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FABRICATION AND CHARACTERISTIC STUDY OF ALUMINA TOOL USING COLD ISOSTATIC PRESS

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DECLARATION

I declare that this thesis entitled "Fabrication and Characteristic Study of alumina Tool Using Cold Isostatic Press" is the result of my own research except as cited in the references. The thesis has not been accept for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

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

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DEDICATION

This thesis is dedicated to my beloved mother, father, siblings and friends. They have been a source of motivation and strength during moments of despair and discouragement, support has been shown in incredible ways recently.

ABSTRACT

In manufacturing, machining is widely used in the production. The selection of a suitable tool will boost production performance and reduce costs. In this study, alumina cutting tools are fabricated and its characteristics information gained through various experiments. Numbers of previous studies using alumina -based composite cutting tool were done and mostly agreed that the alumina based have the potential to produce a homogeneous ceramic cutting inserts with high performance. However, less research were found for the production of alumina milling cutting insert. Therefore, this study focuses on the application of cold isostatic press to produce alumina cutting insert that has a good microstructure and mechanical properties. The characteristic of cutting insert that has been produced then tested through various experiments and test. The inserts produce accordance to triangle shaped inserts. Alumina powder with purity of 91.4 % was used to produce the cutting tool. The powder then compressed through cold isostatic pressure techniques. The pressure applied is range of 15,000 psi, 20,000psi and 25,000 psi. Green body and then dried and sintered at two different temperatures of and 1400 °C and 1550 °C. The density, hardness and shrinkage of alumina milling insert then were studied. Matrix design method was utilized to build experimental and accurate data. Product which were pressed at 20,000 psi and sintered at 1550 °C shows assured result and shall be tested to identify the cutting performance of the inserts.

ABSTRAK

Dalam industri pembuatan, pemesinan digunakan secara meluas dalam pengeluaran produk. Pemilihan mata alat yang sesuai akan membantu memoptimasikan prestasi pengeluaran serta mengurangkan kos. Dalam kajian ini, perkakas pemotong alumina difabrikasi dan sifat-sifat pemotong alumina diuji melalui ujikaji bagi mendapatkan maklumat prestasi sifat perkakas. Beberapa kajian terdahulu menggunakan komposit berasaskan alumina mendapati bahawa perkakas pemotong tersebut berpotensi menghasilkan komponen seramik yang homogen serta berprestasi tinggi. Namun, kurang kajian bagi penghasilan perkakas pemotong kisar alumina. Oleh itu, kajian ini lebih tertumpu kepada aplikasi tekanan sejuk bagi menghasilkan perkakas pemotong alumina yang mempunyai mikrostruktur dan sifat mekanik yang baik. Perkakas yang dihasilkan kemudiannya diuji melalui pelbagai ujikaji bagi mendapatkan maklumat karakter struktur dan mekanikal perkakas. Fabrikasi pembuatan akan mengikut standard komersial TKPN berbentuk segitiga. Fabrikasi perkakas pemotong bermula dengan mendapatkan serbuk alumina ketulenan 91.4%. Ini diikuti dengan pembentukan jasad anum perkakas pemotong alumina melalui teknik tekanan sejuk. Tekanan yang dikenakan adalah pelbagai iaitu 15,000 psi, 20,000psi dan 25,000 psi. Seterusnya, sampel disinter pada dua suhu yang berbeza iaitu 1400℃ dan 1550℃. Jasad kemudian dikaji ketumpatan, kekerasan-vikers dan pengecutan Kaedah rekabentuk matrik telah digunakan sepenuhnya untuk membina ujikaji serta data-data yang tepat. Produk yang ditekan di 20,000 psi dan disinter pada 1550 ° C menunjukkan hasil terjamin dan wajar diuji untuk mengenal pasti prestasi pemotongan serta kualiti pemotongan menggunakan .

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CHAPTER 1

INTRODUCTION

1.0 Background Study

Isostatic presses are widely used to produce pre-form of high density and dimensionally precise products. Isostatic presses shall satisfy fabrication of one elongated dimension products, a complex shape even large volume products (J.S. Reed 1995). One of product that can be produce by isostatic presses is cutting tools. In the manufacturing industry, machining is widely used in the production of products. A tool is considered reliable when it can machined the workpiece with relative ease while producing the desired range of surface finish. The characteristics of a tool with good machineability are when less power needed to cut, can cut in a short time, produced good surface finish and less wear in a short period of usage.

Selection of appropriate cutting tools is very important to produce products with high dimensional accuracy and surface finish quality. Properties of alumina (Al_2O_3) which is high hardess, wear resistance and chemical stability makes it become highly suitable as a research topic to develop its capability as cheap and reliable cutting tool. Ceramic tools materials with alumina based facing increasing interest as they exhibit high hardness, thermal resistance and high abrasion resistance, thus making it suitable for high speed machining (K.Geric 2010).

This project were designed to understand the effect of CIP process on physical behavior of alumina oxide (Al_2O_3) powder to produce a milling cutting insert with respect to shrinkage, hardness and densification.

1.1 Statement of the Purpose

Machining technology facing increasing interest since it improve productivity and produce better workpiece surface quality. Continual improvements consistantly done either by increasing the wear resistant or improving the material used to produce the cutting tools. Development of advanced ceramic tools increasingly active in past decades which ceramic material can significantly increase the tool life relative to ceramic special qualities. Most of the research focus on alumina coated with other materials. Basically, less research were done on fabricating alumina inserts which will be used in milling.

1.2 Problem Statement

Cold isostatic press (CIP) is one of the pressing techniques that available to manufacture ceramic inserts. Developing ceramic insert through powder technology involve with various parameters such as pressing pressure, pressing time and grain size of the alumina powder. These parameters significantly affect the mechanical and physical properties of compacted product before and after sintering process such as density, hardness, strength and dimensional accuracy.

High-speed machining technology has already penetrated in most manufacturing industries to cut various workpiece from steel and alloys to composites. Manufacturing engineers frequently use high-speed milling to remove the greatest possible quantity of material from workpiece. However, using high-speed milling leads to the increase of cutting temperature and soften of the tool material (Liu et al 2002). Therefore, tool material with high wear resistance take a crucial role in high-speed milling.

Demand on high performance cutting tool lead to production of cutting tool with low cost. Alternative material shall be studies to replace conventional material used to produce cutting tool such as carbides, high speed steels and tungsten. Research that has been done on alumina tool in high speed machining area is mostly on turning machines.

Unfortunately, studies on alumina cutting inserts for milling process still not many. Traditional ceramic fabrication used alumina matrix with additives then pressed using hot pressed. The weakness by using this technique, compromising on the hardness and wear tool are inevitable. Pressing using cold isostaic gives promising idea on producing alumina cutting inserts.

1.3 Objectives

The main objectives of this research as follows:

i. To study the effect of CIP parameters on shrinkage, hardness and densification behaviour of alumina oxide after undergo Cold Isostatic Press process.
ii. To develop ceramic cutting insert of alumina oxide (Al_2O_3) using Cold Isostatic Press.

1.4 Scope

In this research, the scope of this project are outline as follows:

1. Prepress sample using uniaxial press machine, Cold Isostatic Press (CIP) process and sintering process will be employed in producing the ceramic cutting tool.
2. The material used for ceramic cutting tools will Alumina Oxide (Al_2O_3).
3. The input parameters that will be used are cold isostatic pressing pressure and sintering temperature.
4. The product to be fabricate according to commercial milling insert with triangular shape.
5. The output responces to be investigated include shrinkage, hardness, prorsity, densification and flexural strength behavior of alumina cutting insert.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The trend toward high speed machining, dry cutting and the need of complex geometry tool cause an increasing demand for ceramic based material as cutting tools for machining steel based alloys in machining industries nowadays. Because of these reasons, the ceramic materials such as alumina and zirconia which are well known as hard and brittle materials are being developed as cutting tools to penetrate the tooling market. Ceramic engineering or advanced ceramics are inorganic non-metallic materials used in high-performance engineering applications. It can be categorized as oxide-based ceramics, carbides, nitrides and borides (Xu & Jahanmir 1996). Among the properties of advanced ceramics are wear and oxidation resistance, high stability against chemical reaction, stable against thermal resistance, thermal insulation and electrical insulation. Research and development of ceramic material are very intensive in order to increase its potential as a high quality cutting tools. The use of ceramics cutting tool has increased due to its ability to operate at high temperatures and resistant to oxidation and chemical reactions (Lee 1999).

The needs and interest on ceramic increase especially in machining field. Machining is a metal forming process and preferable technique in manufacturing industry due to its simple operation and relatively fast in certain aspect. High speed machining operations require cutting tools that are resistant in terms of temperature and pressure.

Some common cutting tools used in machining operations include high speed steel, carbide, ceramic, cement, diamond and cubic boron nitride.

Ceramic cutting tools are considered as a suitable alternative of carbide or high speed steel. It can perform machining operations on both high and low velocity effectively (Lo Casto et al. 1996). Among the ceramic cutting tools most widely used in the market is alumina. Alumina ceramics are among the most notable because it has a high hardness and high stability against temperature and the chemistry (Xu et al., 2001). It is also cheaper than ceramic nitrides and carbides (Xu & Jahamnir 1996). Number of studies has been done in developing the potential of alumina as cutting tools, particularly in terms of the strength properties. Presently, there are several kinds of alumina-based composite insertion tool such as alumina-zirconia, alumina-titanium-carbide, alumina-zircon, alumina-silicon-carbide (K. Geric 2010, Xu et al. 2001).

Cold isostatic press (CIP) is one of the pressing or compaction techniques that available in the manufacturing of ceramic inserts. Compaction process can produce near net shape, density, and particle-to-particle contact which make the part sufficiently strong for further processes (S.Kalpakjian 2001). CIP have a wide range of applications such, as a repair work for casting product or fabrication of metal matrix composite (MMC) and ceramic matrix composite (CMC). Few researches on CIP process on ceramic powder were done. Most researches that have been done were focus on other processes such as slip casting and dry pressing (uniaxial).

This project aims to understand the effect of CIP and sintering process such as temperature and pressure on the physical behaviour of powder ceramic part with respect to shrinkage, hardness, density, flexural strength, Modulus of rupture and fracture strength.

2.1 Ceramic Material

Ceramics are inorganic, non-metalic materials which the metallic and non-metalic elements bonded together primarily by ionic or covalent bonds. Ceramic divided to three basic categories:

1. Traditional ceramics: Silicates for clay products such as pottery.
2. New ceramics: non-silicates ceramics such as oxides and carbides. These categories poses better mechanical or physical properties compared to traditional ceramics.
3. Glass: based primarily on silica and having non-crystalline structure.

New ceramics material relatively has high strength, high temperature resistance, high wear resistance and good corrosion resistance. New ceramics further classified into three distinct categories of oxides, non-oxides and composites. Examples of oxides ceramics are alumina (Al_2O_3) and zirconia (ZrO). Non-oxides materials are carbides, borides, nitrides and silicide. Meanwhile composites ceramic are reinforced material and combinations of oxides and non-oxides.

2.1.1 Properties of Ceramic

In general ceramics are hard, brittle, electric and heat resistance, wear resistance and chemically inert. Physical properties of various ceramics are shown in Table 2.1. Generally, ceramic have low density compared to metals but higher than polymers. The melting temperature of ceramics is higher than most metals. In term of electrical and thermal conductivity, mostly they are insulators but in certain condition they can be good conductor. For thermal expansion, most ceramic having less thermal expansion compared to metals but the effect are more damaging due to brittleness properties of ceramic.

Table 2.1: Properties of various ceramic at room temperature. (S.Kalpakjian 2001)

Material	Symbol	Compressive Strength (Mpa)	Elastic Modulus (GPa)	Hardness (HK)	Density (kg/m^3)
Alumina Oxide	Al_2O_3	1000-2900	310-410	2000-3000	4000-4500
Cubic boron nitride	CBN	7000	850	4000-5000	3480
Silicon nitride	Si_3N_4	No data	300-310	2000-2500	3300
Silicon carbide	SiC	700-3500	240-480	2100-3000	3100
Titanium carbide	TiC	3100-3850	310-410	1800-3200	5500-5800
Tungsten carbide	WC	4100-5900	520-700	1800-2400	10000-15000

2.1.2 Properties of Alumina

Alumina is an oxide ceramic used either in pure form or as a mixture with other oxides. Alumina occurs naturally in large quantities and is available via the Bayer process (J.S. Reed 1995). Naturally, the alumina exists in two forms, namely α-Al2O3 and γ-Al2O3. α -Al2O3 is stable elements when compared with γ -Al2O3. Alumina structure consists of oxygen ions in the close packed hexagonal structure. In Al2O3, Al3 + ions are placed in octahedral interstices makes each ion is surrounded by six O2-ions. Figure 2.6 shows the arrangement of ions in the vicinity of the O2-ions Al3 + in Al2O3 polyhedron structure (Callister 2001). Alumina is very hard crystalline, having hexagonal close pack array of oxygen atoms with metal atoms in two-thirds of octahedrally cordinates interstites. Each metal atom cordinated by six oxyen atoms and each having four metal neighbours (6:4 coordination). Figure 2.1 show the arrangement of oxygen ion and aluminum ions for alumina. Chemical formula of alumina is Al_2O_3 shows the it compounds of aluminium and oxygen. They are available in concentration of 99.5% and 96 % purities. The microstucture of alumina is shown in Figure 2.2. Structure containing alumina powder is known as mullite and spinel, which usually used as refractory materials for high temperature applications. Table 2.2 shows the general specifications of high-purity alumina material.

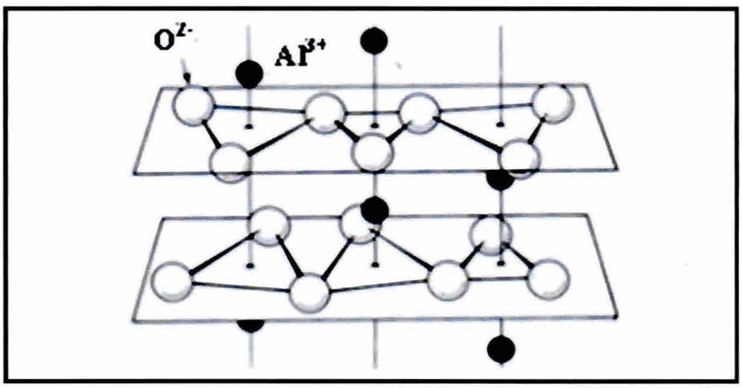

Figure 2.1 Arrangements of ions of O^{2-} Al^{3+} inside Al_2O_3.
(Source: *Callister, 2001*)

Figure 2.2: Micrograph of alumina powder. (Source: *Callister, 2001*)

Table 2.2: General properties of alumina powder. (Lo Casto et. al 1996)

Aluminium Oxide 99.9% Purity	
General	
Molecular formula	Al_2O_3
Molar mass	101.96 g/mol
Properties	
Density and phase	3.97 g/cm^3, solid
Solubality in water	Insoluble
Melting point	2054 °C
Boiling point	~3000 °C
Thermal conductivity	18 W/m.K
Hardness - Vikers	18 Gpa
Modulus Elasticity	350 GPa
Thermal Expension	8.5 x 10^{-6}/°C
Fracture Toughness, K_{IC}	4.6 Mpa m$^{1/2}$

2.2 Cold Isostatic Press

CIP is used extensively in powder metallurgy which include ceramics industry. Isostatic pressing capable to deligate uniform high pressure to produce parts. The product is consistent in density throughout their cross sections compared to parts that produced by uniaxial press. CIP comes in two types; dry bag and wet bag. Dry bag process is molding powder that filled in a forming rubber mold as shown in Figure 2.3(a). Forming process done by transmitting pressure through a pressing rubber mold in high- pressure vassel. The limitation of dry bag CIP is limited to small size parts and simple shapes where products can be removed easily. In the wet bag press, the pressure vassel is filled with liquid,