UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Analysis and Flexural Strength of Mullite Bonded Silicon Carbide Fabricated Using Various Uniaxial Pressure and Milling Duration

Thesis submitted in accordance with the partial requirements of the Universiti Teknikal Malaysia Melaka for the Degree of Bachelor of Engineering (Honours) Manufacturing (Engineering Material)

By

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This thesis submitted to the senate of UTeM and has been accepted as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Material). The members of the supervisory committee are as follow:

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DECLARATION

I hereby, declared this thesis entitled "Analysis and Flexural Strength of Mullite-Bonded Silicon Carbide Fabricated Using Various Uniaxial Mechanical Pressure and Milling Duration." is the results of my own research except as cited in references

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ABSTRACT

In this research, the analysis of mullite-bonded Silicon carbide and also its flexural strength is being conducted. The analysis of the silicon carbide is based on the various uniaxial mechanical pressure and milling duration. The analysis method that used in this research are flexural test, density test, microstructure observation and phase observation. The microstructure observation is implemented by using the Scanning Electron Microscope (SEM) while for the phase observation, it is being done by using X-Ray Diffraction (XRD) tools. The objective of this research is to identify the optimum uniaxial pressure during the preparation of the mullite bonded Silicon carbide‘s green body. Besides that, the mechanical properties of Mullite-bonded Silicone Carbide which is fabricated at various uniaxial pressure and grinding duration also will be study. The result have shown that the highest pressure and milling hour applied to the Silicon Carbide will indicates the highest value of flexural strength and density. The result of microstructure observation and phase observation also show the effect of pressure and milling hour to the microstructure and phase. For the phase observation, the mullite phase is found in the Silicon Carbide.

ABSTRAK

Di dalam kajian ini, analisis ke atas ikatan “mullite” Silikon Karbaid dan juga kekuatan pembengkokan telah dijalankan. Analisis keatas silikon karbaid adalah berasaskan tekanan mekanikal satu arah dan tempoh masa pencampuran. Analisis yang termasuk didalam kajian ini adalah ujian pembengkokan, ujian ketumpatan, pemerhatian mikrostruktur dan pemerhatian fasa. Pemerhatian mikrostruktur dijalankan dengan menggunakan “Scanning Electron Microscope” (SEM) manakala pemerhatian fasa dijalankan menggunakan peralatan “X-ray Diffraction” (XRD). Objektif kepada kajian ini adalah bagi mengetahui nilai tertinggi penekanan satu arah semasa proses penyediaan ikatan mullite silikon karbaid. Di samping itu, sifat mekanikal silikon karbaid juga akan dikaji. Keputusan telah menunjukan bahawa peningkatan tekanan satu arah dan tempoh pencampuran akan menghasilkan kekuatan pembengkokan dan ketumpatan yang lebih tinggi. Keputusan pemerhatian pula menunjukan bahawa kesan tekanan satu arah dan tempoh pencampuran akan menunjukan perubahan kepada mikrostruktur dan fasa. Untuk pemerhatian fasa juga, terdapat ikatan “mullite” pada Silikon Karbaid yang telah dikaji.

DEDICATION

For all your guidance, advice and support, this thesis is gratefully dedicated to my family and my friends. Thank you very much for your continuous support and effort towards the publication of this thesis.

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

m	-	Meter
Max	-	maximum
Min	-	minimum
^{0}C	-	degrees Celsius
%	-	Percent
SEM	-	Scanning Electron Microscope
ASTM	-	American Standard Testing Material
SiC	-	Silicon Carbide
X-RD	-	X-Ray Diffraction
α	-	Alpha
β	-	Beta
LED	-	Light Emitting Diode
SiO	-	Silicon Oxide
MOR	-	modulus of rupture
$Al_2 0_3$	-	Aluminum Oxide
EDM	-	Electrical Discharge machining

CHAPTER 1

INTRODUCTION

1.1 Introduction to Silicon Carbide

Ceramics are inorganic, nonmetallic materials and are typically crystalline in nature. Ceramics are compounded with metallic and non-metallic elements, such as aluminum or calcium, oxygen or silicone and nitrogen. In case of Silicon Carbide, it has hard covalently bonded material predominantly produced by the carbothermal reduction of silica. The exact reaction conditions will resulting the silicon carbide, either a fine powder or a bonded mass that requires crushing and milling to produce a usable feedstock. Several hundred structures of silicon carbide (polytypes) have been identified which have different stacking arrangements for the silicon and carbon atoms. The simplest structure is a diamond structure which is designated β-SiC. Other structures are either hexagonal or rhombic and are referred to as α-SiC. Normally, sintered ceramics are required to have minimum porosity. However, there are cases where porosity is desirable for example in humidity and gas sensors and where the thermal shock resistance is of overriding importance. Porous silicon carbide ceramics is one of the potential materials to be used as filters, thermal expansion coefficient, high thermal conductivity and excellent mechanical property compared with alumina.

The fabrication process of porous ceramics involves precision mixing, forming, firing and machining. The effect of charge composition, characteristic of the starting silicon carbide powder and pore-forming agent on the formation of highly porous SiC-based will be studied. In order to realize the low-temperature fabrication of porous SiC ceramics, secondary phases may be added to bond SiC particles using reaction bonding process. In this study, it is covers the in situ mullite bonding on the SiC particles. It is believed that mullite possesses better high temperature stability and oxidation resistance, matching thermal expansion and good chemical compatibility between mullite and SiC. The graphite will be used as pore-former as it will keep the skeleton of the green bodies intact before the bonding phase formed at higher temperature.

1.2 Statement of the purpose

The purpose of this research is to study the mechanical properties, which is hardness testing and flexural strength of mullite bonded silicon carbide at various fabrication uniaxial mechanical pressures and various grinding hours. This research also aims to identify the optimum pressure during the preparation of mullite bonded Silicon Carbide green's bodies.

1.3 Problem Statement

The usage of porous ceramic is widely used in filter part. But, the quality of the porous ceramic is influent by the different processes in fabrication. The different of the ceramic quality is effected from the fabrication parameter, such as pressure, temperature, grinding duration and composition. In order to achieve the good mechanical properties, these parameter must be control properly. In this project, the mechanical properties of the prepared Mullite-bonded Silicone Carbide fabricated at various uniaxial pressures will be studied and analyzed in order to identify its optimum fabrication uniaxial pressure. The fabrication process also is being done at various grinding hours. The mechanical properties testing that will be covered in this project is hardness and flexural test. The results will be explained with the help of the microstructural result obtained from Scanning Electron Microscope (SEM) or Image Analyzer. This study will path way to the understanding and improvement of the fabrication process of the porous ceramic especially for the filter part.

1.4 Objective

The purpose of this project is:

i. To study the mechanical properties of Mullite-bonded Silicone Carbide fabricated at various uniaxial pressure and grinding duration.
ii. To identify the optimum uniaxial pressure during the preparation of Mullite-bonded Silicone Carbide's green body.

1.5 Scope of the study

The Silicon Carbide is fabricated by using the cold press molding method and sintering process. Density test and flexural test is involved in determining the mechanical toughness. The microstructure of the testing specimen is observed by using Scanning Electron Microscope (SEM). While the phase observation is done by X-Ray Diffraction (XRD)

CHAPTER 2

LITERATURE REVIEW

2.1 Silicon Carbide

2.1.1 Use of Silicon Carbide

2.1.1.1 Semiconductor

Actually, the earliest electrical application of Silicon Carbide (SiC) was for lightning in electric power systems. These devices have high resistance but when the voltage across the device, at which point their resistance must drop to a lower level and maintain this until the applied voltage drops. It was recognized early on that SiC had such a voltage-dependent resistance, and SiC pellets were connected between high-voltage power lines and the earth. Unfortunately, such SiC columns proved to conduct significantly at normal power-line operating voltages and thus had to be placed in series with a spark gap. This spark gap is ionized and rendered conductive when lightning raises the voltage of the power line conductor, thus effectively connecting the SiC column between the power conductor and the earth, where it then operates as before.

Silicon carbide is used for blue LEDs, ultrafast, high-voltage diodes, and high temperature thyristors for high power switching. Due to its high thermal conductivity, SiC is also used as substrate for other semiconductor materials such as gallium nitride. Due to its wide band gap, SiC-based parts are capable of operating at high temperature (over 350 °C), which together with good thermal conductivity of SiC reduces problems with cooling of power parts.

2.1.1.2 Heating element

Silicon carbide can be used for the heating element because it can offered the higher operating temperatures compared to the metallic heaters, although the operating temperature was limited initially by the water-cool terminals, which brought the electrics current to the silicon carbide hot zone. The terminals were not attached to the hot zone, but were held in place by weights, or springs. Operating temperature and efficiency was later increased by the use of separate low resistance silicon carbide "cold ends", usually of a larger diameter than the hot zone, but still held in place only by mechanical pressure. Silicon carbide elements are widely used in the melting of non-ferrous metals and glasses, heat treatment of metals, float glass production, production of ceramics and electronics components.

2.1.1.3 Steel

Piece of silicon carbide used in steel making Silicon carbide dissolved in a basic oxygen furnace used for making steel acts as a fuel and provides energy which increases the scrap to hot metal ratio. It can also be used to raise tap temperatures and adjust the carbon content. 90% silicon carbide is used by the steel industry as a ladle deoxidizer, a source of silicon and carbon in the ladle, an electric furnace slag deoxidizer, and as a synthetic slag additive. The silicon carbide used as a steel additive or fuel comes as a granular product in either bulk or bags. 50% and 65% silicon carbide are used in the steel industry for processing steel and iron scrap. Typically supplied as blocks and made from silicon carbide crucible scrap, it helps extend the hot metal supply and raises the tap temperature. The blocks are typically made using an automated concrete block making machine, and utilize water and limestone cement as a binder.

2.1.2 Properties of Silicon Carbide and bonding

2.1.2.1 General properties

Silicon carbide (SiC) has greatly properties of a semiconductor material and very suitable for the high- power, high-frequency, and high-temperature application. Silicon carbide also has a wide bandgap semiconductor material with high breakdown electric field strength, high saturated drift velocity of electron, and a high thermal conductivity. In combination with these properties, a native substrate of reasonable size exist, and we may readily grow the material and dope it both n- and p- type. In addition, SiC, like silicon (Si), has SiO_2 as its stable, native oxide. It is very important to any semiconductor technology if we look by the processing perspective. Therefore, these properties make Silicon carbide is suitable for numerous of application.

2.1.2.2 Mechanical Properties

Table 2.1: Mechanical properties of Silicon Carbide (SiC)

Item	Unit	Reaction sintered SiC	Pressureless sintered SiC
Purity	%	>=90	>97
Density	G/cm^3	3.05	3.05-3.15
Hardness		110-125(HS)	>92(HRA)
Elastic Modulus	Gpa	420	400
Poisson Ratio		0.15	0.14
Bending Strength	Mpa	350-450	400-580
Compressive Strength	Mpa	3000	3900