UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

EFFECT OF ZIRCONIA AND CHROMIA ON THE MECHANICAL AND TRIBOLOGY PROPERTIES OF ALUMINA CUTTING TOOL

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EFFECT OF ZIRCONIA AND CHROMIA ON THE MECHANICAL AND TRIBOLOGY PROPERTIES OF ALUMINA CUTTING TOOL

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DECLARATION

I declare that this thesis entitled "Effect of Zirconia and Chromia on the Mechanical and Tribology Properties of Alumina Cutting Tool" is the result of my own research except as 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 : Muhamad Naim Fahmi bin Abdul Manap

Date : 9 July 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature :……………………………………………..

Supervisor Name : Associate Prof. Ir. Dr. Mohd Hadzley bin Abu Bakar

Date : 9 July 2021

DEDICATION

To my beloved father, mother, my family, my supervisor and my supportive friends that accompanying me along the difficult pathway in my university life.

ABSTRACT

Due to their excellent hardness, high abrasion resistance and chemical stability, alumina based cutting tools are suitable for the high speed machining, which contributed to the high productivity. The properties of high hot hardness play significantly roles to perform in dry machining which further reduce operational cost. However, at some extent, alumina are prone to catastrophic failure, sudden breakage and thermal shocks due to brittle structure. Therefore, alteration of alumina composition with addition of Zirconia and Chromia is proposed to improve fracture toughness and wear resistance. In this research, the effect Zirconia and Chromia addition on the dimension accuracy, mechanical properties, tribology and wear performance were investigated. The study started with the mixture of Alumina-Zirconia with up to 25 wt% Zirconia content. These compositions were blended using ball mill, compacted using hydraulic and Cold Isostatic Press (CIP) and sintered at constant parameters. The mechanical properties of sintered Alumina-Zirconia were evaluated based on the dimension accuracy, density and hardness. The composition with maximum hardness was selected to be further composed with Chromia in range of 0.2-0.8 wt%. The result show that composition of Alumina–zirconia with ration 80-20 wt% presented maximum hardness of 70.07 HRC. With the addition of 0.6 wt% Chromia, the hardness was increased to 71.03 HRC. Further, composition that demonstrated highest hardness, which is Alumina-Zirconia-Chromia with the ratio of 80-20-0.6 wt% have been selected for machining tests. Machining trials with AISI 1045 carbon steel shows that Alumina-Zirconia-Chromia demonstrated maximum 360s tool life, which is 33.33% better that Alumina-Zirconia cutting tool. Wear mechanisme for both cutting tools dominated by the chipping, abrasive, built-up edge and built-up layer. Analysis shows that the addition of Chromia expanded Alumina particles and changed the overal grains distribution into bimodal structure. This provided Zirconia particles that inflitrated between Alumina particles interlocked overal structure, which facilitated into higher deformation resistance into overall structure. As potential application, cutting tool of Alumina-Zirconia-Chromia developed in this study suitable in machining low carbon steel up to 200 m/min cutting speed.

KESAN ZIRKONIA DAN KROMIA TERHADAP SIFAT-SIFAT MEKANIKAL DAN TRIBOLOGI UNTUK PERKAKAS PEMOTONG ALUMINA

ABSTRAK

Disebabkan sifat-sifatnya yang keras, rintangan abrasif tinggi dan stabil dalam kimia, perkakas pemotong berasaskan alumina sesuai digunakan dalam pemesinan berhalaju tinggi, yang mana memberi impak kepada produktiviti tinggi. Sifat-sifat seperti kekerasan panas tinggi memberi kesan signifikan dalam pemesinan kering, yang mana merendahkan lagi kos operasi. Walau bagiamanapun, pada keadaan tertentu, alumina cenderung untuk gagal secara katastropik, patah mengejut dan kejutan terma disebabkan strukturnya yang rapuh. Oleh yang demikian, perubahan komposisi alumina dengan pernambahan Zirkonia dan Kromia dicadangkan untuk menambahbaik keliatan patah dan rintangan haus. Dalam kajian ini, kesan penambahan Zirkonia dan Kromia ke atas ketepatan dimensi, sifat-sifat mekanikal, tribologi dan prestrasi haus telah diselidik. Kajian bermula dengan pencampuran serbuk Alumina-Zirkonia sehingga 25 wt% kandungan Zirkonia. Komposisi ini dikisar menggunakan mesin Pengisar Bebola, dimampatkan menggunakan Mesin Penekan Hidraulik dan Mesin Penekan Isostatik Sejuk (CIP) dan disinter pada parameter yang malar. Sifat-sifat mekanikal untuk Alumina-Zirkonia yang disinter dinilai berasaskan ketepatan dimensi, ketumpatan dan kekerasan. Komposisi yang memiliki kekerasan maksimum dipilih untuk dicampur dengan Kromia pada kadar 0.2-0.8 wt%. Keputusan menunjukkan sampel Alumina-Zirkonia dengan nisbah 80-20 wt% menghasilkan kekerasan maksimum 70.07 HRC. Dengan penambahan 0.6 wt% Kromia, kekerasan meningkat kepada 71.03 HRC. Seterusnya, komposisi yang menunjukkan kekerasan tertinggi, iaitu Alumina-Zirkonia-Kromia dengan nisbah 80-20-0.6 wt% telahpun dipilih untuk ujian pemesinan. Percubaan pemesinan dengan AISI 1045 keluli karbon prestasi pemesinan bersama keluli karbon AISI 1045 menujukkan Alumina-Zirkonia-Kromia menghasilkan 360s maksimum hayat perkakas, yang mana 33.33% lebih baik daripada perkakas pemotong Alumina-Zirkonia. Mekanisma haus pada kedua-dua perkakas pemotong didominasi oleh penyerpihan, haus abrasif, serpihan dengan pinggir terbina dan serpihan dengan lapisan terbina. Analisis mendapati penambahan Kromia mengembangkan partikel Alumina dan menjadikan keseluruhan taburan ira menjadi stuktur dwi-modal. Ini membolehkan partikel Zirkonia yang menyelinap di celah-celah partikel Alumina bertindak mengunci ira yang membawa kepada peningkatan rintangan deformasi kepada keseluruhan struktur. Potensi aplikasi perkakas pemotong Alumina-Zirkonia-Kromia yang dibangunkan dalam kajian ini sesuai dalam pemesinan keluli rendah sehingga 200 m/min halaju pemesinan.

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LIST OF ABBREVIATIONS

AISI	-	American iron and steel institute
Al	-	Aluminium
Al_2O_3	-	Aluminium oxide/ alumina
ASTM	-	American society for testing and materials
BUE	-	Built-up edge
CBN	-	Cubic boron nitride
CeO_2	-	Cerium oxide
CIP	-	Cold isostatic press
CNC	-	Computer numerical control
CrN	-	Chromium nitride
EN	-	Euro norm
F	-	Feed rate
Ff	-	Load at fracture
HIP	-	Hot isostatic press
HSS	-	High speed steel
ISO	-	International standard organization
L	-	Distance
Mg	-	Magnesium
MgO	-	Magnesium oxide/ magnesia
O	-	Oxygen

R	-	Radius
S_3N_4	-	Silicon nitride
SEM	-	Scanning electron microscope
SiC	-	Silicon carbide
TiAlN	-	Titanium aluminium nitride
TiC	-	Titanium carbide
TiCN	-	Titanium carbon nitride
TiN	-	Titanium nitride
Vc	-	Cutting speed
W	-	Weight
Y_2O_3	-	Yttrium oxide
Zr	-	Zirconium
ZrN	-	Zirconium nitride

LIST OF SYMBOLS

m/min	-	Meter per minute
%	-	Percent
°C	-	Degree Celsius
mm	-	Millimeter
µm	-	Micrometer
K	-	Kelvin
kg/m^3	-	Kilogram per cubic meter
mm/rev	-	Millimeter per revolution
N	-	Newton
kW	-	Kilowatt
rpm	-	Revolution per minute
Nm	-	Newton meter
L/min	-	Liter per minute
HRC	-	Rockwell C hardness
HV	-	Vickers hardness
MPa	-	Megapascal
W/ m/K	-	Watts per meter per kelvin
J/ g.K	-	Joule per gram per kelvin

GPa	-	Gigapascal
Psi	-	Pound per square inch
s		second

LIST OF PUBLICATIONS

<u>Journal</u>

1. Hadzley Abu Bakar, Naim Fahmi, Faiz Mokhtar, Norfauzi Tamin, Umar Azlan, Abdul Aziz Adam, Raja Izamshah and Shahir Kasim, 2018. Fabrication and Machining Performance of Powder Compacted Alumina Based Cutting Tool. *MATEC Web of Conferences* 150, 04009.

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CHAPTER 1

INTRODUCTION

1.1 Research background

Technology in ceramic processing has advanced to a level where ceramic is developed to enhance its properties so that it can perform very well. There are many applications that can be facilitated with the advancement of ceramic processing including insulators and structure in construction industries, thermal barriers and magnetic materials in electronic industries, high strength component in defence and manufacturing industries. The unique properties of advanced ceramic are high abrasive, high hardness, high toughness, low or non-thermal conductivity and chemical stability providing advantages to be applied for these applications (Abbas et al., 2015).

Some of the commonly used ceramic tool materials are polycrystalline diamond (PCD), cubic boron nitrite (CBN) cemented carbide, silicon nitride and alumina. Each cutting tool have different characteristics, capability, suitable workpiece materials, cutting conditions and cost. These ceramic cutting tools have been widely used due because of the combination of the high facture toughness, high hot hardness, oxidation resistance, chemical stability and good chipping resistance (Harrison and Lee, 2016). Some of the cutting tools such as diamond and CBN are suitable to machine high strength materials such as titanium and nickel alloys. Whereas some others such as carbide, silicon nitride and alumina mostly used to machine common materials in industry such as tool steel, carbon steel and aluminium.

In ceramic processing, the ceramic cutting tools are normally fabricated using the powder metallurgy process. This process involves which require many techniques such as ball milling, uniaxial pressing, cold isostatic pressing and sintering. During the process, the base material which is ceramic is mixed and milled with reinforced material with specific composition to produce refractory body for the tribological application. The behaviour and microstructure of ceramics are significantly affected by many factors such as ceramic processing, initial powder state, particle size and sintering process (Abu Bakar et al., 2018). A fine and uniform grain size of the powder during the ceramic cutting tool processing should produce denser ceramic products especially when the ceramic powders are engaged with other secondary material such as chromia and zirconia. Hence, this will provide additional advantages not only to achieve high hardness but also to resist wear from the heat and refractory condition during machining.

Alumina-based materials are amongst the popular choices of material to be used in machining operation due to its high abrasion resistance, high hardness and its excellent chemical inertness against the machining environment and workpiece (Lee et al., 2016). Years ago, due to the superior properties, alumina was only used as engineering materials to produce ball mills, seal rings, thread guides and grinders (Senthil et al., 2003). Nowadays, alumina has been applied in wide application that requires abrasive, wear and tribological performance varied through automotive, aerospace, oil and gas and medical industries. Several components that established require alumina as main material are piston rings, brake pad, bearing, artificial bones, etc.

One of the major advantages of alumina based cutting tool over carbide is the capability to be operated at dry condition. Machining with carbide is difficult in dry condition which coolant is compulsory to reduce the heat generated at the cutting zone. At some extent, machining with carbide increase the cost of production due to the requirement