PHYSICAL AND MECHANICAL PROPERTIES OF CLAY RECYCLE GLASS – PAPER CERAMIC BY SLIP CASTING TECHNIQUE

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To my beloved mother (Sikam Juraimi) and father (Abu Samah Yaakob) who have given me the meaning of life

For my siblings and friends thanks for the prayers and support

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ABSTRACT

A series of ceramics based on (*x*) incinerated paper - (80-*x*) cullet – 20 Kaolin clay (where $10 \leq x \leq 45$ wt %) has successfully been made by slip casting technique followed by sintering at 1000°C for 2 hours. The physical properties are evaluated based on their density, water absorption and thermal shrinkage. Meanwhile, the hardness, Young's modulus and impact energy strength are determined using Vickers Indenter, Universal Testing Machine and Izod Impact Tester, respectively. The surface morphology and the elemental compositions of the ceramic are observed using Scanning Electron Microscope (SEM) and Energy Dispersive of X-ray Analysis (EDAX), respectively. The phase identification of the ceramic is performed by using X-Ray Diffraction (XRD) technique. It is found that the density of the ceramic is in the range of 2.170 gcm^{-3} to 2.420 gcm^{-3} while the water absorption and thermal shrinkage are in the range of 0.63% to 31.60% and 6.50% to 18.10%, respectively, depending on the cullet-paper ratio content. It is also found that the mechanical property of ceramic increases as the cullet-paper ratio is increased. The hardness, Young's modulus and impact energy strength are found in the range of 152.0 MPa to 1463.0 MPa, 1.522 kJm^{-2} to 7.124 kJm^{-2} and 195.4 MPa to 603.3 MPa respectively. The morphological studies show that samples at lower cullet level exhibit granular texture, rough surface area and more pores but at higher cullet level, the textures become smooth, vitrified and less pores. From EDAX analysis, the actual contents of the sintered samples are Si, Al, Ca, Na and K. The phases of ceramic are of Quartz (SiO_2), Wollastonite ($CaSiO_3$), Anorthite ($Ca(Al_2SiO_8)$), CaO and Al_2O_3. It can be concluded that this ceramic exhibits a potential application for refractory materials.

ABSTRAK

Beberapa siri seramik berdasarkan (*x*) *incinerated paper* - (80-*x*) *cullet* – 20 tanah liat kaolin (dengan $10 \leq x \leq 45$ wt%) telah berjaya disediakan melalui kaedah tuangan gelinciran diikuti dengan persinteran pada suhu 1000°C selama 2 jam. Sifat fizikal ditentukan berdasarkan kepada ketumpatan, serapan air dan pengecutan bahan. Manakala, kekerasan, modulus Young dan kekuatan tenaga hentak masing-masing ditentukan menggunakan penusuk Vickers, mesin ujian universal dan ujian hentakan Izod. Morfologi permukaan seramik dicerap menggunakan Mikroskop Pengimbasan Elektron (SEM), dan unsur komposisi ditentukan menggunakan Analisis Penyebaran Tenaga Sinar-X(EDAX) manakala perubahan fasa sampel dikaji menggunakan teknik Pembelauan Sinar-X (XRD). Ketumpatan seramik yang diperoleh berada dalam julat 2.170 gcm^{-3} hingga 2.420 gcm^{-3} manakala kadar serapan air dan pengecutan terma masing-masing berada dalam julat 0.63% hingga 31.60% dan 6.50% hingga 18.10% bergantung kepada kandungan nisbah kertas-*cullet.* Didapati juga sifat mekanik seramik meningkat dengan bertambahnya nisbah kertas-*cullet.* Nilai kekerasan, modulus Young dan kekuatan tenaga hentak masing-masing berada dalam julat 152.0 MPa hingga 1463.0 MPa, 1.522 kJm^{-2} hingga 7.124 kJm^{-2} dan 195.4 MPa hingga 603.3 Mpa. Keputusan kajian morfologi pada tahap kandungan *cullet* rendah mempamerkan tekstur berbutir, kawasan permukaan kasar dan banyak liang rongga tetapi pada tahap *cullet* yang lebih tinggi, tekstur berubah menjadi licin, berkaca dan kurang liang rongga. Daripada analisis EDAX didapati bahawa kandungan unsur yang terdapat dalam sampel adalah Si, Al, Ca, Na dan K. Fasa-fasa yang wujud di dalam seramik adalah fasa Kuartz (SiO_2), Wolastonit ($CaSiO_3$) dan Anortit ($Ca(Al_2SiO_8)$), CaO dan Al_2O_3. Dapat disimpulkan bahawa seramik ini berpotensi untuk digunakan sebagai bahan refraktori.S

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

α	Alfa
γ	Gamma
θ	Theta
ρ	Density
w_a	Weight sample in air
w_ℓ	Weight sample in liquid
ρ_f	Density liquid
h_o	Diameter of pre-sintered sample
h_1	Diameter of sample after sintered
σ	The applied stress (MPa)
ε	The strain (cm)
°C	Degree Celsius
A	Total surface area of permanent identation
Al	Aluminium
Al_2O_3	Aluminium Oxide
$Al_2Si_2O_5(OH)_4$	Kaolinite
Ca	Calcium
CaO	Calcium Oxide
$CaSiO_3$	Wollastonite
Cl^-	Chloride ion
cm	Centimeter
cm^2	Centimeter square
Cu	Copper
$CaAl_2Si_2O_8$	Anorthite

E	Young Modulus (MPa)
F	Load in Newton
Fe_2O_3	Iron Oxide
ft-lb/in	Pound per Inch
g/cm^3	Gram per Centimeter cubic
GPa	Gega Pascal
H	Hardness
H_2O	Water
H_v	Vickers Hardness
J/cm	Joule per Centimeter
J/m^2	Joule per Meter square
K	Potassium
K_2O	Potassium Oxide
keV	Kiloelectron Volt
kV	Kilovolts
l	Average of diagonal length
Li	Lithium
m	Mass
M	Mass of Sample
μm	Micrometer
MgO	Magnesium Oxide
mL	Milliliter
MPa	Mega Pascal
N	Newton
n	Lattice constant
Na	Sodium
Na^+	Natrium Ion
Na_2O	Sodium Oxide
nm	Nanometer
O	Oxygen
OH^-	Hydroxide
Si	Silicon

SiO_2	Silicon Oxide
α -SiO_2	Quartz
TiO_2	Titanium Dioxide
V	Volume
W%	Water absorption rate
W_1	Weight sample before immersed in water
W_2	Weight sample after immersed in water
wt%	Weight percent
ZrO_2	Zirconia dioxide

LIST OF ABBREVIATIONS

CRT-	Chatode Ray Tube
EDAX-	Energy Dispersive of Analysis X-ray
EDS-	Energy Dispersive Spectrometer
MSW-	Municipal Solid Waste
SEM-	Scanning Electron Microscope
US-	United States
XRD-	X-ray Diffraction
XRF-	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.0 Background of Study

In recent years, the municipal solid waste (MSW) in Malaysia has become a national anxiety since the amount generated has continuously rising up every year (Manaf *et al.,* 2009). According to Agamuthu and Victor (2011), in 2000, the total solid waste generated in Malaysia is estimated about 9.0 million tonnes per year and would be increasing up to 15.6 million tones per year by 2020. Generally, vast amount of increment of solid waste in Malaysia is due to exponential growth rate of population, accelerated urbanization and development of industry and technology (Saeed *et al.,* 2009; Kathirvale *et al.,* 2003; Zahari *et al.,* 2010). Besides, the main approach to manage the waste is by disposing it into landfills (Mohamed *et al.,* 2011; Eusuf *et al.,* 2007). However, this approach has been a critical issue due to the limitation of landfills, negative environmental impact and public health issue (Mohamed *et al.,* 2011). In order to minimize this problem, recycling has been promoted due to its more environmental friendly technique to reduce waste and it can also generate economy for Malaysian communities (Isa *et al.,* 2005; Saeed *et al.,* 2008). Thus, to satisfy the needs for reducing wastes disposal, the invention of new materials from recycle waste is very important and will be an eye-opening since it can convert the wasted materials to valuable products.

Ceramic industry is one of the compatible industries that can be generated to promote conservation of solid waste because it comprises a variety of compounds and could be prepared through various methods (Junkes *et al.,* 2011). The main advantages using waste in ceramic processing is the ability of the ceramic to tolerant with variation of waste composition. There are abundant of waste such as cullet glass, incinerated ash, sludge ash, dust wood and etc that have been explore and exhibit potential to be used in manufacturing of ceramic product. In addition, the mechanical and chemical properties of the ceramic from wastes material are comparable with the commercial products (Isa, 2011; Boccaccini *et al.,* 2006). Kim *et al.* (2005) indicated that cullet glass of 70 wt% when mixed with clay has comparable physical and mechanical properties of commercial clay tiles. The density of the tile is about 2.3gcm^{-3}, water absorption of about 0.9% and maximum compressive strength of about 210 MPa.

Cullet glass has been widely studied as a recyclable material in the ceramic processing (Meyer, 2001). Generally, it can react as fluxing agent in many ceramic products such as stoneware, tiles, bricks concrete and cement. Then, it also reduces the sintering temperature when mixing with clay (Shi and Zheng, 2007; Lin, 2007). For some reasons, it can also improve durability of ceramic product such as concrete due to glass high durability properties (Meyer, 2001). Besides, cullet has a competitive price, widely available, abundant and chemically inert thus reportedly suitable to perform as a filter media that possessed higher resistance to the affection of organism and growth of bacteria (Barlow, 2001; Meland and Dahl, 2001). In some cases, the mixture of cullet with other waste material to form ceramic is very encouraging since it can improve some of the limitation properties of ceramic that produced only with cullet and clay. Moreover, it can also reduce the consumption of environmental source since the waste itself has the same composition with natural sources.

The mixture of cullet with incinerate paper ash is very promising since they are composed of ceramic raw materials such as SiO_2, CaO, Al_2O_3 and MgO (Asquini *et al.,* 2008). It has recently been demonstrated that the mixtures of cullet and

incinerate paper sludge ash with red clay using dry pressing method have met the industrial standards in the production of ceramic material such as earthenware tiles (Maschio *et al.,* 2009). Elsewhere, the insulation of brick with adequate mechanical strength of industrial standard have successfully been produced from a combination of brick raw material and paper processing residues using the same method (Sutcu and Akkurt, 2009). Thus, it is clear that much work has to be done especially to promote any process, techniques and other ways to increase the usage of cullet in different areas.

In the present study, some properties of ceramics-based incinerated paper-cullet-Kaolin clay will be reported. The dependence of such properties with the amount of cullet content will be discussed in detail.

3.2 Statement of Research Problem

The study of cullet-clay as well as cullet-incinerated paper which emphasis on the ceramic products has previously been done by many reasearchers (John *et al.,* 1996; Liaw *et al.,* 1998; Maschio *et al.,* 2009; Toya *et al.,* 2006; Tuccia *et al.,* 2004). Most of them are prepared using the dry pressing method. However, for some reasons the preparation of ceramic by slip casting technique has not very well mentioned in literature. Consequently, most of the ceramic made by slip casting technique from waste like fly ash, phosphogypsum, slag, slate powder and etc were focused on filter medium ceramic. Then, it was characterized more on physical and microstructure properties (Qin *et al.,* 2011; Peres *et al.,* 2006; Jonker and Potgieter, 2005).

Thus, the aims of this project to study the properties such as physical, mechanical and microstructure of the ceramic fabricate via the slip casting technique. The optimization of these properties is very important to acknowledge the optimum

composition in ceramic products. From this point of view, this reasearch is engage towards the performance improvement compared to the other technique of the preparation in ceramic products especially for sustainable materials.

1.3 Objectives of the Research

The objectives of the study are:

i) To fabricate the incinerated paper – cullet - Kaolin ceramic by slip casting technique.

ii) To characterize the physical properties of the ceramics from different composition of incinerated paper – cullet - Kaolin.

iii) To characterize the mechanical properties of the ceramics from different composition incinerated paper – cullet - Kaolin.

iv) To characterize the microstructural properties of the ceramics.

1.4 Scope of Study

1.4.1 Preparation of Sample

A relatively fine powders of recycle paper is obtained by inceration process at 800^{o} C for 2 hours before being sieved by a 100 μm siever in size. Meanwhile, a glass powder is prepared by crushing the cullet into small pieces followed by grinding using a ball milling for 24 hours. A 100 μm size of siever is used to get the glass powder. Meanwhile, the Kaolin clay is supplied by the local ceramic industry and also sieved by a 100 μm siever in size.

The samples are fabricated using slip casting process with 8 different composition in the range of (x) recycle paper - (80-x) cullet – 20 Kaolin clay, where $10 \leq x \leq 45$ wt%. The samples are then sintered to get a suitable composition of ceramic.

1.4.2 Sample Characterization

The physical properties of the ceramic are characterized in term of their density, water absorption and thermal shrinkage at different composition.

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The mechanical properties of ceramic is characterized in term of their hardness, Young's modulus and impact energy strength which are measured using Vickers Indenter, Universal Testing Machine and Izod Impact Tester, respectively.

The surface morphology of the ceramic is observed using Scanning Electron Microscope (SEM) and the elemental compositions are determined using Energy Dispersive Analysis (EDAX) while the phase identification of the ceramic is performed by X-Ray Diffraction(XRD) technique.

1.5 Significant of the Study

This study will give an alternative ways of converting some waste products into more marketable, valuable and environmental friendly materials. In some ways or another, lots of landfill area will be secure from being the dumping area.

More important, this reaserch will create awarness among the society on how important to preserve the natural resources without denying the needs for developement via green technology.

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