALLOY Ti-6Al-4V IN MILLING OPERATION USING CVD CARBIDE INSERT

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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DECLARATION

I hereby, declared this report entitled "Machining Performance of Titanium Alloy Ti-6Al-4V in milling operation using CVD Carbide Insert" is the results of my own research except as cited in references.

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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 (Manufacturing Process) (Hons.). The member of the supervisory committee is as follow:

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(Dr. Mohd Sanusi Bin Abdul Aziz)

ABSTRAK

Titanium aloi digunakan secara meluas dalam pelbagai bidang terutama sekali dalam aeroangkasa, perubatan dan industri makanan memandangkan ia memiliki kekuatan yang tinggi terhadap nisbah berat, serta rintangan retakan dan kakisan yang sangat baik. Mata alat karbida bersalut CVD sering digunakan dalam pemesinan titanium aloi, tetapi mekanisme haus pada mata alat sering berlaku kerana titanium sukar untuk dimesin. Kajian ini focus kepada prestasi pemesinan terhadap Titanium Aloi Ti-6AL-4V dengan menggunakan mata alat karbida bersalut CVD. Semua proses pemesinan telah dijalankan di bawah keadaan kering. Objektif kajian ini adalah untuk mengkaji perkembangan kadar haus dan kekasaran permukaan. Selain itu, ia juga untuk mengkaji kesan parameter pemotongan terhadap kadar haus dan kekasaran permukaan. Mikroskop stereo digunakan untuk mengukur kadar haus sementara alat mengukur kekasaran permukaan mudah alih digunakan untuk menguji kekasaran permukaan. Parameter yang digunakan dalam kajian ini diperolehi hasil daripada graf jurang penyelidikan yang berpandukan rujukan beberapa jurnal yang berkaitan. Ia didapati bahawa, kadar haus yang seragam berlaku pada permulaan pemesinan manakala kadar haus tajam berlaku di kebanyakan akhir pemesinan. Hayat penggunaan mata alat direkodkan paling lama adalah 625 minit iaitu pada kelajuan pemotongan, Vc = 120 m/min, kadar suapan, Fz = 0.1 mm /gigi dan kedalaman pomotongan, DoC = 0.3 mm. Kemasan permukaan yang baik telah dicapai pada kelajuan pemotongan tinggi, Vc = 180 m/min, kadar suapan rendah, Fz = 0.1 mm/gigi dan kedalaman pemotongan, DoC = 0.3 mm. Kadar haus meningkat selaras dengan peningkatan kadar suapan dan kedalaman pemotongan. Walaubagaimanapun, kenaikan kelajuan pemotongan tidak banyak mengurangkan kadar haus. Tambahan pula, kenaikan kelajuan pemotongan pada kadar suapan dan kedalaman pemotongan yang rendah akan menghasilkan kekasaran permukaan yang rendah.

ABSTRACT

Titanium alloy is widely used in many areas especially in aerospace, medical and food industry since it has properties of high strength-to-weight ratio, high fracture resistance and excellent corrosion resistance. CVD coated carbide insert is often used during machining titanium alloy, but the wear mechanism frequently occur because titanium is difficult to machine material. This research focuses on machining performance of Titanium Alloy Ti-6Al-4V in milling operation using CVD carbide insert. All the milling processes were conducted under dry condition. The objective of this study is to investigate the tool wear progression and surface roughness as well to study the effect of cutting parameter on wear rate and surface roughness in milling Titanium Alloy Ti-6Al-4V using CVD carbide insert under dry condition. Stereo microscope was used to measure the tool wear while portable surface roughness tester was used to measure the surface roughness. The cutting parameters used in this research were obtained from the research gap of previous related studies. It was found that, uniform flank wear was formed at the start of machining while notch wear occurs at the end of most experiments. Longer tool life of 625 minutes was recorded at cutting speed, Vc = 120 m/min, feed rate, Fz = 0.1 mm/tooth and depth of cut, DoC = 0.3 mm. A better surface finish was achieved at high cutting speed, Vc = 180 m/min, low feed rate, Fz = 0.1 mm/tooth and depth of cut, DoC = 0.3 mm. Wear rate increased due to the increasing of feed rate along with the depth of cut. However, the increasing of cutting speed did not reduce the wear rate significantly. Furthermore, the increasing of cutting speed at lower feed rate and depth of cut produced lower surface roughness.

DEDICATION

To my beloved parents, family and friends

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

A	-	Insert diameter
Al	-	Aluminium
CNC	-	Computer Numerical Control
CVD	-	Chemical Vapor Deposition
De	-	Effective diameter
DoC	-	Depth of Cut
Fz	-	Feed rate
HRC	-	Rockwell Hardness
HSM	-	High speed machining
HSS	-	High Speed Steel
J	-	Joule
LCD	-	Liquid Crystal Display
N	-	Spindle speed
PVD	-	Physical Vapor Deposition
r_ε	-	Nose radius
S	-	Thickness
Ti	-	Titanium
TiC	-	Titanium Carbide
TiCN	-	Titanium Carbonitride
TiN	-	Titanium Nitride
V	-	Vanadium
Vb	-	Flank wear
Vc	-	Cutting speed
XRD	-	X-ray diffraction

CHAPTER 1
INTRODUCTION

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

1.1 Project Background

Nowadays in manufacturing industry, the uses of carbide insert are very important aspect in milling process. Carbide insert normally used to expand the tool life and reduce the frequent of tool changes. Besides that, it also reduces the manufacturing cost and setup time. The usage of carbide insert can be determined by four factors which are insert grade, insert shape, insert size and nose radius. By this factor, carbide insert is chosen according to the suitability of the material that wants to be machined. However, the hardness and toughness of carbide insert can be decreased due to its frequent machining where it can slowly produce a wear on the structure of the insert (Kalpakjian and Schmid, 2001).

The prediction and control of tool wear is one of the most essential problems emerging in cutting operations. High friction between cutting tool and workpiece material are the common factor that contribute to the tool wear which is then can reduce the volume of tool material on contact surface. High thermal effect, chemical reaction, abrasion and mechanical damage are the potential causes of tool wear (Ezugwu and Wang, 1997). As compared to turning and drilling, the end of tool life in milling often occurs due to cutting edge breakage, cracks propagation and macro chipping.

There are many researches and experiments were made to improve the quality of cutting tool life. Most of the researchers done the experiment to overcome the wear problem of carbide insert as well to get the optimum machining parameter to increase the insert life. To maintain a long life in machining, carbide insert should be coated in order to obtain a high physical aspect such as hardness, toughness and wear resistance (Upadhyaya, 1998). One of the most common coating methods applied on carbide insert is Chemical Vapour Deposition (CVD).

Chemical Vapour Deposition (CVD) is a coating method that involves a solid material which is then converted to vapour through a chemical reaction that occurs on or in the surrounding of a normal heated substrate. The solid material is then known as a coating. This CVD method often to be a choice to industry for any related application because of its characteristic which are excellent throwing power and enable to produce a uniform coating with a low porosity even on a substrates of complicated shape (Astakhov, 2006).

The application of cutting tool especially insert depend on the type of materials to be cut such as titanium, cast iron, mild steel and others. Generally, CVD coated carbide inserts often used in milling a titanium alloy due to its extreme difficulty to machine material. Bhargava et al. (2011) stated that titanium alloy was found widely used in aviation and rocket engineering, ship building and chemical processing. For aerospace applications, Jawaid et al. (2000) claimed that CVD coated carbide insert performed a good cutting when face milling titanium alloy under dry condition. Moreover, titanium alloy possess several attractive characteristic such as good mechanical and chemical properties, excellent corrosion resistance and high strength-to-weight ratio.

1.2 Problem Statement

CVD carbide insert often used during machining titanium alloy, but the wear mechanism are frequently to occur because titanium is difficult to machine material. Wear is usually undesirable where it can affect the quality and machining cost. Carbide insert that have high wear resistance can serve in a long period time with a good and consistent dimension and surface finish, while carbide insert that fail rapidly and unpredictable can increase the tooling cost and scrap rates. There are various measures that can be taken in order to increase wear resistance. The most fundamental way that often been carried up is by studying the behaviour of the carbide insert wear according to its machining parameters such as cutting speed, feed rate and depth of cut.

1.3 Objectives

The objectives of this study are:

i. To study the tool wear progression and surface roughness with different cutting parameters in milling Titanium Alloy Ti-6Al-4V using CVD carbide insert under dry condition.
ii. To study the effect of cutting parameters on wear rate and surface roughness in milling Titanium Alloy Ti-6Al-4V using CVD carbide insert under dry condition.

1.4 Scope

This study only focus on tool wear progression of CVD carbide inserts as well to study the surface roughness of Titanium Alloy Ti-6Al-4V under dry condition. The type of cutting tool used is grade 5 round shape carbide insert while the machining process is end mill. The machining parameters evaluated are cutting speed, feed rate and depth of cut.

CHAPTER 2

LITERATURE REVIEW

In this chapter, every aspect that involved in this research will be explained and elaborated extensively by the guidance from previous research. The aspect to be discusses consists of the material itself which is Titanium Alloy Ti-6Al-4V, cutting parameter and cutting tool insert (CVD carbide insert). This chapter also covers the machining performance which consists of tool life, surface roughness and material removal rate.

2.1 Titanium Alloy

Chang and Shiue (2006) stated that titanium and its alloy are relatively subjected as engineering metals since they have existed as structural materials only since 1952. Titanium alloy are captivating since they possess a high strength and temperature properties to about 550°C, and excellent corrosion resistance.

Unfortunately, titanium and its alloy cost scarcely more than prevalent metals because the manufacturing or production for titanium alloy must be performed under controlled melting point and consistent fabricating techniques. The higher cost of titanium alloy fabrication is principally the result of the metal's high reactivity and affinity for interstitial element such as oxygen, nitrogen, hydrogen and carbon (Smith, 1993). Nevertheless, titanium and its alloy are reliable in giving a good impact in different areas where their special properties can be acclimated to advantage. For example, the importance properties that been set as main criteria in aerospace industry are high strength-to-weight ratio and high elevated-temperature properties. For other areas such as chemical and food industries, properties like excellent corrosion resistance was highlighted as a priority in order to maintain a good quality. New uses for titanium and its alloy are being constant sought and discovered.

As focused to aerospace super alloy, some typical characteristics that needed are austenitic matrix which promotes rapid work hardening, reactivity between cutting tool materials and workpiece under atmospheric conditions and low thermal conductivity (Che Haron et al., 2001). According to Bhargava et al. (2011), titanium alloy was found widely used in aviation and rocket engineering, ship building and chemical processing due to their high room temperature and elevated temperature strength, moderate ductility, good resistance to corrosion and high specific strength.

Table 2.1: Properties of Titanium

Density	4.54 g/cm³
Melting point	1668°C
Modulus of Elasticity	16.8×10^6 lb/in

Based on the table, titanium can be considered as light metal because of its lower density of 4.54 g/cm³, which is intermediate between aluminium (2.71 g/cm³) and iron (7.87 g/cm³). Titanium has high melting point of 1668°C, which is greater than iron (1536°C), and a modulus elasticity of 16.8×10^6 lb/in², which is intermediate between aluminium and iron (Smith, 1993).

One of the most widely used titanium alloy is Ti-6Al-4V. This alloy has high strength-to-weight ratio, good fatigue and creep strength, and high resistance to oxidation (Bhargava et al., 2011). On the other hand, Ti-6Al-4V by far has been claimed as the most important titanium with the percentage of 60 % of the titanium market in 1989. The reason of why this type of titanium became the main choice was due to its availability in variety of mill product such as sheet, extrusions, wire and rod. Plus, it is also heat-treatable to an ultimate tensile strength of 165 ksi and has a good metallurgical stability to 482°C (Smith, 1993).

There are a several cutting tools that highly react with titanium alloy especially in term of chemical reaction. Because of its low thermal conductivity, the temperature of cutting tool edge tends to increase. Besides that, high adhesion also affects the tool wear. Moreover, the machinability of titanium alloys might affected due to its low modulus of elasticity (Che Haron et al., 2007).

2.2 Machining Parameter

The most consequential factors affecting the efficiency of milling operation are cutting speed, feed rate, and depth of cut. If the cutter is too gradually, valuable time will be wasted, while extortionate speed results in loss of time in superseding and regrinding cutters. Somewhere between these two extremes is the efficient cutting speed for the material being machined. The rate at which the work is fed into the revolving cutter is consequential. If the work is too gradually, time will be wasted and cutter chatter may occur which minimizes the tool life of the cutter. If work is fed too fast, the cutter teeth can be broken. Much time will be wasted if several shallow cuts are taken instead of one deep or roughing cut. Therefore, speed, feed rate and depth of cut are three consequential factors in milling operation (Krar et al., 1999).

2.2.1 Cutting Speed

According to Krar et al. (1999), the cutting speed for a milling cutter is the speed, either in feet per minute or in meters in minute, which the periphery of the cutter should travel when machining a certain metal. The speeds utilized for milling cutters are much equivalent to those utilized for any cutting tool. Several factors must be considered when determining the opportune revolutions per minute at which to machine a metal. The most important factors are type of workpiece, material and diameter of cutter, surface finish required and rigidity of the machine.

2.2.2 Feed Rate

Krar et al. (1999) stated feed rate is mainly about the movement of cutting tool through workpiece which quantified in mm/tooth or mm/min. The milling feed is resolute by multiplying the chip size desired, the number of teeth in the cutter, and the revolutions per minute of the cutter. The feed rate on a milling machine depends on a variety of factors such as depth and width of cut, type and sharpness of cutter, workpice material and type of surface finish needed.

2.2.3 Depth of Cut

Depth of cut is primarily affecting the surface roughness. Roughing cuts should be deep, with a feed as heavily ponderous as the work and the machine will sanction. Heavier cuts may be taken with helical cutters having fewer teeth than with those having many teeth. Cutters with fewer teeth are more vigorous and have a more preponderant chip clearance than cutter with more teeth (Krar et al., 1999).

2.3 Insert

In the late of 1940s in the USA, tool holders were being manufactured with pockets at the nose of the load in which hard metal pieces were clamped. The pieces were square, triangular or round. Each corner of the squares and triangles was utilized for cutting and as one corner became worn, the piece was indexed to an unutilized corner. In the case of a round, it was rotated to an unsullied part of the circumference. These pieces were known as 'Throwaway Tips' which was an unfortunate choice as thy still had a scrap value when exhausted. Since the late 1960s, they have been known as 'Indexable Inserts'. All indexable inserts are made by a powder processing route and with good pressing technology, it is possible to perform roughing and semi roughing operations with inserts which do not have to be ground on the periphery to a smaller tolerance size (Edwards, 1993).

Figure 2.1: Simple indexable insert
(Source: Sumitomo Milling 2011-2012)

Figure 2.1 shows a simple indexable carbide insert where regrinding of "throw away" carbide inserts is done to further reduce carbide tool cost, and scrap carbide inserts are being recycled by commixing some finely divided used tool material with virgin powder in incipient tool manufacture. Indexable carbide inserts are now available in a wide variety of shapes including triangle, squares, circles, rectangles, hexagon, pentagons, and diamonds having a variety of angles (80°, 55°, 42°, and 35°). The American National Standards Institute (ANSI) has introduced a special numbering system for inserts and tool holders (Shaw, 2005).

2.3.1 Shape of the Insert

The plan view or shape of the insert is designated by a single letter. For example, S (square), T (triangle) and R (round). A parallelogram and Rhombus can have different angles e.g. 55°, 35°, 80° etc. Each of these is described using its own allocated letter. There are 16 letters in use at the present day (Shaw, 2005).

2.3.2 Insert Type

An insert may be plain (no hole, no chipgroove), this is designated N. An insert which is plain with a chipgroove on one face is designated R and an insert with a plain cylindrical hole and a chipgroove on one face is designated M, etc. 15 letters are used, 14 of which cover specific cases of detail. The remaining one, which is X, is reserved for special types peculiar to any one supplier (Shaw, 2005).

2.3.3 Insert Size

Because indexable inserts originated in the USA, they are dimensioned in inches, e.g. 1/2" square, 3/8" triangle (3/8" being the diameter of the inscribed circle). When the ISO standard was drawn up, it was decided to quote the dimensions in whole millimetres. The size of the insert is quoted by reference to the length of the cutting edge when looking at the plan view except for rounds where the reference dimension is the diameter (Shaw, 2005).

2.3.4 Insert Thickness

As with insert size, the thickness is dimensioned in whole fractions of an inch but it is designated in millimeters. 9 thickness positions are listed in the standard are 01, 02, 03, T3, 04, 06, 07, 09 and 12. They range from 1.59 mm to 12.7 mm thick. T3 is an exception in that a letter is introduced. It was added as an extra thickness position at a later stage (Shaw, 2005).

2.4 Carbide Tool

According to Upadhyaya (1998), tungsten carbide is mostly well known and been used in the production of carbide cutting tools. There's a lot types of carbide that been used in order to meets the metal and alloy properties in machining operating. It is divided into three type which the first one is tough grades where it is been used in slow speeds and interrupted cutting. The second one is harder grades where it is functioned especially for high speed machining. Third is heat resisting alloyed grades where it is widely used in machining superalloys, for crater resistant compositions and coated varieties in machining steel. However, to select the proper cutting tool material, there's a variable that need to be followed which are type and hardness of material, outer surface of material, type of operation and rigidity of the machine.

Carbide tools are compounds of hard carbide particle, nitrides, borides, and silicates. These compounds are bonded together using binder such as cobalt. Performance of carbide tool is depended on the composition and grain size; these tools have sufficient toughness, impact strength, and high thermal resistance but have limitation in hardness properties. The hardness of carbide tool drops rapidly at high temperature. Consequently, it cannot be used at high cutting speed which involves high temperature. Nowadays, development of coated tools technology can improve the tool life of uncoated carbide tools (Kalpakjian and Schmid, 2001).

2.5 Coating Material

Coating material is basically generated on a tool based on the type of workpiece that want to be machined. The purpose of coating material is to increase tool life and to achieve higher metal removal rates. It is normally being known as thin film coating of material. According to Davis (2003), there's a lot type of thin film coating of material such as Titanium Nitride (TiN), Titanium Carbide (TiC), Titanium Carbonitride (TiCN), Hafnium Nitride (HfN) and Aluminium Oxide (Al_2O_3). But, in this research, the coating of material that been focused on is Titanium Nitride (TiN) because the tool that been used is related with this type of coating material.

2.5.1 Titanium Nitride (TiN)

It is known that titanium nitride (TiN) coating have been used by the industry for many years. Most of the reason that this type of coating been selected is because of their excellent wear resistance (Stachowiak and Batchelor, 2005). On the other hand, Mattson (2010) claimed that titanium nitride is one of the most effective approaches of thin coating material.

Titanium nitride (TiN) possesses a high hardness which is from 2000 to 2500 Hv and because of these criteria it has increase the wear resistance of tool especially in abrasive and flank wear. Besides that, TiN also has high chemical stability where it resulting in a high resistance to solution wears. Furthermore, the interfacial cracking can be prevented by the good adhesion to the substrate (Holmberg and Matthews, 2009).

In term of material removal application and surface finishing, Bangalore (1980) stated that titanium nitride coatings are found beneficial where by exploiting the toughness of the carbide substrate of the titanium nitride coating, it will gives a much higher of tool life than tungsten carbide.

Titanium nitride also produce a uniform coating where it is always became a choice to industry for the application of missile, aerospace, computer and semiconductor applications (Tracton, 2006).