UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

WEAR PERFORMANCE OF ALUMINA BASED CUTTING TOOL WHEN MACHINED WITH AISI 1045 CARBON STEEL

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Master of Manufacturing Engineering
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A thesis submitted
in fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Manufacturing System Engineering)

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DECLARATION

I declare that this dissertation/project entitled "Wear Performance of Alumina Based Cutting Tool when Machined with AISI 1045 Carbon Steel" is the result of my own research except cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………

Name : ……………………………

Date : ……………………………

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Manufacturing Engineering (Manufacturing System Engineering).

Signature : ....

Supervisor Name : PM IR. DR. MOHD HADZLEY BIN ABU BAKAR

Date : 7/6/2018

DEDICATION

This work is dedicated to my beloved parents who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve,

Mr. Mazda @ Mazdarudin bin Md. Isa & Mdm. Zoraida binti Muhamad,

other family members,

and

wonderful coursemates whom I shall forever remembered and grateful for your presence and support.

ABSTRACT

Latest developments in the manufacturing industry aim to produce high quality products with reduced time and cost. Automated and flexible manufacturing systems such as the computerized numerical control (CNC) machines are employed due to the capable of minimizing the processing time while achieving high accuracy. Machining essentially will produce high cutting temperature that reduce tool life. Tool wear is a paramount factor in determining tool life. It affects surface quality and precision of dimensions of the workpiece. Therefore, ceramic cutting tools are widely used for machining hard materials such as cast irons, alloy steels and carbon steels. These materials are so hard that they possess wide range of hardness and high temperature resistance due to high hot hardness and very good chemical stability (Whitney, 1994). Alumina cutting tool is commonly used for machining hard materials in high speed. It is also suitable for dry machining for its uniqueness in mechanical and chemical properties, especially at high temperature, such as high wear resistance, relatively low chemical reactivity with steels, high hot hardness, chemical inertness and high abrasion resistance (Deng et al., 2012). However, it is still expected that there will be temperature rise that may result to molten metal to cause material deformation. Another type of alumina cutting tool; alumina with zirconia reinforcement is said to offer an improved properties from the alumina based. The two types of ceramic cutting tool are fabricated and machined using AISI 1045 carbon steel to evaluate and compare the performance of tool wear and surface roughness of the workpiece. Results shows that both alumina and alumina-zirconia is capable to be fabricated as cutting tools and solidly represent the round shape of cutting tool with adequate hardness. Cutting tool fabricated with alumina and zirconia powder exhibited better wear performance as compared to the cutting tool with alumina only. The alumina-zirconia based cutting tool recorded a maximum of 200s tool life as compared to 145s for alumina based cutting tool. Surface roughness when AISI 1045 is machined with both cutting tools exhibited almost similar characteristics. Maximum value is recorded at 3.16 µm when machining with alumina-zirconia cutting tool after 150s. Whereas, minimum surface roughness is recorded at 0.67 µm with the same cutting tool type; the alumina-zirconia based which is at 150s cutting time. Wear development of cutting tool demonstrated uniform wear land at the early stage of machining before gradually notching at the specific region of wear before attachment of built up edge along cutting edges. For alumina based tool, the wear mechanism is dominated by the obvious formation of built up edge and adhesive wear. Whereas for alumina-zirconia based cutting tool, wear mechanism is dominated by the minor formation of built up edge and small particles detachment at the cutting edge.

ABSTRAK

Perkembangan terkini dalam industri perkilangan bertujuan untuk menghasilkan produk berkualiti tinggi dengan mengurangkan masa dan kos. Sistem perkilangan automatik dan fleksibel seperti mesin kawalan berangka berkomputer (CNC) digunakan kerana mampu meminimumkan masa pemprosesan selain ketepatannya yang tinggi. Pemesinan pada dasarnya akan menghasilkan suhu pemotongan tinggi yang mengurangkan hayat alat. Haus alat adalah faktor utama dalam menentukan hayat alat. Ia memberi kesan kepada kualiti permukaan dan ketepatan dimensi bahan kerja. Oleh itu, alat pemotong seramik digunakan secara meluas untuk pemesinan bahan keras seperti besi tuang, keluli aloi dan keluli karbon. Bahan-bahan ini sangat sukar sehingga mereka mempunyai pelbagai kekerasan dan rintangan suhu tinggi kerana kekerasan panas yang tinggi dan kestabilan kimia yang sangat baik (Whitney, 1994). Alat pemotong alumina biasanya digunakan untuk pemesinan bahan keras dalam kelajuan tinggi. Ia juga sesuai untuk pemesinan kering untuk keunikannya dalam sifat mekanikal dan kimia, terutamanya pada suhu tinggi, seperti rintangan haus yang tinggi, kereaktifan kimia yang rendah dengan keluli, kekerasan panas yang tinggi, ketaksempurnaan kimia dan rintangan lelasan yang tinggi (Deng et al., 2012). Walau bagaimanapun, dijangkakan bahawa kenaikan suhu akan mengakibatkan logam cair menyebabkan penyimpangan bahan. Satu lagi jenis alat memotong alumina; alumina dengan penambahan zirkonia dikatakan menawarkan sifat yang lebih baik dari alumina. Kedua-dua jenis alat pemotong seramik dibuat dan dimesin menggunakan keluli karbon AISI 1045 untuk menilai dan membandingkan prestasi alat dan kekasaran permukaan bahan kerja. Keputusan menunjukkan bahawa kedua-dua bahan ini mampu direka sebagai alat pemotong dan jelas mewakili bentuk bulat alat pemotong dengan kekerasan yang mencukupi. Alat pemotongan yang dibuat dengan serbuk alumina dan zirkonia mempamerkan prestasi haus yang lebih baik berbanding alat pemotong dengan alumina sahaja. Alat memotong alumina-zirconia mencatatkan maksimum 200s hayat alat berbanding 145s untuk alat pemotong berasaskan alumina. Kekasaran permukaan apabila AISI 1045 dipotong dengan kedua-dua alat pemotong menunjukkan ciri-ciri yang hampir sama. Nilai maksimum dicatatkan pada 3.16 µm apabila pemesinan dengan alat pemotong alumina-zirconia pada 150s. Manakala kekasaran permukaan minimum direkodkan pada 0.67 µm dengan jenis alat pemotong yang sama; dengan masa pemotongan 150s. Haus pembangunan alat pemotong menunjukkan tanah haus seragam pada peringkat awal pemesinan sebelum beranjak secara beransur-ansur di rantau tertentu haus sebelum lampiran tepi dibina di sepanjang sisi pemotong. Untuk alat berasaskan alumina, mekanisme haus dikuasai oleh pembentukan jelas kelebihan binaan dan pelekat. Sedangkan untuk alat pemotong berasaskan alumina-zirconia, mekanisme haus dikuasai oleh pembentukan kecil tepi terbina dan pengurangan zarah kecil di sudut.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

Al_2O_3	-	Alumina
ZrO_2	-	Zirconia
°	-	Degree
˚C	-	Degree of Celsius
cm	-	Centimetre
g	-	Gram
m	-	Meter
mm	-	Millimetre
mol	-	Mole
K	-	Kelvin
HF	-	Hydrogen fluoride
H_2SO_4	-	Sulphuric acid
rev	-	Revolution
RPM	-	Revolutions per minute
D_{avg}	-	Average diameter of workpiece, mm
d	-	Depth of cut, mm
f	-	Feed rate, mm/rev
N	-	Rotational speed of workpiece, RPM
D_o	-	Initial diameter of workpiece, mm
D_f	-	Final diameter of workpiece, mm
d	-	Depth of cut, mm
f	-	Feed rate, mm/rev
V	-	Cutting speed, m/min
D	-	Diameter of workpiece, m
N	-	Rotational speed of workpiece, RPM
D_o	-	Initial diameter of workpiece, mm

D_f	-	Final diameter of workpiece, mm
V	-	Cutting speed, m/min
D	-	Diameter of workpiece
M	-	Mega
G	-	Giga
Pa	-	Pascal
psi	-	Pounds per square inch
ksi	-	One thousand pounds per square inch
BUE	-	Built up edge
Ra	-	Surface roughness
WC	-	Tungsten carbide
Vc	-	Cutting speed
F	-	Feed rate
DoE	-	Design of experiment
ANOVA	-	Analysis of Variance
CNC	-	Computerised Numerical Control

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Tool wear is a paramount factor in determining tool life. It affects surface quality and precision of dimensions of the workpiece. Machining is the process of removing unwanted materials into a desired shape that serves with function. There are three major factors that contributed to efficiency of machining which are cutting tools, workpiece material and cutting parameters. The machining process strongly depends on the cutting tool to shear the workpiece and perform abrasive actions. If cutting edge fails, tool is obsolete and no longer can be used. Therefore, ceramic cutting tools are widely used for machining hard materials such as cast irons, alloy steels and carbon steel. These materials are so hard that they possess wide range of hardness and high temperature resistance due to high hot hardness and very good chemical stability (Whitney, 1994). The ceramic cutting tool has been extensively used to machine these materials due to their excellent properties to endure load in high speed and high temperature machining.

Latest developments in the manufacturing industry aim to produce high quality products with reduced time and cost. Automated and flexible manufacturing systems such as the computerized numerical control (CNC) machines are employed due to the capable of minimizing the processing time while achieving high accuracy. Turning process is one of the most used methods for cutting and finishing of machined parts (Gao et al., 2016).

Machining essentially will produce high cutting temperature, which not only reduces tool life, but also affect the product quality. High performance cutting tools that have high strength, high toughness and high hardness are required to machine these materials effectively and safely (Azuan, 2013; Khan *et al*, 2009). Machining using a cutting tool is done either in wet or dry condition. Wet machining has been a concern in terms of machining cost, health and effects on the environment.

So the study is focused on the performance of machining in dry condition to counter the issues occurred if cutting fluids are involved. Dry machining has been proved to offer better surface roughness due to softening caused by heat generation during machining the material (Azevedo, 2013). Despite those advantages, it may affect the life span of cutting tool. Amongst many ceramic cutting tools, alumina based materials are frequently used materials for dry cutting and high speed machining. The alumina based cutting tools have unique mechanical and chemical properties, especially at high temperature, such as high wear resistance, relatively low chemical reactivity with steels, high hot hardness, chemical inertness and high abrasion resistance. As promising as the cutting tool can be, alumina alone has its own flaws. The addition of zirconia to alumina structure is said can increase the density, flexural strength and fracture toughness of alumina, basically fabricating a more advanced cutting tool.

The study also includes the fabrication of alumina and alumina-zirconia cutting tools and experimental procedures to investigate the performance of both of the cutting tools and the material AISI 1045 carbon steel using various approach and equipment.

1.2 Problem Statement

There are many ceramic-based cutting tools used in the industry. Cemented carbide, cubic boron nitrite, silicon carbide and diamond are among the frequent and preferred cutting tools. This is due to their excellent performance in high speed and high temperature machining (Kalpakjian and Schmid, 2013). It goes back to the nature of ceramics that possess variety properties such as high hardness, high thermal shock resistance and high chemical stability. Composite ceramics cutting tools are developed in order to eliminate the use of coolant and hence promoting sustainable machining practice.

Alumina cutting tool is commonly used for machining hard materials in high speed. It is also suitable for dry machining for its uniqueness in mechanical and chemical properties, especially at high temperature, such as high wear resistance, relatively low chemical reactivity with steels, high hot hardness, chemical inertness and high abrasion resistance (Deng et al., 2012). However, it is still expected that there will be temperature rise that may result to molten metal to cause material deformation. Another type of alumina cutting tool; alumina with zirconia reinforcement is said to offer an improved properties from the alumina based.

Cutting parameters also affect wear performance of the cutting tool. Therefore, it is necessary to study the performance of both of the alumina cutting tools in dry condition. Both types of the cutting tools is fabricated to go through machining process. It is done to investigate their performance in terms of tool wear as well as effect to surface roughness of the workpiece used, thus comparison can be made within those aspects. Wear mechanisms occured from the machining can also be observed and understood better.

1.3 Objectives

The objectives of the study are:

1) To fabricate alumina and alumina-zirconia cutting tools.
2) To evaluate the performance of alumina and alumina-zirconia cutting tools in terms of tool wear and surface roughness when machined with AISI 1045 carbon steel in dry condition.
3) To compare the performance of alumina and alumina-zirconia cutting tools.
4) To analyse the failure modes of alumina and alumina-zirconia cutting tools after machined with AISI 1045 carbon steel.

1.4 Scope of Study

The study involves a machining process that is conducted using a CNC lathe machine. The cutting tools, alumina and alumina-zirconia insert is fabricated. Then the alumina cutting tool is to be machined with AISI 1045 carbon steel by varying parameters such as cutting speed, feed rate while depth of cut is kept constant. There might be some uncontrollable factors that may influence the surface roughness. However, only these controllable parameters are considered and tested in this study as the uncontrollable factors such as vibration are unpredictable and require special tools such an accelerometer for vibration detection and measurement. The performance of the machining is evaluated in terms of flank wear and surface roughness values. A surface roughness tester is used to obtain the values. A microscope is used to observe the surface profile to study the failure modes of alumina cutting tool after machined with AISI 1045 carbon steel. The effects of cutting parameters on the performance of the cutting tools and AISI 1045 carbon steel is analysed and evaluated. Further comparison between the cutting tools is presented in the study.

1.5 Organisation of Report

This master project report consists of several completed chapters. Chapter 1, Chapter 2 and Chapter 3 are completed during Master Project 1, meanwhile Chapter 4 and 5 are finalised during Master Project 2. In Chapter 1, introduction of the project such as background, objective and scope of study is discussed. Then, Chapter 2 discussed the literature review of the study such as introduction to machining, ceramics cutting tools, causes of tool wear and failure, surface roughness and so on. Chapter 3 deliberated the methodology of study which elaborate in details about the parameters selected and the procedures needed to carry out the experiment. Chapter 4 presented the results and discussion on analysis obtained through the experiment. Lastly, Chapter 5 concluded the findings of study and recommendations are also provided for future improvement.