UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF CUTTING PARAMETERS IN MILLING TITANIUM ALLOY TI-6AL-4V USING PVD 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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Signature	:	………………………………………….....
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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 is as follow:

………………………………

(Dr. Mohd Sanusi bin Abdul Aziz)

ABSTRAK

Titanium mempunyai ciri-ciri mekanikal dan bahan yang bagus seperti kuat dan ringan. Ia digunakan secara meluas di dalam industry penerbangan kerana ciri-cirinya yang bagus seperti keras dan kuat. Jangka hayat mata alat menjadi satu masalah apabila memotong titanium. Memotong bahan yang keras menggunakan mata alat yang tidak sesuai menyebabkan kerosakan mata alat. Mata alat yang mempunyai ciri-ciri yang bagus perlu digunakan untuk memperolehi keputusan yang bagus dalam memotong bahan yang keras. Kos mata alat yang mempunyai ciri-ciri yang bagus adalah tinggi. Sebagai alternative, mata alat bersalut karbida yang mempunyai ciri-ciri yang bagus dan rendah kos boleh digunakan. Kajian ini menumpukan tentang perkembangan kadar kehausan mata alat dan kekasaran permukaan. Selain itu, objectif kajian ini adalah untuk mengenalpasti efek parameter permotongan kepada kehausan mata alat dan kekasaran permukaan. Parameter yang digunakan dalam penyelidikan ini adalah kelajuan memotong (120 – 180 mm/min), kadar suapan (0.1 – 0.2 mm/gigi) dan kedalaman permotongan (0.1 – 0.5mm) dan dijalankan tanpa bendalir pemotong. Analisis dan pengukuran dilakukan dengan menggunakan alat dan pengukuran mikroskop stereo dan pengukuran kekasaran menggunakan penguji kekasaran permukaan yang mudah alih. Berdasarkan keputusan kajian ini, setiap parameter mempunyai signifikannya tersendiri yang memberi kesan kepada kehausan alat dan kekasaran permukaan. Kelajuan memotong yang tinggi menyebabkan kadar kehausan yang tinggi dan kekasaran permukaan yang bagus. Kadar suapan yang tinggi pula menyebabkan nilai kadar kehausan dan kekasaran permukaan meningkat. Kadar kedalaman pemotongan yang tinggi pula menyebabkan nilai kadar kehausan dan kekasaran permukaan juga meningkat.

ABSTRACT

Titanium possesses good mechanical and material properties, which are high strength and lightweight. It is widely used in aerospace industry due to its good properties. The problem of machining titanium alloy is the tool life durations. Machining hard materials using inappropriate cutting tool leads to tool failure. In order to achieve better results in machining hard and strong materials, good properties of cutting tool is needed. Cutting tools that have good properties might cost a lot. As an alternative, coated carbide insert can be used as the tool posses good properties and lower cost. This research focuses on the tool wear progression and surface roughness when machining titanium alloy. Another objective of this research is to study the effect of machining parameters on the tool wear and surface roughness. The parameters that have been used in this research are cutting speed (120 - 180 mm/min), feed rate (0.1 – 0.2 mm/tooth) and depth of cut (0.3 – 0.5 mm). and performed with no cutting fluids. The tool wear was measured by using stereo microscope and the surface roughness was measured using portable surface roughness tester. Based on the experimental results, it was found that each parameter have significant effects to the tool wear and surface roughness. Parameters with high cutting speed resulting in high wear rate and better surface roughness. However, the increasing of feed rate resulting in the increase of wears rate and surface roughness value. The increasing of depth of cut resulting in the increase of wear rate and surface roughness value.

DEDICATION

Specially dedicated to my beloved family, project supervisor and all my friends that encouraged me throughout my journey of education.

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CHAPTER 1
INTRODUCTION

1.1 Background

The development of new alloys and engineered material produces higher strength and stiffness properties. Technologies of machining have been enhanced in order to achieve better quality for machining high strength and toughness materials. These types of materials are commonly used in making automotive and aerospace components. Nowadays, the capabilities of machine and cutting tools allow the manufacturer to machining hardened steels. However, in order to gain the most optimized results, there are several of factors need to be considered such as types of cutting tools, type of machine and cutting parameters. Coated cutting tools are established for refining performance in machining and also to lesser the effort of machining hard materials. Coated cutting tools can increase tool life up to ten times longer than uncoated cutting tools, which allowing for high cutting speed (Kalpalkjian and Schmid, 2006). This will decrease machining time and also reduce production cost.

1.2 Problem Statement

One of the major concern in manufacturing environments is the tool life durations, which also affecting the economics of operations. Milling operation can be used for machining ferrous and non-ferrous materials.

The selection of good cutting tool is one of the most critical factors to be considered before machining operation. Appropriate cutting tool will contribute to longer tool life performance and better surface finish for the machined parts. However, good cutting tools that possess good mechanical properties are high cost. The need of good cutting tools is a must for machining hard materials. As an alternative, coated carbide insert can be used as it's possess good mechanical properties and capable to do high speed machining. The cost of coated carbide inserts is lower than high end cutting tool materials. Coated carbide insert has been widely used due to its good mechanical properties and low cost.

In machining, cutting parameters must be considered as it is one of the most influenced factor that affecting the outcome of the machining. A good machining result depends on the types of materials, types of cutting tool and cutting parameters. This research was conducted to identify and compare the wear rate of the PVD coated carbide tool and the surface roughness of the machined titanium using CNC milling machined.

1.3 Objectives

The fundamental objectives of this research are:

i. To study the tool wear progression and surface roughness when machining titanium alloy Ti-6Al-4V using PVD Carbide Insert
ii. To study the effect of different machining parameters on the tool wear and surface roughness of the titanium alloy Ti-6Al-4V

1.4 Scope

The scopes of this research are:

i. This research will be focus on CNC milling operates under dry conditions
ii. The carbide insert is coated by using physical vapor deposition (PVD)
iii. The form of the selected carbide insert is round, which is 10mm diameter
iv. The workpiece for this research is titanium alloy Ti-6Al-4V
v. The measurement of tool wear is measure using Stereo Microscope
vi. The measurement of surface roughness is measure using Portable Surface Roughness Tester

1.5 Outline of the Project

This research contains 5 chapters which containing PSM 1 and PSM 2. PSM 1 consists 3 chapters, which includes introduction, literature review and methodology. PSM 2 consists 2 chapters, which includes result and discussion of this experiment and conclusion. The chapter 1 is generally about the overview of the project, problem statement related to industry issues, objectives, scope of the project and the important of the study.

Chapter 2 is the literature review based on the references collected from journal papers, books and website. This chapter discussed about the information about this specific research area. It also discuss concisely about milling machine and operations, cutting tools and about previous and recent research that have significant relationships with this research.

Chapter 3 is discussing the methodology applied in this research. This will contain the details of the design and outline to run the experiment of this research.

Next, chapter 4 contains result and discussion, which the data that collected from the experiment is analyzed and discussed.

Finally, in chapter 5 the conclusion and the recommendation of the final year project will be concluded.

CHAPTER 2
LITERATURE REVIEW

The literature review is a simple summary of the sources where the knowledge, information or ideas of the author in a particular subject area which is established and defined. The discussion on the problem issue, research objectives and the methodology used are supported by the established knowledge that reviewed from the books, journals and articles. This chapter provides detailed explanation on titanium, cutting parameters, coated cutting tools, machining performances and surface roughness.

2.1 Titanium

Titanium is a material that is strong and light metal. Titanium has the element symbol of Ti, originates from the Greek called Titans. Metallic titanium usually used to build structural parts for planes and their mechanisms. Atoms occurred in everything around you. Atoms contain tinier particles, which is protons, neutrons and electrons. Both of the neutrons and protons are found in the nucleus, which located at the center of each atom. The electrons rotate around the nucleus in a multiple of layers called electron shells. Titanium has 22 atomic numbers due to 22 positively charged protons in the nucleus. Neutrons are about the similar size as protons but have no electrical charge. So, the atomic mass of the titanium is 48. Then number of electron for titanium is similar to the number of proton, which makes the amount of electrons are 22.

2.1.1 Characteristic of Titanium

The pure metal is rather soft and weak, however when titanium enhances stronger after it is mixed among other metals to form alloys. Woodford (2003) stated that titanium reacts very easily with oxygen. Titanium metal becomes layered with a coating of titanium dioxide due to the existence of air. This oxide layer benefits to repel corrosion from salt water and other chemicals. Titanium's high melting point makes it as an ideal material for the creation of high-speed airplane and astronomical vehicles. Titanium is very strong, lightweight and can resist tremendously high temperatures. Matthew (2000) stated that the density of titanium is approximately 60% of the steel or nickel-base super alloys. The tensile strength of titanium alloy can be compare with lower strength martensitic stainless and better than austenitic or ferritic stainless alloy. The marketable alloys of titanium are beneficial at temperatures approximately 538° to 595°C depends on composition. However, there are several alloy structures may have useful strengths exceeding this temperatures. Ballester (2000) stated that the price of titanium is approximately 4 times greater than stainless steel. Titanium has exceptional corrosion resistance, surpasses the resistance of stainless steel in most circumstances. Titanium also may be forged, cast able and processed by standard techniques. It can be processed by powder metallurgy. Moreover, Matthew (2000) also stated that titanium can be joined together by fusion welding, adhesives, brazing and fasteners.

2.2 Cutting parameters

The cutting operation of titanium alloys is alike to other alloy systems. There are several cutting tools that affecting the results of the operation which are tool life, cutting speed, forces, power requirements, cutting tools and fluids.

2.2.1 Tool life and cutting speed

The cutting tools for machining titanium alloys are sensitive to changes in feed. The tool life is very short when at high cutting speed. However, as the cutting speeds reduce, tool life considerably increases.

2.2.2 Cutting Tool Materials

The characteristic of cutting tool that required to machining titanium is abrasion resistance and suitable hot hardness. Examples of materials that usually used for machining titanium are ceramics, coated carbide and polycrystalline diamonds. The cutting tools should be maintains sharp as wear tools causes poor surface finish and tearing.

2.2.3 Cutting Fluids

Coolant can extremely extend the cutting tool life. Coolant allows heats to transfer efficiently and decrease cutting forces among the tool and work piece. This cutting fluid doesn't cause any degradation of the properties of the work piece. Cutting fluids help to transfer the heat and it also washes away chips and reduces cutting forces.

2.2.4 Machining Speeds and Feeds

Two of the most significant parameters for all types of machining operations were cutting speed and feed rate. This is because speed and feed rates have a direct influence on the tool life. A low cutting speed helps to decrease tool edge temperature and increase tool life. Tool tip temperature is affected by cutting speed. In the aspect of feed rates, it should be maintain and consistently done. However, tool temperature is affected more by cutting speed than the feed rates.

2.3 Coated Cutting Tools

Metal cutting industry undergoes one of the most revolutionary changes over the last 30 years in with the development of thin-film hard coatings and thermal diffusion processes. These developments brought significant advantages to users or machining industry and also increasing applications. Nowadays, most of the cutting tool in which 50% of high speed steel (HSS), 85% of carbide and 40% of super-hard tools used in industry is coated. Titanium aluminum nitrate (TiAIN), titanium carbonitrade (TiCN), solid lubricant coatings and multilayer coatings are the most common coating for substrate such as carbides. Coating increases tool life productivity and performance in cutting tool. It makes high speed and high feed cutting in dry machining or when machining of difficulty to machine materials (Astakhovand and Davim, n.d.).

Functional properties of tools are determined by the stresses that occur in hard coatings deposited on the edge of the cutting tools. Almost all-vacuum metallic and non-metallic deposited coating undergoes stress. Stress on the coating are determined by critical factor of the coating material and base material, which are coating structure, the relationship between deposition temperature and melting point of the coated material, temperature in which this coating is exploited and method of deposition. Functional properties of coated cutting tools also depend on the thermal internal stresses that can leads to crucial stress. Substrate that has bigger thermal expansion coefficient than the material of the coating material causing compressive stress in the coating is more favorable. Compressive stresses in the coating prevent production of cracks. (Dobrzanski et al. 2009).

Several types of coating characteristics such as hardness, adhesion, low coefficient of friction, structural constitution and residual stress are important and can be optimized by optimizing process parameters. For example, tool life of TiAIN coated cemented is 3 until 4 times higher than tool life of TiN coated in drilling process. The excellent thermo physical, tribological and mechanical behavior is the advantages in coating material. Due to these facts, various types of cutting operation such as high speed cutting and cutting with or without coolant can be performing using coated carbide tool. (Lughscheider, 2003).

2.4 Coated Carbide Tools

Grover (2012) stated that the growth of the coated carbides start about 1970 signified a significant development in cutting-tool technology. Coated carbides are also known as cemented carbide insert coated with one or more thin layers of wear-resistant material, such as titanium carbide, titanium nitrate and cemented carbide. The coating is applied to the substrate by chemical vapor deposition or physical vapor deposition. The thickness of the coating is approximately between 2.5 to 13μm (0.0001 to 0.0005 in). It has been discovered that thicker coatings manage to be brittle, resulting in cracking, chipping and separation from the substrate. The first production of coated carbides had only a single layer coating. Nowadays, coated carbides have been advanced that contain of numerous layers. Coated carbides are used to cut cast irons and steels in turning and milling processes. The best parameters to be applied is at high cutting speeds which the thermal shock and dynamic force is minimal. Chipping of the coating can happened if the cutting process being interrupted. This can lead to premature tool failure. The strength of the uncoated carbides is favorable. However, coated carbide tools mostly give the advantage for using high cutting speed compared with uncoated cemented carbides. From time to time, the use of the coated carbide tools is developing to nonferrous metal and nonmetal applications for improved tool life and higher cutting speeds. Ceramic carbide, tungsten carbide and diamonds are the examples of different coating materials.

2.5 Physical Vapor Deposition (PVD)

Chemical vapor deposition (CVD) and physical vapor deposition (PVD) are the main processes used to add coating material to cutting tools where the substrates are high speed steel (HSS) cemented carbide, ceramic or a super hard material. (Destefani, 2002). Physical vapor deposition (PVD) was developed in the 1980 as a viable process for applying hard coatings to cemented carbides tools. The coating is deposited in a vacuum. Evaporation or sputtering produce metal species of the coating then react with a gaseous species such as nitrogen or ammonia in the chamber and deposited onto the substrate. Physical vapour deposition (PVD) is one of the hard coating processes that have the ability to reduce tool wear of high speed steel (HSS) and carbide metal cutting tools. The service lifetime of cemented carbide tools coated with titanium carbide (TiC) and titanium nitride (TiN) increase by a factor of ten compare to uncoated tools (Watmon et al. 2010). Mehrota and Quinto (1985) stated that composition, microstructure and mechanical properties of the coating material and substrate are important to increase performance of coated tools. Figure 1.1 shows the schematic diagram of PVD process.

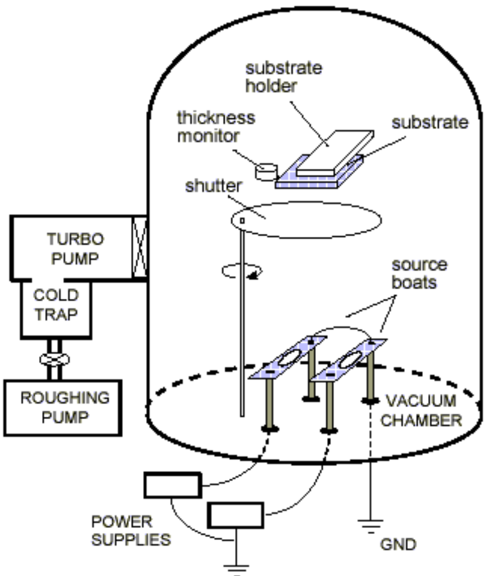

Figure 2.1: The schematic diagram of PVD process

(https://stuff.mit.edu/afs/athena.mit.edu/course/3/3.082/www/team2_f02/Pages/PVD.gif)

2.6 Comparison between PVD and CVD

The PVD coating process is executed at lower temperatures which approximately 500°C. The PVD coating process has a line-of-sight disadvantage. On the other hand, CVD coating required high deposition temperature which approximately 1000°C. These will lead the coating to degrade the strength of the cemented carbide substrate. Figure 1.2 shows comparison chart of the transverse rupture strength of uncoated and coated carbide tools.

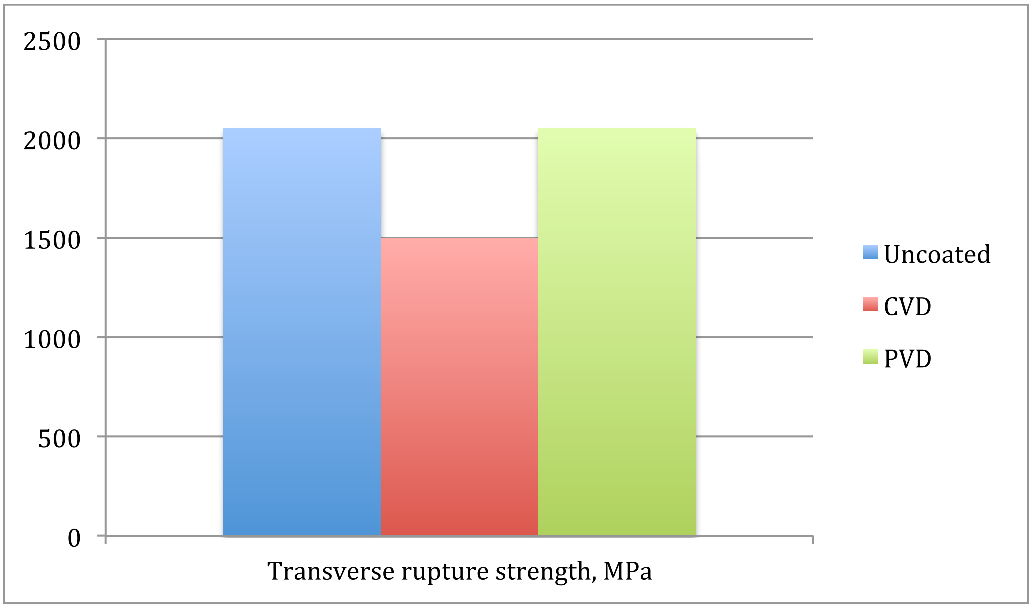

Figure 2.2: Comparison of the transverse rupture strength of uncoated and coated carbide tools. Measured by a three-point bend test on 5 x 5 x 19 mm specimens of 73WC-19C-8Co (Joseph, 1995)

CVD layers provide excellent adhesion and wear resistance and the PVD layer offers a hard, fine-grain, crack-free, smooth surface capable with compressive residual stress. However, amorphous PVD Al_2O_3 coatings are unstable and are not as pleasant as the crystalline Al_2O_3 attained in CVD. PVD TiAlN coatings are also chemically stable and offer the possible for high-speed machining of steels.

2.6.1 Microstructure

PVD process possesses finer grain sizes and better compressive residual stress. Compressive residual stress grown during ion bombardment in definite PVD processes retards crack propagation and thus creates a fracture toughness benefits for PVD-coated tools.

2.6.2 Adhesion

Good performance of the coated tools depends on how superior the coating adhesions to the substrate are. Coating phase transformations can also induce stresses that may affect adhesion. Substrates surface impurities due to coating, especially in the PVD process, can have unfavorable effects on coating adhesion and should be reduced. Current PVD technology offers well-adhering coatings that are as efficient as CVD coatings in demanding applications.

2.6.3 Coating Thickness

The coating thickness needs to be optimized to achieve maximum metal cutting productivity. If the coating thickness is too thin, the effect persists for a negligibly short time during cutting. If the modified tool surface is too thick, the layer will act as a bulk material and the benefit of an engineered composite may be lost. Working tool coatings should be 2 to 20μm thick. Coatings deposited by CVD are normally 10μm thick, while PVD coatings are typically less than 5μm thick.

2.7 Machining Performances

Machining performances, also called machinability is defined, as the chip might happen to separate from the base material. There are two main factors that affecting the machinability of material, which are the properties of the work piece and the machining conditions.

The machining conditions that affect the machining performances are:

i. Tool life
ii. Surface roughness
iii. Cutting force
iv. Material removal rate

The material properties that affect the machining performances are:

i. Shear strength
ii. Strain hardenability, the growth in strength and stiffness with increasing plastic deformation
iii. Hardness, the properties of material to prevent indentation
iv. Coefficient of friction, which leads to various reaction between the cutting tool and chips
v. Thermal conductivity

2.7.1 Tool Life

Tool life can be stated as the stage of time that the cutting tool performs proficiently. There are various of factors can be considered to affect the tool life, such as the cutting speed, feed rate, depth of cut and cutting conditions. Cutting tools are exposed to high stress and high temperatures. Tool wear gave many disadvantages such as it will decrease the tool life, the dimensional accurateness and the economics of cutting processes. The rate of tool life mostly affected by tool failures. Tool cutting edges lose their usefulness through wear, breakage, chipping, or deformation. Wear failures is the most common failures. Wear failures are very complex and involves chemical, physical and mechanical processes.