THE EFFECT OF SINTERING TEMPERATURE AND CLAY ADDITION ON GLASS CERAMIC PRODUCED FROM RECYCLED GLASS FOR STRUCTURAL APPLICATION (CIP METHOD)

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) with Honours.

By

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2010

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **The effect of sintering temperature and clay addition on glass ceramic produced from recycled glass for structural application (CIP Method)**

SESI PENGAJIAN: 2009/10 Semester 1

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I hereby, declared this report entitled "THE EFFECT OF SINTERING TEMPERATURE AND CLAY ADDITION ON GLASS CERAMIC PRODUCED FROM RECYCLED GLASS FOR STRUCTURAL APPLICATION (CIP METHOD)" is the results of my own research except as cited in references.

Signature : _____

Author's Name : NUR RIFHAN BINTI ROSLI

Date : 23 MAY 2010

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) with Honours. The member of the supervisory committee is as follow:

……

(DR. JARIAH BINTI MOHAMAD JUOI)

ABSTRACT

The purpose of this project was to determine the effect of sintering temperature and clay addition on glass ceramic produced from recycled glass. In this study, recycled glass of soda lime silica glass is used as main raw materials and ball clays as filler. The scope of this project mainly focused at the effect of sintering temperature and soda lime silica glass to ball clay weight ratio on glass ceramic produce from recycled glass for structural applications. The glass powders are prepared by crushing to a particles size distribution < 75 µm. The SLSG powder are then mixed with the ball clay according to the ratio of SLSG to ball clay of 95:5 wt.%, 90:10 wt.% and 85:15 wt.%. The glass ceramic samples are fabricated using uniaxial pressing and cold isostatic pressing with constant pressure at 40 MPa. The best mixing ratio is 85:15 wt.% ratio of SLSG to ball clay because the presence of ball clay helps the uniformity of the green body. Sintering process is conducted at three different temperatures at 750°C, 850°C and 950°C with 1 h holding time. There are several changes in terms of shape, color and appearance after the sintering process. Physical analyses and mechanical testing of the samples are carried out according to the specific ASTM standard of testing. For physical and mechanical analyses, majority the results showed that the increasing of temperature and percentage of ball clay had significantly increased the porosity and water absorption percentage, bulk density and microhardness properties of the glass ceramic produced. Microstructure analysis showed the surface of glass ceramic samples and phase analysis identified quartz and calcite phases is presence in the sample produced. Temperature 850°C with 85:15 wt.% ratio of SLSG to ball clay is chosen as the optimum parameter to produced new glass ceramic material produced from recycled glass.

ABSTRAK

Tujuan penyelidikan ini adalah untuk mengenal pasti kesan daripada suhu pembakaran dan penambahan tanah liat terhadap penghasilan seramik kaca yang dihasilkan daripada kaca buangan yang boleh dikitar semula. Dalam kajian ini, sisa kaca buangan dari kapur kaca digunakan sebagai bahan utama dan ketulan tanah liat sebagai pengisi. Bidang lapangan kajian ini lebih menitik beratkan kepada kesan suhu pembakaran dan nisbah kapur kaca kepada ketulan tanah liat untuk kegunaan – kegunaan struktur. Kapur kaca akan dihancurkan untuk mendapatkan saiz butiran kaca kurang daripada 75 µm dan kemudian dicampur dengan ketulan tanah liat. Campuran akan dibentuk menggunakan mesin *Uniaxial Pressing* terlebih dahulu sebelum dimasukkan ke dalam mesin c*old isostatic pressing (CIP)* dengan tekanan tetap iaitu sebanyak 40 MPa. Nisbah campuran yang terbaik adalah pada 85:15 wt.% nisbah kapur kaca kepada ketulan tanah liat kerana kehadiran ketualan tanah liat yang membantu kepadatannya. Proses pembakaran akan dilakukan pada tiga suhu yang berbeza iaitu 750°C, 850°C dan 950°C bersama 1 jam waktu perendaman. Terdapat perubahan dari segi bentuk, warna dan penampilan selepas proses tersebut. Analisis fizikal dan mekanikal dilakukan berpandukan piawaian ASTM. Untuk analisis fizikal dan mekanikal, kebanyakkan keputusan menunjukkan apabila meningkatnya suhu dan peratusan ketulan tanah liat, secara tidak langsung sifat-sifat seramik kaca seperti peratus keliangan dan penyerapan air, ketumpatan keseluruhan dan mikro-kekerasan yang dihasilkan meningkat. Analisis mikrostruktur menunjukkan dengan lebih jelas permukaan seramik kaca yang dihasilkan dan fasa yang wujud didalam seramik kaca adalah *quartz* dan *calcite*. Parameter optimum yang dikenal pasti sesuai untuk menghasilkan seramik kaca dari kaca buangan adalah pada suhu 850°C dengan 85:15 wt.% nisbah kapur kaca kepada ketulan tanah liat.

DEDICATION

Dedicated to my father, Rosli Bin Hasan and my mother, Rahmah Binti Nordin
To my supervisor, Dr. Jariah Binti Mohamad Juoi, lecturers and friends for all of their help and friendship.

ACKNOWLEDGEMENT

I would like to convey my thanks to those who have been very helpful in conducting this project for their favorable advice in finding most solution. Thus, I take this golden opportunity to express my millions of gratitude to my supervisor, Dr. Jariah Binti Mohamad Juoi for her kindly advice and guidance during the project; providing tremendous consideration and useful comments and materials to overcome obstacles that I had faced. These thanks also dedicate to Associated Professor Dr Thangaraj Joseph Sahaya Anand and Dr. Azizah Binti Shaaban for their encouragement, fully support, by providing me enormous guidance and idea for my research project. Also, my special thanks to Mrs. Norhafizah Binti Ishak, for your time and co-operation completing my research project. Subsequently to Mr. Mohd Farihan Bin Sabtu and Mohd Azhar Bin Abu Shah and all technicians involved to complete this project. Special thanks to my friends for their help during undertaking this project. Thanks are also extended to FKP lecturers who had provided technical help and assistance throughout the project. Lastly I would like express my gratitude with highly appreciation and dedication to my family who has been the loveliest advisor for their continuous support and inspiration throughout my campus life.

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LIST OF ABBREVIATIONS

ASTM	-	American Standard Testing Material
$CaCO_3$	-	Calcium carbonate
CaO	-	Calcium Oxide
CIP	-	Cold Isostatic Pressing
FA	-	Fine Aggregate
FG	-	Fine Glass
K	-	Kelvin
MHz	-	Mega hertz
MPa	-	Mega pascal
Na_2O	-	Natrium Oxide
PVA	-	Polyvinyl Alcohol
SEM	-	Scanning Electron Microscope
SLSG	-	Soda lime Silica Glass
SiO_2	-	Silicon Oxide
Tg	-	Transition glass temperature
Tm	-	Melting temperature
Wt. %	-	Weight percentage
XRD	-	X-Ray Diffraction
$\alpha\tau$	-	Thermal expansion coefficient
µm	-	micro meter
°C	-	Degree Celsius

CHAPTER 1
INTRODUCTION

1.1 Background of study

Glass ceramic can be defined as a fine-grained crystalline ceramic material that was formed as a glass and subsequently devitrified (Callister W. D., 2005). Nowadays, the used of glass ceramic becomes famous in structural applications as well as in manufacturing industry. The primary advantages of glass ceramic are higher strength, chemical durability, and electrical resistance and can be made with very low thermal expansion coefficients, giving excellent thermal shock resistance (Rahaman M. N., 2003). Throughout its performance, glass ceramic play a vital role in consumer needs or products that exhibits high level of mechanical properties. The main purpose of using recycled glass in glass ceramic is to improve the physical and mechanical properties of existing ceramic materials.

The production of glass ceramic materials made by recycling industrial waste is an innovative development in glass ceramic industry. Many researchers have paid much attention to produce glass, glass ceramic and sintered materials from industrial wastes to make them reasonably safe for the environment (M.Erol *et al*., 2008). For example, many investigations reuse soda lime silicate glass (SLSG) to manufacture glass ceramic products. SLSG is the most common commercial glass and less expensive. Normally, this soda lime glass has composition of 60 wt. % – 75 wt. % silica, 12 wt. % – 18 wt. % soda, and 5 wt. % – 12 wt. % lime. The reuse of the SLSG waste in ceramic system has capable to improve the performance compare to conventional ceramic material, especially in highly demanding the structural applications.

In line with the idea to reuse the SLSG to manufacture glass ceramic products, there have several factors that should be considered in order to make it beneficial. Factors such as particle size distribution and fillers used during powder preparation, processing method and sintering process are among crucial factors that should be properly considered. Physical analyses and mechanical testing for the product should also be considered in order to ensure its quality.

Particle size distribution is important, depending on which consolidation or shaping technique is to be used. Low porosity and fine grain size are beneficial to achieve a glass ceramic with high strength (Richerson D. W., 2005). Thus, fine grained size below than 75 μm is going to be employed in this study. The addition of binder and filler will affect the performances and properties of the new material produce from recycled glass. Various types of binders have been used from previous study by the researchers such as polyvinyl alcohol (PVA), ball clays, quartz-feldsphatic sands and others. These binders and fillers are widely used to provide enough strength in the 'green body' (unfired compact) to permit handling, 'green' machining, or other operations prior to densification (Richerson D. W., 2005). Therefore, the introduction of ball clays as filler has been employed in this study to develop properties which have the precise composition and ratios that give significant affects on some properties.

It is essential to finalize the suitable processing method for this study. In general, pressing method is widely used for forming of ceramic materials. There are various types of pressing techniques such as pressing, slip casting and tape casting. In this study uniaxial pressing and cold isostatic pressing (CIP) is chosen as a method for compaction and shaping of the powder materials into a rigid die body.

Subsequently, rigid die body then has been dried and surface finished (green body) in a furnace to develop the desired microstructure and properties. This stage is called sintering which imply the shrinkage and densification. The performance of the final product will be analyzed in terms of its microstructures, phase's present and physical properties.

In this study, Scanning electron microscope (SEM) and x-ray diffraction (XRD) analysis are use to analyze the microstructure and phases present in the samples produced. Physical analysis and mechanical testing are also conducted in order to analyze the properties of the samples.

1.2 Problem statement

Today in Malaysia, recycled waste such as glasses, papers, plastics and others are not used very constructive. Usually the waste management used landfill method to throw out this disposal. Only certain of that disposal are being used for recycling purpose. Regarding to these, disposal like glasses is reused by crushed into small pieces and melted at high temperature. Then the glass is reformed into desired shape such as bottles and food containers. Recently, glass is choose as an alternative materials in upgrading ceramic into glass ceramic that is useful for various structural applications. Thus is an alternative way in recycling glass waste. Example of glass ceramic used for structural applications are porcelain stoneware tiles which used waste of soda lime float and container glass as raw materials in replacement of sodic feldspar (Matteucci *et al.,* 2002). It is essential and possible to produce a new types of glass ceramic that exhibit the economically and environmentally benefits for this applications. Therefore, it is necessary to characterize and determine the properties for the glass ceramic produce forming. In this work such possibility is investigated, recycled glass is being used to produce glass ceramic because of its potential to improve the general properties of glass ceramics. In this research, new advanced materials are produced to fulfill the requirement as beneficial materials in order to ensure that the glass ceramic available for structural applications, it is being characterize and its physical and mechanical properties is investigated.

1.3 Objectives

The objective of this project is:

i. To study the effects of sintering temperature and clay addition toward glass ceramics produced from recycled glass by using Cold Isostatic Pressing (CIP) Method.
ii. To analyze the physical and mechanical properties of glass ceramics samples produced from recycled glass.
iii. To study the microstructure and phases present in the glass ceramics samples produced from and recycled glass.

1.4 Scope of study

The scope of this project is mainly focus on converting recycling glass into glass ceramic product. This study uses soda lime glass as the raw material. The process started by preparing the soda lime glass powder. The powders of SLSG were prepared by crushing raw materials using hammer. The size of particle then was sieved by using the sieve to determine the average particle size.

Next stage of process involves the mixing the raw materials with filler. The use of filler is to bind the materials together while mixtures. The filler that used in this project is ball clays. The chosen of filler is important to improve the strength of the as-formed product to provide strength for handling (green strength) before the product is densified by firing (Reed J. S., 1995).

The processes then continue with the pressing method to make the compaction on a powders and shaping by confined it in a rigid die or a flexible mold (Reed *et al*., 1995). Firstly, the mixtures are pressed by using uniaxial pressing before do the second compaction by using cold isostatic pressing (CIP) method which also referred as hydrostatic pressing is used. The CIP method is chosen because of its advantage compared to uniaxial pressing has limitations such as the green density of isostatically pressed part is higher and much uniform. Some of the limitations can be

overcome by applying pressure from all direction instead of only one or two directions. Application of pressure from multiple directions achieves greater uniformity of compaction and increased shape capability (Richerson D. W., 2006).

In line with the objectives of this study, the effects of sintering temperature and addition of ball clay are analyzed on the physical and mechanical properties of glass ceramics. Various sintering temperature are used according to the transition glass (Tg) of recycled waste which will result the final product. In this study, there are three sintering temperatures and ratios of SLSG to ball clay are employed.

The samples produced are then analyzed accordance to the appropriate American Standard Testing Material (ASTM) for physical and mechanical properties. ASTM C 373 will be used for physical tests which include porosity, density measurement and water absorption. Morphological and crystallography analysis are observed by using SEM and XRD. The mechanical tests that conducted are microhardness by using Vickers microhardness machine.