INVESTIGATION OF MACHINING PERFORMANCE OF COATED ALUMINA CUTTING TOOL INSERT WITH SAND BLASTING SURFACE PRETREATMENT

MOHD AZRULNIZAM B. ABD AZIZ

This report submitted in fulfillment of the requirements
For the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

ABSTRACT

The sand blasting process had been used as a process of surface pretreatment for the alumina cutting tool. The cutting tool insert were received as amorphous graphite deposited by using PVD technique. Machining workpiece was conducted on Ti alloy. Morphological observation by metallurgical microscope, the optical measurement has been used for observing the effect of flank wear and for surface roughness, the perthometer had been used in order to investigate the effect of surface pretreatment. The results show that alumina with PVD coated and sand blasting surface pretreatment had lower flank wear compare with alumina uncoated (as received) and alumina with only PVD coated. The surface roughness of alumina with sand blasting surface pretreatment are higher than as received cutting tool. The surface roughness of coated alumina with surface pretreatment is 0.634 nm higher than coated alumina without surface pretreatment which is 0.617 nm after machining process.The improvements of the alumina oxide affect their properties and cutting tool performance. The pretreatment with coated cutting tools give higher results in wear resistance compared to non-pretreatment and as received.

ABSTRAK

Proses semburan pasir telah digunakan sebagai satu proses prarawatan permukaan untuk pemotongan alumina. Sisipan alat pemotong telah diterima sebagai grafit amorfus yang didepositkan dengan menggunakan teknik PVD. Kerja pemesinan telah dijalankan ke atas aloi Ti. Pemerhatian morfologi oleh mikroskop logam, ukuran optik telah digunakan untuk memerhatikan kesan haus rusuk dan kekasaran permukaan, perthometer yang telah digunakan untuk menyiasat kesan prarawatan permukaan. Hasil kajian menunjukkan bahawa alumina dengan PVD bersalut dan pasir permukaan prarawatan semburan adalah rendah berbanding dengan alumina tidak bersalut (seperti yang diterima) dan alumina dengan PVD hanya bersalut. Kekasaran permukaan alumina dengan prapengolahan permukaan semburan pasir adalah lebih tinggi 0.634 nm daripada alat pemotong sebagaimana yang diterima iaitu 0.617 nm selepas proses pemotongan. Kekasaran permukaan daripada alumina bersalut dengan prarawatan permukaan adalah lebih tinggi daripada alumina yang bersalut tanpa peningkatan rawatan permukaan. Permukaan oksida alumina menjejaskan hartanah mereka dan prestasi alat memotong. Prarawatan dengan alat pemotong bersalut memberi keputusan dalam rintangan haus yang lebih tinggi berbanding dengan bukan prarawatan dan sebagaimana yang diterima.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS/ ABBREVIATIONS

V	Cutting speed
RPM	Revolution Per Minutes
Sfpm	Surface feet per minute
V_B	Flank wear
A	Area
D	Diameter
F	Feet rate
PVD	Physical Vapour Deposition
HFCVD	Hot Filament Chemical Vapour Deposition

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The challenge of modern machining industries is mainly focused on the achievement of high quality, in term of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase of the performance of the product with reduced environmental impact.

As an angular, durable blasting abrasive, aluminum oxide can be recycled many times. It is the most widely used abrasive grain in sand blast finishing and surface preparation because of its cost, longevity and hardness. Harder than other commonly used blasting materials, aluminum oxide grit powder penetrates and cuts even the hardest metals and sintered carbide. Plant, The arc process is successfully applied industrially especially for coating of tools (Brainard, 1979).

Approximately 50% lighter than metallic media, aluminum oxide abrasive grain has twice as many particles per pound. The fast-cutting action minimizes damage to thin materials by eliminating surface stresses caused by heavier, slower cutting media. The aluminum samples were coated with an arc-PVD

Sand blasting is a kind of mechanical equipment spraying the abrasives (metallic and nonmetallic) onto the surface of the work piece by dint of the compressed air as its power. The abrasives onto the surface for impacting and grinding, remove the impurity, mottle and oxide layer, at the same time, roughen the medium surface increasing the surface area, which can improve the adhesion so as to make the coating generate the best resistance of acid and alkali for better coating quality, also can reduce the residual stress and increase the surface hardness of basic materials (GuoyingLi, 1998).

The case study for this project is focused on the performance of the tool bit which is alumina coated with diamond that had been applied with sand blasting process and will be machined with the titanium work piece.

1.2 PROBLEM STATEMENT

Demands on the products and production processes are the driving factors behind developments in today's cutting technologies. Innovations such as the application of the advanced work material concepts, together with needs for non-polluting machining processes, increased flexibility and improved cost-effectiveness trigger the application of high performance conventional tool materials. Coating technology is one means of achieving a crucial enhancement in tool performance. The uncoated cutting tool shows significant wear resistant capability. However, the wear resistant could be improved by coating and also it can be improved wear resistant of cutting tool in turning operation. However, there is such a huge variety of available coating system is essential. Using accessible know-how concerning coated cutting tools and their behaviour in a wide range of the different machining tasks, the studies shows methods to test, evaluate and influence the properties of tool coatings by the sand blasting process. Applying this know-how may contribute to improving the systematic selection and development of coatings for specialized cutting operations.

The aluminum oxide (Al_2O_3) ceramic cutting tool has been used in machining because of their excellent properties such as high hardness, high resistance to chemical corrosion and good mechanical properties at high temperature. However their low strength, toughness and low thermal shock resistance limit their application. So, the cutting tools need to be improved. In order to solve this problem, the cutting tools need to be modified by using surface pre treatment and coating process. One type of the surface treatment is a sand blasting process. Sand blasting is used to remove the oxide layer on cutting tool to increase surface adhesion .Uncoated cutting tools show significant wear resistance capability. So, their wear resistance could be improved by coating process. The application of coating technology into cutting tool can give a lot of improvement in their structure and weariness.

1.3 PROJECT OBJECTIVE

The objectives of the project are to:

(i) To investigate the effect of sand blasting pretreatment on alumina cutting tool wear performance and surface morphology.
(ii) To determine the effect of coated cutting tool in machining, turning operation performance.

1.4 SCOPE OF PROJECT

In order to achieve the objectives of this project, the scopes are listed as below:

(i) Alumina was used as cutting tools inserts.
(ii) Surface pretreatment done with sandblasting process.
(iii) Machining to titanium work piece and wear rate evaluation.
(iv) Using an optical measurement machine to determine the surface morphology, microstructure of the coating and parameter to find the surface roughness.

1.5 IMPORTANCE OF PROJECT

The advantages of amorphous graphite coating for cutting tools is that it combines all the properties of natural graphite on the tool surface with the fracture toughness of carbide as the underlying tool material (Verlag, 1983). In addition, the hard amorphous graphite coating completely covers and protects all the complex three-dimensional shapes found on cutting edges of end mills, drills, and other round tools, as well as the multiple cutting edges of the inserts with complex chip breaker designs. Amorphous graphite can extend the life of uncoated carbide tools by 10 to 20 times and more when cutting non-metal composites, plastics, and non-ferrous metals with faster metal removal. The most impressive performance advantages of graphite-coated tools are in applications that demand abrasion resistance, corrosion resistance and lubricity that uncoated carbide tooling alone cannot offer. So that is why, the coated cutting tools also will give the lower result in wear rate compared to uncoated. The aluminum oxide grit powder has a wide variety of applications, from cleaning engine heads, valves, pistons and turbine blades in the aircraft industry to lettering in monument and marker inscriptions. It is also commonly used for matte finishing, as well as cleaning and preparing parts for metalizing, plating and welding. Aluminum oxide abrasive grain is the best choice for an abrasive sand blasting and polishing grain as well as for preparing a surface for painting. Aluminum oxide is used for its hardness and strength. It is widely used as a course in fine abrasive in grinding operation, particularly cutoff tools. The aluminum oxide cutting tools surface material will undergo surface pretreatment by sand blasting surface. The implementation of a cutting tool to this surface material will give benefit for it properties for example the hardness and weariness of cutting tool. The surface material will coated with crystalline diamond using PVD technique. The different result will be evaluated for the surface material between the coated cutting tool and uncoated cutting tools. The expected result is coating cutting tools will give the lower result in wear rate compared to uncoated.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide the review from previous research that is related to this final year project. There are previous researches on the alumina and the process of sandblasting surface. The method that are using which is used different materials and experiment design to obtain the best sand surface on the alumina coated.

2.2 GUIDELINES FOR DESIGNING EXPERIMENTS

In order to use the statistical approach in designing and analysing an experiment, it is necessary for everyone involved in the experiment to have a clear idea in advance of exactly what is to be studied, how the data are to be collected, and at least a qualitative understanding of how these data are to be analyzed. Further detail about the design of experiments one can refer to the 'Design and Analysis of Experiments' book (Montgomery, 2009).

(i) Recognition of and statement of the problem
(ii) Selection of the response variable
(iii) Choice of factors, levels, and ranges
(iv) Choice of experimental design
(v) Performing the experiment
(vi) Statistical analysis of the data
(vii) Conclusions and recommendation

2.3 CUTTING TOOL

2.3.1 Ceramics

Ceramics and ceramic composites are promising materials having rather high strength characteristics but quite low crack resistance properties at the same time. This is one of the major factors hindering the wide-scale application of these materials in various fields of human activities. The crack resistance is critical not only for ceramic products operating under extreme mechanical and thermal loads but also for structural components whose brittle fracture is intolerable even under arbitrary loads.

For many years, the performance of ceramics has been evaluated on the basis of full-scale tests. However, their fracture toughness characteristics have not always been the object of scientific interest. Wide-scale fracture toughness investigations were started only in the late 1980s. International prestandard aimed at the assessment of the accuracy and reliability of the data obtained from commonly accepted test methods were important steps in this field (Salem et al., 2002).

2.3.2 Aluminum Oxide (Alumina)

The mechanical characteristics of aluminum offer an increasing application field, especially where lightweight constructions are required. The demands for improved characteristics such as higher strength and greater durability are achieved by the development of new aluminum alloys. Continuous efforts are made in research into new possibilities for making use of the advantages of aluminum in applications that were reserved up to now for harder and more wear-resistant materials. Because of their environmental benefits modern PVD processes represent a better alternative to a number of conventional coating processes to deposit wear-resistant films on aluminum surfaces (Knotek, 1983).

Aluminum-based coatings are potential candidates for a sacrificial protection of steel. Such coatings, elaborated by magnetron sputtering, offer a good corrosion protection but often present poor tribological properties (Sanchette et al., 1993).

Aluminum and multilayer aluminum coatings have been deposited on steel substrates. Aluminum multilayer on low carbon steel lead to better corrosion resistance than a monolayer coating.Considering steel corrosion, aluminum coatings may ensure a good protection. It is well known that aluminum is electrochemically more active than steel and will be corroded in the case of a galvanic coupling, while titanium is less active and must be compact to prevent any corrosion of the substrate (Mazille, 1992).

2.3.3 Tungsten Carbide

Tungsten carbide is actually grains of tungsten carbide in a matrix. Commonly this matrix is cobalt. This is pretty handy because it can mix carbon, tungsten and cobalt together and sinter them. The tungsten and the carbon form tungsten carbides and the cobalt does not. It's getting very hard grains for wear resistance and the cobalt stays relatively soft for impact resistance. These are sometimes called cemented materials and cemented tungsten carbide because the tungsten carbide grains are cemented together with cobalt or other materials such as nickel and nickel-chrome alloys (Bolz et al., 1973).

Tungsten carbide is fairly yielding compared to the ceramics. You can take tungsten carbide, heat it and bend it into spirals and curves for cutters, which you cannot do with ceramics. Tungsten carbide, or WC, has a number of unique and impressive characteristics, the most significant being the ability to resist abrasion. It is the hardest metal known to man. Sintered and finished carbide has a combination of compressive strength, extreme hot hardness at high temperatures, and resistance to abrasion, corrosion and thermal shock (Opitz.H et al., 1967).

2.4 PRETREATMENT

2.4.1 Pretreated by Sand Blasting

Sand blasting is a kind of mechanical equipment spraying the abrasives (metallic and nonmetallic) onto the surface of the work piece by dint of the compressed air as its power. The abrasives onto the surface for impacting and grinding, remove the impurity, mottle and oxide layer, at the same time, roughen the medium surface increasing the surface area, which can improve the adhesion so as to make the coating generate the best resistance of acid and alkali for better coating quality, also can reduce the residual stress and increase the surface hardness of basic materials (Raykowski et al., 2001).

The effect is similar to that of using sandpaper, but provides a more even finish with no problems at corners or crannies. Sandblasting can occur naturally, usually as a result of the particle blown by the wind causing eolian erosion, or artificially, using compressed air. An artificial sandblasting process was patented (Benjamin, 1870).

According to the blasting away, blast machine can be subdivided into pressure fees type and suction type. The pressure feed type mixing the compressed air and abrasives while blasting in the same container, can make the best use of compressed air and be easy to regulate the flow rate of air and sand, which not only can be applied to large area processing, but also can blast small parts (Jianxin et al., 2000).

2.5 COATED THE CUTTING TOOLS BY HFCVD/PVD TECHNIQUE

2.5.1 PVD Technique

Physical vapor deposition (PVD) coated particularly in applications where sharp edges are required and in cutting applications that have a high demand for a tough cutting edge, e.g. Drilling. In solid carbide cutting tools (end-mills and drills) PVD is the standard coating technology (Wertheim, 1998) “The stress characteristic of the PVD coating, in combination with the usual small layer thickness, provides good cutting edge strength, fracture toughness and bending strength".

2.5.2 HFCVD Technique

Chemical Vapor Deposition (CVD) involves the dissociation and/or chemical reactions of gaseous reactants in an activated (heat, light, plasma) environment, followed by the formation of a stable solid product. The deposition involves homogeneous gas phase reactions, which occur in the gas phase, and/or heterogeneous chemical reactions which occur on/near the vicinity of a heated surface leading to the formation of powders or films, respectively. Though CVD has been used to produce ultrafine powders, this review article is mainly concerned with the CVD of films and coatings (DeLodging, 1893).

2.5.3 Comparison between PVD and CVD

Table 2.1: Comparison between CVD and PVD coating technique

Physical Vapour Deposition (PVD)	Chemical Vapour Deposition (CVD)
(i) In PVD, the material that is introduced onto the substrate is introduced in solid form whereas.	(i) CVD it is introduced in gaseous form
(ii) In PVD, atoms are moving and depositing on the substrate.	(ii) CVD the gaseous molecules will react with the substrate.
(iii) PVD coating is deposited at a relatively low temperature around 250 ^{0}C to 450 ^{0}C	(iii) CVD uses high temperature in the range of 450 ^{0}C to 1050 ^{0}C.
(iv) PVD is suitable for coating tools that are used in application that demand a tough cutting edge.	(iv) CVD is mainly used for depositing compound protective coatings.

2.5.4 PVD Carbon coating

Of all the available tool coatings, amorphous graphite has the properties of a super-hard material that protect the tool's cutting edge when machining highly abrasive non-ferrous metals and composites. PVD coatings with metal nitride compositions, such as titanium, aluminum nitride, have a micro hardness value of only one-third that of amorphous graphite, but the amorphous carbon coatings with micro hardness values that reach up to about one-half that of crystalline diamond (Mahan, 2000).

The performance advantage of amorphous graphite coating for cutting tools is that it combines all the properties on the tool surface with the fracture toughness of carbide as the underlying tool material. In addition, the amorphous graphite coating completely covers and protects all the complex three-dimensional shapes found on cutting edges of end mills, drills, and other round tools, as well as the multiple cutting edges of the inserts with complex chip breaker designs (Qi. Y et al., 2005).

Amorphous graphite coating can extend the life of uncoated carbide tools by 10 to 20 times and more when cutting non-metal composites, plastics, and non-ferrous metals with faster metal removal. The most impressive performance advantages of amorphous graphite coating tools are in applications that demand abrasion resistance, corrosion resistance and lubricity that uncoated carbide tooling alone cannot offer.

2.6 MACHINING TO TITANIUM WORKPIECE AND WEAR RATE EVALUATION

2.6.1 Titanium

Titanium is a silvery white metal, its high strength-to-weight ratio and corrosion resistance at room and elevated temperatures. Titanium alloys have been developed for service at 550 ^{0}C for long periods of time and at up to 750 ^{0}C for shorter periods.

Unalloyed titanium, known as commercially pure titanium, has excellent corrosion resistance for applications where strength considerations are secondary. Aluminum, vanadium, molybdenum and other alloying elements impart properties such as improved workability, strength and harden ability.

The body-centered cubic structure of titanium (beta-titanium) is above 880 ^{0}C and is ductile; whereas it's hexagonal close-packed structure (alpha-titanium) is somewhat brittle and is very sensitive to stress corrosion. A variety of other structures (alpha, near –alpha and beta) can be obtained by alloying and heat treating, so that the properties can be optimized for specific application. Titanium aluminide intermetallics (TiAl and Ti3Al) have higher stiffness and lower density than convectional titanium alloys and they can withstand higher temperatures. Manufacturing engineering and Technology, fifth edition in SI units.

2.6.2 Turning

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

(i) With the work piece rotating
(ii) With a single-point cutting tool
(iii) With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setups, which are often employed in turning. In such setups, each tool operates independently as a single-point cutter.

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

(i) Speed - always refers to the spindle and the work piece. When it is stated in revolutions per minute (*RPM*) it tells their rotating speed. But the important figure for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference (in feet) of the work piece before the cut is started. It is expressed in surface feet per minute (*sfpm*), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same.

(ii) Feed - always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in inches (of tool advance) per revolution (of the spindle). The figure, by the way, is usually much less than an inch and is shown as decimal amount.

(iii)Depth of Cut - is practically self explanatory. It is the thickness of the layer being removed from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in inches. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

2.6.3 Tool wears

Tool wear mechanisms most studies agree that there are five basic causes of wear. Tool wear mechanisms are divided into five categories and can occur in combination with the others or singly. “The causes of wear do not always behave in the same manner, nor do they always affect wear to the same degree under similar cutting conditions " (Nee, 1998). The five categories are listed below with a brief explanation (Ullman, 1997). Abrasive wear was a mechanical action that occurs when hard particles found within the work piece cut, chip, groove, or dislodge sections of the cutting tool surface.

(i) Plastic deformation of the cutting edge was caused by the extreme pressure imposed on the cutting edge that causes a depression or bulging of the edge. The more the tool deforms the greater the pressure and temperature on the tool resulting in more deformation and possible edge wipe out.

(ii) A chemical reaction between the tool and the work piece occurs at elevated temperature. The tool has tiny sections that are weakening due to the pressure and temperature of the cutting process. These tiny sections have smaller particles within them that react to the work piece material thus forming a bond between the tool and the work piece. As the bond strengthens the weakened particles from the tool are carried away with the chip or stay with the work piece.

(iii) Diffusion between work and tool material occurs when a section of the tool reaches a critical temperature and a change in composition happens between the tool and the chip interface. This composition change usually induced by elevated temperature and the bond between the section and the chip strengthen as the section was torn away from the tool.

(iv) The welding of asperities between work piece and the tool occur at lower temperatures than the diffusion and chemical reaction. These asperities are joined to the work piece material as it was removed in the work-hardened chip. The high pressure in the cutting process enables the asperities to be pulled away from the tool as the chip removed from the work piece.

2.6.4 Metallurgical Microscope MEIJI TECHNO IM 7000 Series

Microstructure analysis of film morphology was done using Metallurgical Microscope MEIJI TECHNO IM 7000 Series is used to determine the surface morphology, microstructure and grain size of the coating. Metallurgical uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology texture. In most applications, data were collected over a selected were on the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Chapter 3 was to discuss the methodology of the project in general, with a specific focus on improvement of the cutting tool which is alumina oxide by sand blasting surface pre treatment and coating for machining process. The work is based on methodology flow chart. Chapter 3 also presents current progresses on research of the cutting tool improvement process. Understanding prior and current research in this project provides a method for the research contributions outlined in subsequent chapters.

The methodology flow chart is used as guidelines and the sequences to make this project do with progress. As refer to Figure 3.1, firstly literature review was being studied in the field that regards to this project.