EFFECT OF SINTERING TEMPERATURE AND SOAKING TIME ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF ALUMINA- ZIRCONIA CUTTING TOOL

Submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled "Effect of Sintering Temperature and Soaking Time on Microstructure and Mechanical Properties of Alumina-Zirconia Cutting Tool" is the result 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 Universiti Teknikal Malaysia Melaka as partial fulfilment of the requirements for degree of Bachelor of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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(PM Ir. Dr. Mohd Hadzley b. Abu Bakar)

ABSTRAK

Kajian ini adalah untuk mengenal pasti kesan masa rendaman dan suhu persinteran kepada sifat mekanikal dan mikrostruktur alat pemotong alumina-zirkonia. Secara umum, alumina dapat digunakan untuk aplikasi alat pemotong kerana ianya mampu menghasilkan kualiti permukaan yang baik dan mempunyai kekerasan pada suhu tinggi. Namun, alumina mempunyai ketangguhan patah yang rendah dan mudah untuk rapuh yang menyebabkan kegagalan malapetaka dan sumpik. Ciri ini tidak sesuai untuk aplikasi mata alat dan disebabkan itu zirkonia telah ditambah dalam matriks alumina untuk meningkatkan sifat mekanikal alumina termasuklah meningkatkan ketangguhan patah. Walau bagaimanapun, kajian berdasarkan suhu persinteran melebihi 1500℃ dan masa rendaman masih kurang. Oleh itu, kajian ini memfokuskan kepada fabrikasi mata alat alumina-zirkonia dan mengenal pasti sifat mekanikal seperti kekerasan, ketumpatan, rintangan haus dan mikrostruktur berdasarkan suhu persinteran dan masa rendaman. Komposisi campuran serbuk, 80 bt % alumina + 20 bt % zirkonia (YSZ) telah dicampurkan menggunakan mesin ball mill dengan penambahan polietilena gliko (PEG) sebagai ejen pengikat. Kemudian, sampel telah diberi tekanan 10 tan menggunakan mesin tekanan hidraulik dan seterusnya sampel dipadatkan melalui kaedah tekanan isostatik sejuk dengan tekanan 300MPa. Sampel disinter dalam lingkungan suhu persinteran 1500℃ hingga 1700℃ dengan julat masa rendaman dari 4 jam hingga 6 jam. Sampel kemudiannya diuji dengan ujian kekerasan, ketumpatan, tribologi iaitu rintangan haus dan mikrostruktur menggunakan alat penguji kekerasan Vickers, densimeter, tribometer dan “scanning electron microscope (SEM)”. Keputusan menunjukkan pada suhu persinteran 1500℃, masa rendaman 6 jam manghasilkan saiz partikel yang lebih kecil, ketumpatan maksimum iaitu 4.0916g/cm3 dan kekerasan 1321.23 Hv. Keputusan juga menunjukkan maksimum koefisien geseran adalalah pada suhu persinteran 1600℃ dan masa rendaman 5 jam.

ABSTRACT

This research identified the effect of soaking time and sintering temperature on the mechanical properties and microstructure of alumina-zirconia cutting tool. It is known alumina can be used for cutting tool application as it is able to produce good surface quality and has high-temperature performance and hardness. However, alumina also has lower toughness and easily brittle which in turn, cause catastrophic failure and chipping. These properties are not suitable for cutting tool application. Thus, zirconia was added in alumina matrix to enhance alumina mechanical properties which include, improving its fracture toughness. But, there is still a lack of studies based on sintering temperature greater than 1500℃ with soaking time. So, this research was focused on the fabrication of the alumina-zirconia cutting tool and to investigate the mechanical properties such as hardness, density, wear resistance and microstructure with respect to the sintering temperature and soaking time. The composition of powder mixture, 80 wt % alumina + 20 wt % yttria stabilized zirconia (YSZ) was mixed using ball mill machine with additional of polyethylene glycol (PEG) as a binder agent. Then, the samples were pressed using a hydraulic hand press machine under 10 tons pressure and eventually, the samples were compacted through the cold isostatic pressing method with 300 MPa pressure. Next, the green compacts were sintered in the range of 1500℃ to 1700℃ with a range of a soaking time from 4 hours to 6 hours. The sintered samples were then proceeded for hardness, density, tribology test specifically, wear test and microstructure using Vickers hardness tester, electronic densimeter, micro pin-on-disc tribotester and scanning electron microscope (SEM) respectively. The data collected from the testing were then analysed and discussed. The results showed the sintering temperature at 1500℃, 6 hours soaking time produced smaller grain size, maximum density and hardness of 4.0916g/cm3 and 1321.23 Hv respectively. It is also found that the maximum coefficient of friction recorded was 0.28 at 1600℃ sintering temperature and soaking time of 5 hours.

DEDICATION

This project won’t be completed without continuous support from my parents, sisters and brothers. Not to forget to my project supervisor, PM Ir Dr Mohd Hadzley and friends for keeping me motivated in completing this project successfully.

Thank you!

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In the name of Allah the most gracious, the most merciful, praise to Allah, with his permission I manage to complete this final year project with success even though there are obstacles and challenges that need to face.

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LIST OF ABBREVIATIONS

SEM	-	Scanning electron microscope
UTeM	-	Universiti Teknikal Malaysia Melaka
FKP	-	Fakulti Kejuruteraan Pembuatan
DOE	-	Design of Experiment
COF	-	Coefficient of Friction
ANOVA	-	Analysis of Variance
YSZ	-	Yttria Stabilized Zirconia
PEG	-	Polyethylene glycol
Al_2O_3	-	Alumina
CBN	-	Cubic boron nitride
PCD	-	Polycrystalline diamond
CIP	-	Cold isostatic pressing
SiC	-	Silicon carbide
Si_3N_4	-	Silicon nitride
HSS	-	High speed steel
BUE	-	Built-up edge
CVD	-	Chemical vapour deposition
PVD	-	Physical vapour deposition
TiN	-	Titanium nitride
TiC	-	Titanium carbide
TiB_2	-	Titanium diboride
ZrO_2	-	Zirconia
SiC_p	-	Silicon carbide platelets
(W, Ti)C	-	Tungsten titanium carbide
Ti(C, N)	-	Titanium carbide nitride
SiC_w	-	Silicon carbide-whisker

LIST OF SYMBOLS

cm	-	Centimetre
m	-	Metre
%	-	Percent
g/cm^3	-	Grams per centimetre cube
wt. %	-	Weight percent
mm	-	Millimetre
°C	-	Degree celsius
phr	-	Part per hundred resin
mm/min.	-	Millimetre per minute
Hv	-	Hardness values
µm	-	Micrometre
MPa $m^{1/2}$	-	Megapascal under root metre
HRA	-	Rockwell hardness measured on A
N	-	Newton
cm/s	-	Centimetre per second
K	-	Kelvin
K/min	-	Kelvin per minute
°C/min	-	Degree celcius per minute

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In the manufacturing industry, there are a lot of machines used to cut the stocks or parts through several machining operations such as turning, milling and drilling. In order to accomplish the machining processes, the cutting tool is the utmost important equipment. In the market, there are various types of cutting tool materials available, ranging from plain carbon steels, high-speed steels, cubic boron nitride (CBN), polycrystalline diamond (PCD), cemented carbide, ceramics and cermets and also a natural diamond. These cutting tools types have their own strengths and weaknesses. According to Kalpakjian, the ceramic cutting tool has been used widely in the industry (Ting, 2018). Ceramic, specifically, alumina, is used as a cutting tool as this type of material has very high strength that allows it to cut even the hardest materials. It is also reported that ceramic cutting tools are very good at producing good surface finish quality on precision metal parts. However, the brittleness and low toughness properties in this type of cutting tool have embarked the introduction of zirconium oxide or zirconia in the alumina matrix. It is believed that the addition of zirconia, especially, yttria-stabilized zirconia (YSZ) has improved the fracture toughness and hardness of alumina cutting tool.

Many preliminary kinds of researches have been done on the addition of other materials into alumina-zirconia structure to overcome its weaknesses such as low fracture toughness that is vital properties for each cutting tools. Despite that, there is research by Hao et al., (2010) which is focused on only sintering rates instead of sintering temperature. There is also a lack of trials using cold isostatic pressing (CIP) method after the green compacts were brought to press using a pressing method by a manual hydraulic hand press machine.

Mustaffa et al. (2006), in their investigation, only concentrated on the mechanical properties of zirconia toughness alumina composite using cold isostatic pressing and uniaxial pressing without further the investigation on detailed sintering process parameters such as sintering temperature and soaking time. Furthermore, there are very few studies on tribology of ceramic cutting tool especially alumina-zirconia cutting tool. Thus, the effect of sintering temperature and soaking time on the microstructure and mechanical properties of alumina-zirconia cutting tool is the main target of this paper. The mechanical properties that will study deeper are hardness, density after sintering process and tribology.

1.2 Problem Statement

Alumina has been widely used for cutting inserts application since it resists to hot hardness and high abrasion. Stable in chemical also has made this type of material has been selected as one of the candidates for cutting inserts fabrication, even it is better than high-speed steels and carbide cutting inserts. But, lower toughness in alumina cutting tool makes it easily suffer from chipping and catastrophic failure. It is also reported that alumina and zirconia are the ceramics that do not easily react when there are oxidation processes occur compared to other ceramics like carbide-based ceramics (SiC) and nitride-based ceramics (Si3N4). However, alumina and zirconia are relatively low in hardness. This condition makes alumina not suitable in making the structure as high strength is the important properties that materials involved must have. Besides that, zirconia has shown high toughness property after it has been sintered. But, it is lower in thermal conductivity than alumina by almost three times. The advantages and disadvantages of alumina and zirconia make these two types of materials become the hot topics for researches to mix them and gain their superior properties. However, the detailed study on the effect of soaking time and sintering temperature above 1500°C to the microstructure and mechanical properties of alumina-zirconia has not been well established. Thus, this is the main goal of this study.

1.3 Objectives

The purposes of this study are as follows:

(a) To fabricate the cutting tools based on alumina-zirconia.

(b) To evaluate the appropriate sintering temperature and soaking time when fabricated alumina-zirconia cutting tools based on density and tribology (wear).

(c) To investigate the microstructure and hardness of fabricated cutting tools based on maximum and minimum density.

1.4 Scope

Ceramic cutting tools available in various types of ceramic materials. Thus, the development of alumina-zirconia cutting tool is the main focus of this study. In addition, there are also several types of tests that can be done on ceramic cutting tool including mechanical properties tests, microstructure tests and machining tests. This research is restricted only for mechanical properties and microstructure tests. Furthermore, there are several types of cutting tool geometries such as triangular, 35° diamond, square and circular. This research will focus on the development of a circular-shaped cutting tool only as this type of cutting tool has the greatest strength and the fabrication of the circular-shaped mould is the easiest. Other than that, will not cover in this study due to time constraint and semester.

1.5 Significant of Study

Alumina-zirconia cutting tool will be fabricated as its promised advantages such as high abrasion resistance, chemically inert and resist from elevated temperature during machining. In this research, yttria-stabilized zirconia (YSZ) will be added in the alumina powder as the additive material. Sintering temperature and soaking time are the parameters that will be controlled in this research as these two parameters are important as they will affect the mechanical properties and microstructure of the sintered cutting tools.

1.6 Organization of Report

This research report focuses on the effect of only two variables which are sintering temperature and soaking time on the mechanical properties and microstructure of alumina and zirconia as a cutting tool. First, a brief background of this study, problem statement, objectives, scope and significant research of ceramic cutting tool are discussed in chapter 1. Next, in chapter 2, a thorough discussion on alumina and zirconia cutting tool and the variables that are concerned in this research, sintering temperature and soaking time are presented. Then, in the methodology chapter, the processes and equipment involved in this research are presented. After that, the results gained are discussed in chapter 4. Finally, the conclusion and recommendations are presented in the last chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the cutting tool, the types and properties of materials incorporate with the cutting tool. Next, a brief cutting tool geometry and tribology explanations are given. Apart from that, the processes that previous researchers have been applied in their work in the fabrication of cutting tool, also are brought into the discussion.

2.2 Cutting tool

Figure 2.1: Wide ranges of cutting tools from shapes, geometries, coatings and compositions are available (NTK Cutting Tools The Americas, n.d.)

According to Collins online dictionary, a cutting tool is defined as an object with a pointed tool which is mounted in a machine tool and used for cutting the materials ("Definition," 2018). The cutting tool has been used widely for many machining methods such as turning, milling, boring and drilling. Tooling refers to non-consumables and consumable items. Among of the non-consumable items are tool holders, cutting inserts and tools, screws, washers, tool presetters, tool handling equipment and screwdrivers/Allen keys. The examples of consumable items mentioned are cutting fluid, hand wipes and tool kitting grease or oils. There are many types of cutting tools or inserts in terms of shapes, geometries, compositions and coatings available in the market. Cutting tool associated with several problems which are tool life, insert breakage and edge chipping. These are the reasons why cutting data such as workpiece material, depth of cut, feed rate and cutting speed must be set appropriately.

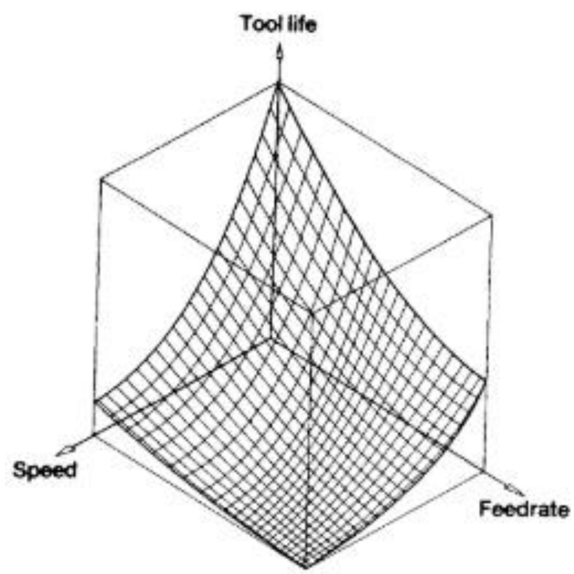

Figure 2.2: The relationship between feed rate, speed and tool life (Smith, 2008)

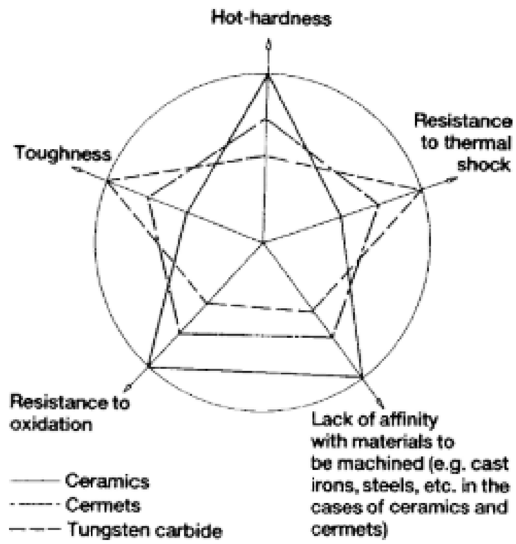

Figure 2.3: The five qualities of an ideal cutting tool with typical materials superimposed on a circle (Smith, 2008)

Figure 2.2 and Figure 2.3 show the main elements that influence cutting tool life in 'steady-state' cutting conditions. Speed, tool life and feed rate parameters have the relationship with other factors such as depth of cut, workpiece material, lead angle, nose radius, insert grade and insert geometry as portray in Figure 2.1 These parameters need to be optimized before one decides to use the cutting tool for any machining. The cutting tool with five qualities which are toughness, hot-hardness, resistance to thermal shock, resistance to oxidation and lack of affinity with materials to be machined is the ideal cutting tool. These qualities have made the cutting tool manufacturers balance carefully in order to gain the desired performance from the cutting tool.

Hot hardness is one of the criteria that cutting tools must have as it will preserve the consistent and sharp cutting edge in the condition of high temperature during machining. The tip of the tools will degrade easily if there are no sufficient hot hardness in them and the tool cannot be used anymore. Thermal shock, on the other hand, is a must to prevent the effects of cooling and heating which is usually happened in the milling process and during the periodic turning process. High-speed steels (HSS) cutting tools have been found that they suffer from 'comb cracks' as the resistance to thermal shock in them are low.

Besides that, lack of affinity also is the factor that needs to be concerned of in fabricating the prolonged lifespan of cutting tools. The built-up edge (BUE) must be avoided as this formation will alter the geometry tool which is results from any affinity degree. Then, the ability for breaking the chip become poor and with the generation of greater forces will worsen the surface finish of the workpiece. Another factor affecting the cutting tool is oxidation resistance. This factor is important to minimize the wear which is results from oxidation during elevated temperature machining operation (Smith, 2008).

Recently, manufacturers of this item have offered their customers with the workpiece-cutting ability like feed rate and speeds in wider ranges. Consequently, tooling inventories can be reduced. (Smith, 2008). George (2002) pointed out his opinion which is hardness, wear resistance and toughness are the three characteristics that all cutting tool must fulfil in order to fabricate an economical and good part. Balela et al., (2007) and George (2002) agree on the fact that workpiece machinability influences the cutting tool that will be used. Hence, wide ranges of tool types from various materials must be available for machining various materials of workpieces. They also stated that the tool which can complete the job efficiently, economically and quickly is the best tool and not must be the cheapest or the most expensive one.

2.2.1 Cutting tool materials

Balela et al., (2007) postulate in their journal article entitled, A Review on Alumina-Based Ceramic Composites as Cutting and Machining Tool Materials, all cutting tools have high wear resistance and hardness. The invention of ceramic composites cutting tool as a new type of material for cutting tool contributes to the improvement in cutting speed and feed rate when this type of cutting tool is used in the machining operations. Smith (2008) investigated that there is an evolution of cutting tool materials. The materials for the cutting tools‘ compositions include plain carbon steels, high-speed steels (HSS), cubic boron nitride (CBN), polycrystalline diamond (PCD), cemented carbide, ceramics and cermets and also a natural diamond. There is also present the development of tool coatings using many techniques and materials such as