MECHANICAL PROPERTIES AND FRACTURE BEHAVIOUR OF GREEN INNOVATIVE GLASS (GIG) MADE FROM WASTE

This report submitted in accordance with the requirements of Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons)

by

MUHAMAD ASHRAF BIN AZMAN

B051510136

960402-10-5453

FACULTY OF MANUFACTURING ENGINEERING

2019

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

Tajuk: **MECHANICAL PROPERTIES AND FRACTURE BEHAVIOUR OF GREEN INNOVATIVE GLASS (GIG) MADE FROM WASTE**

Sesi Pengajian: **2018/2019 Semester 2**

Saya **MUHAMAD ASHRAF BIN AZMAN (B051510136)**

mengaku membenarkan Laporan Projek Sarjana Muda (PSM) ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. *Sila tandakan (√)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/ badan di mana penyelidikan dijalankan)

☐ TIDAK TERHAD

Disahkan oleh:

_____________________________ _____________________________

Alamat Tetap:
No 8, Jalan Pinggiran USJ 1/19,
Taman Pinggiran USJ,
47600 Subang Jaya,
Selangor Darul Ehsan.
Tarikh: 24/06/2019

Cop Rasmi:

Tarikh: ________________________

*Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “Mechanical Properties and Fracture Behaviour of Green Innovative Glass (GIG) Make from Waste” is the results of my own research except as cited in reference.

Signature : ……………………………………………

Author’s Name : MUHAMAD ASHRAF BIN AZMAN

Date : 24th June 2019

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Management) (Hons.). The member of the supervisory committee is as follow:

…………………………….

(ASSOCIATE PROF. DR. JARIAH BINTI MOHAMAD JUOI)

ABSTRAK

Kaca Inovasi Hijau (GIG) adalah jubin seramik yang menggunakan serbuk kaca sebagai satu daripada bahan campuran tanah liat. Bahan asas dalam prosess pembikinan GIG adalah kaca silika soda batu kapur adalah diambil daripada PUM Cullet SDN BHD yang terletak di Johor Bahru sebagai botol and bekas kaca. Terdapat dua formulasi GIG jubin seramik, satu nya adalah formulasi hijau dan satu lagi formulasi putih. Objektif kertas ini adalah untuk menjalankan ujian mekanikal keatas GIG jubin seramik dan seterusnya mengumpul data untuk menganalisis watak keretakan. Makanya dapat menghubungkaitkan sifat mekanikal GIG jubin seramik dengan cara pemprosesan dan komposisi dibandingkan dengan jubin ynag terdapat di pasaran. Kajian ini akan melaksanakan tiga langkah, antaranya identifikasi sampel, ujian mekanikal, dan seterusnya analisis retakan pada GIG jubin seramik. Ujian keretakan telah dilakukan dan mendapati bahawa seramik porcelain mampu menahan retak sehingga ke 33 kN/mm^2 sementara kepanjangannya sehingga 5.74mm. GIG putih menghasilkan keputusan 36 kN/mm^2 dan kepanjagan sehingga 3.6mm. GIG hijau pula menghasilkan 46 kN/mm^2 dan kepanjangan 3.6mm. daripada ujian XRD mendapati bahawa seramic porselin biasa mengandungi fasa kristabolit dan para-wollastonit. GIG hijau dan putih mengandungi fasa wollastonit, kristobalit, dan fosterit. Analisa keretakan juga mendapati bahwa GIG hijau menghasilkan retak yg agak ketara arah retaknya manakala GIG putih menghasilkan retak yg kurang jelas dan akhir sekali seramik porselin menghasilkan retak yg agak teruk dan amat besar.

ABSTRACT

Green Innovative Glass (GIG) is a ceramic tile that uses waste glass powder as a part of the composition of the clay mixtures. The basic raw material used for fabricating GIG is soda lime silica glass (SLSG) which were collected from PUM Cullet SDN BHD. located in Johor Bharu as the glass requested are from waste glass containers or bottles. There are two types of formulation of GIG ceramic tiles, which are green and white formulation. The objective of this paper is to conduct mechanical testing for GIG ceramic tiles and to gather information and data for fracture analysis, hence able to correlate the high performance of mechanical properties with the processing parameters, and composition of GIG ceramic tiles compared to the conventional ceramic tiles. This paper will conduct 3 steps of method which is sample identification, the preparation of the ceramic tiles before to the next step which is mechanical testing of GIG ceramic tiles on a three-point bending test, and finally fracture analysis on the surface of fracture. Flexural test results in the unglazed ceramic porcelain results in 33 kN/mm^2 while the elongation is 5.74mm while the white GIG results in 36 kN/mm^2 and the elongation is 3.6mm. Lastly the green GIG shows the highest stress absorption with 46 kN/mm^2 and the elongation is 3.6mm. XRD analysis shows that unglazed ceramic porcelain contains cristobalite and para-wollastonite phase while the white and green GIG contain wollastonite, cristobalite, and fosterite. Fracture analysis shows that the alignment of the crack propagation from the unglazed ceramic porcelain shows that obvious cracks occurs in the material while not in the white GIG as it cracks more disperse and showing less crack with the presence of pores on the fracture surface. Lastly green GIG shows that the deepest cracks as it be able to repel lots of stress with less elongation.

DEDICATION

The one and only

My heart and soul,

Azman bin Kasman & Noraini binti Misran.

My sweet sisters,

Aneeda binti Azman & Natasha binti Azman,

You brought me love and fortune and everything that goes with it

I thank you all.

ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully.

I am here humbly being thankful for my respected supervisors, Associate Professor Dr. Jariah Binti Muhamad Juoi for her kind supervision, advice and guide for giving me such opportunity to experience the knowledge of handling this research Besides, her supervision and support that she gave me and she truly helps during the period of conducting my final year project.

Next, I would like to dedicate my thankful to FKP lecturers, laboratory technicians, and staff who have welcome me so whole-heartedly and kind to provide sincere assistance and good cooperation whenever I needed their help and guidance throughout my final year project period.

Finally, I would like to expand my sincere appreciation to my beloved family and my friends who have being so understanding, kind and supportive during completion of this final year project. My appreciation also goes to all those who help me directly and indirectly in completing this report. Thank you all.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UTeM	Universiti Teknikal Malaysia Melaka
FKP	Fakulti Kejuruteraan Pembuatan
GIG	Green Innovative Glass
ASTM	American Standard for Testing and Material
ISO	International Organization for Standardization
SEM	Scanning Electron Microscopy
MOR	Modulus of Rupture
SLS	Soda Lime Silicate
XRD	X-Ray Diffraction
OM	Optical Microscopy
SiO_2	Silicon Oxide
AlO_3	Aluminium Oxide
MgO	Magnesium Oxide
Fe_2O_3	Ferric Oxide

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Today, glasses, papers, plastics and other materials are rarely used for recycling. Waste management seldom used landfill method to dispose the garbage from residential area. Only few of them are used for recycling. Others are left on the landfill to decompose and for the materials that do not decompose will stay there for hundreds of years more. Regarding to these, disposal such as glasses are reused. Soda-lime Silica (SLS) glass is one of example of urban waste consist of mainly Silicon, Sodium, and Calcium Oxide.

There is additionally an extraordinary distress in regards to the expanding measure of industrial wastes, for example, plastic, glass, mud, slag and carbon. For instance, Japan underscores recuperation of waste and results through usage of procedures to supplant material sources with innovation improvement (Erkman *et al*., 2002). There are a few methods to arrange the wastes, either by recycling practice or land filling practice. The accomplishment of glass recycling programs has brought about more post-consumer glass than towns can use; there is additionally a post-industrial glass waste accessible *(Mohamad Ali, 2013)*. Usage of burned waste bottom slag, carbon dark and spent bleach earth into delivering helpful items or into glass composite material would be a compelling effort in defeating the downside of land-filling which is the current planned waste treatment technique (Juoi *et al*.,2013)

Clay minerals, feldspar from a natural mineral that acts to reduce the firing temperature and other chemical additives that is needed for shaping process. The recycled materials must be pulverized and characterized by molecule size. From Figure 1.1, primary crusher is utilized to eliminate large pieces of material. A jaw crusher is utilized, which work using a horizontal squeezing motion between steel cones or steel plates.

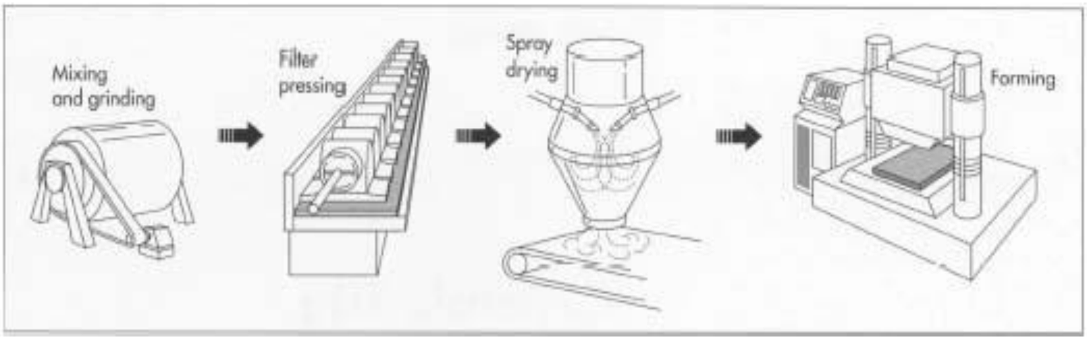

Figure 1. 1: The step-in manufacturing ceramic tiles is mixing the ingredients. The leftover water is removed by pressing filter and spray drying. The powder is then pressed into the desired tile body shape.

Next is pressing which will decreases smaller lumps into particles. Ball mills are frequently used which comprises of vast rotating cylinders somewhat loaded up with spherical in shape grinding media. Roller or cone type crusher can also be utilized. Third step might be the most essential steps to decrease molecule size. Tumbling sorts of mills are gradually decrease in size while mixing with abrasive particles.

Screens or sieve are used to segregate powder in a particular size range. The screens work in an inclined position and are shake mechanically or electromechanically to enhance powder flow through the screens. Screens are characterized by mesh number, the higher the work number, the smaller the opening size. A fine glass powder is sprayed onto the surface of the tiles during firing process so that the glass powder can melt on top of the tile surface. Hence it will sticks on the surface during cooling. Coatings are used to give the tiles more resistance to water and beautification, as they will add colour or can create special surfaces.

In this pressing method, the free running powder containing natural binder or a low level of dampness. Streams from a container into the shaping die. The material is compacted in a steel cavity by steel plungers and is then cast out by the base plunger. A few different strategies are likewise utilized where the tile body is in a wetter, progressively flexible shape. One of the pressing methods used in powder compaction in ceramic fabrication is uniaxial pressing. The powder is pressed two times with load about 90 MPa and the holding time is 1 second.

Ceramic tile should be dried at relatively high wetness later after shaping, particularly if a wet technique is utilized. Drying, that can take a few days, eliminated the water at sufficiently slow rate to avoid shrinkage cracks. Along these lines, one of technique to filter the material legitimately is by drying the material in stove/hot temperature around 4-5 hours. The temperature of the stove can be estimate around 120 until 150 Celsius. In the long run the material will wind up dry and it will breeze through the test sieve effortlessly.

Sintering process is a standout amongst the most vital stages in the fabricating of ceramic tiles. Amid this procedure, a progression of responses happen that change the microstructure of the tile, making the essential final properties, for example, mechanical strength, size steadiness, protection from chemical agents and fire and easy cleaning. Amid the sintering stage, the main factors in the thermal cycle are the firing time and temperature and the furnace air, which rely upon the composition of the raw materials and the kind of product required. Sintering method used is conventional sintering which two stages heat treatment applied to the ceramic body.

Ceramic tend to be fragile in tension, yet strong in compression. For a metal, the compressive strength is close to that of the tensile strength, while for a ceramic, the compressive strength might be multiple times the tensile strength. The inconsistency among tensile and compressive strength is somewhat because of the brittle nature of the ceramic. At the point when exposed to a tensile load, ceramic, in contrast to metals, can’t yield and relieve the stress. Another vital feature is the existence of internal flaws from which cracks can propagates in tension, however not in compression.

1.2 Problem Statement

Added substances could be of a critical significance around here and regularly, even in the event that the possibilities of mineral segments (clay minerals, carbonates and feldspars) are not all that high amid the procedure of firing, some unforeseen crystalline structures could be made within the sight of the added substances. Waste glass advances an increasingly successful liquefying of quartz and a halfway disintegration of mullite, prompting a progressively rich and less viscous fluid phase, which speed up the sintering kinetics (F. Matteucci, 2002). A few added substances are utilized so as to make progresses in to thermal behaviour of the clay bodies, or for design a ceramic microstructure resistant to potent ecological conditions (R. Rekecki, 2003). To analyse the fracture toughness of the ceramic tiles made from waste, only mechanical test will be conducted. High-rate loads are come across in many engineering applications and it is vital to see how these loading routines influence the fundamental crack mechanisms with the end goal to guarantee the decency of the material. For the most part, high-rate loading is characterized by the need to investigate the stress wave causing in a material to completely know its behaviour.

The effect creates a stress wave that movements into the specimen, interact with the crack and reflects from the far end. On the off chance that the effect speed is adequately high, it is conceivable to start the fracture instance before the arrival of the stress wave at the supporting posts. In the event that the crack does not start upon the main pass of the stress wave, the wave will accordingly reflect between the top and bottom surfaces of the specimen and in the end put the beam into oscillatory movement. On the off chance that the stress wave develop makes fracture happen after the sample has acquired a dynamic balance state, at that point this condition is similar to the semi static routine and analysis can propagates as indicated by the laws of elasto-statics. It ought to be evident that on the off chance that the crack propagates with the main go of the stress wave, a more perplexing examination is required. In what is in all probability the latest distributed work, (Jiang *et al.*, 2018) altered the test procedure portrayed to utilize four-point bending as an alternative to three. Every single other part of the setup was basically the same. The four-point bending ought to dispose of any misalignment issues and guarantee pure opening during crack inception.

1.3 Objectives

1. To conduct mechanical testing on the tiles made from waste then analyse the fracture behaviour.
2. To correlate the mechanical performance of the GIG ceramic tiles to the composition and processing parameter.

1.4 Scope of Study

The scope of this project is mainly about studying the mechanical strength of the Green Innovative Glass (GIG) tiles made from waste. The process started by preparing the green innovative glass. The composition and the processing parameters of GIG ceramic tiles have been identified as the best parameters throughout the previous research to fabricate the GIG ceramic tiles so that the best ceramic tiles made from waste being able to produce. The scope is mainly about the mechanical properties and microstructure of the GIG ceramic tiles and how it affects the fracture behaviour compared to conventional tiles.

CHAPTER 2

LITERATURE REVIEW

This chapter consist of article or paper that has been done previous researchers to assist this research by providing an explanation, summary, and critical assessment of the works related to this research that being investigated.

2.1 Ceramic Tiles

Ceramic tiles possess such high-water absorption and mechanical strength for which makes it become a choice for user on such high stress usage. The low porosity of the ceramics comes from a few processing parameters which are from fine structure of clay after milling process, proper pressure of powder compaction, firing temperature, and the production of liquid phases that is produced by the material amid sintering process (high drying up). In any case, on account of polished ceramic, mechanical properties may be reduced by the closed pores that stay permanently in the material’s structure during fabricating processes, for example, its ability to resist stains.

Ceramic tile that is a severely vitrified will deliver defined body by combinations of kaolin, quartz and feldspar are widely used as house pottery, laboratory, and industrial applications. For practical purpose, ceramic tiles are electrical, thermal, chemical, mechanical and structural resistant. The kaolin, offers plasticity to the clay combination which consists of rock or quartz, will maintain the shape of the part during sintering and feldspar on the other hand, fills in as transition. Those three components combined together and results in ceramic to have a phase structure as far as oxide constituents, thus the term triaxial ceramic tiles (Buchanan 1991 and Olupot, 2006).

From feldspar and the other low melting point impurities in the mixture, there is mullite and undissolved quartz crystals rooted to the continuous glassy phase. As illustrated by Thurnauer (1954), by changing the composition of the three ingredients, it is likely to vary the thermal, dielectric, mechanical properties of the materials.

2.2 Mechanical Properties of Ceramics

For household and construction applications, metallic and organic materials are contending to be selected. The major criteria are in terms of the required mechanical properties, such as strength, toughness, density and stability in the life-long usage, and the most important the cost. A proper material choice must be carefully selected so that the basis of relative cost is required. The variations of the composition of the three main elements (quartz, feldspar and kaolin), the processing parameters, and the firing schedule being applied are the main factors that influenced the properties of each porcelains product.

Carbon content in the raw material is significantly important as Kanjiza Clay material need a very particular approach to control the carbon content as it may act as an important role as a stabilizer and mineralizer. But precaution steps have to be taken as it may also be a starting point of a very deadly failures (T. Mumenthaler *et* al., 1995). In order for this not happened, the carbonate have to be finely ground and spread evenly in the clay mixtures.

There are many efforts to increase the strength of ceramics by highlighting on minimization the usage of quartz in the porcelain mixture composition. This is because of the β to α phase transposition of the quartz which occur at 573°C during cooling (Olupot, 2006). The change effects the quantity of the quartz in the ceramic body and thus induce cracks. The tensile strengths of material hold more information more than required. Generally, the best metals are stronger than the best ceramics while the best ceramics are stronger than the best plastics (Davidge and Evans, 1970).

Additives can be an important element in this field and even the common mineral components such as feldspar, clay minerals, and carbonates has less effects during firing process. Some unexpected crystalline forms could be form in the presents of the additives. Ceramic tile is a sort of the ceramic materials which have the glassy attributes. Vitrification process enhance the level of melting of the material on firing process which results in porosity <0.5 % and high >40 % glass content on fired ceramics (Perez *et al.*, 2013). Unlike other ceramic materials, porcelain possess such high hardness, low electrical and thermal conductivities, and brittle fracture (Callister, 2008).

The major disadvantage of ceramics is that the brittleness compared to other materials. Its tendency to cause devastation damage that can lead to failure under certain shock load. For instance, in building constructions, the need for mechanical properties is low. Hence traditional ceramics such as bricks, cement, and concrete are widely used. This is majorly because it cost less. Where in some cases, ceramics are too brittle, metals are mainly used. Despite of their limited mechanical properties, ceramics possess some other special properties including hardness, chemical inertness, low thermal and electrical conductivities, and high temperature stability.

2.2.1 Mechanical testing for ceramic tiles.

Yokoyama *et* al., (1993) used a modified Kolsky bar assembly to conduct three-point bend dynamic crack initiation experiments. Two transmission bars were used as the supports for a pre-cracked beam and the incident bar was used to apply the dynamic load. The time-to-fracture is found by mounting a semiconductor strain gauge on the specimen and using the peak strain as the time when the crack initiates.

Popelar *et* al. (2000) fully utilized the modification of instrumented Hopkinson bar in three-point bend tests of a pre-cracked beam. Incident pulse is recorded as the dynamic load is applied through the incident bar. The samples were equipped with strain gages to monitor the contact of the sample with the support pins to make sure that the beam is not move and ‘jump off’ the supports. An eddy current sensor was used to monitor CTOD. There is also a crack ladder gage to measure time-to-fracture and give a discrete measurement of crack growth speed. The authors use what they call a quasi-dynamic model to measure the dynamic stress intensity factor from the CTOD data. Their model comes from

A solution for the CTOD produced by Tada *et* al., (2000) for a propagating crack. For brevity these equations are omitted here, however in value the dynamic stress intensity factor, and in turn its critical value, K_{Ic}, from these equations for a propagating crack they are failing to consider the dynamic crack initiation and propagation toughness as independent material attributes as suggested by other researchers.

More recently, Weerasooriya *et* al. (2006) used a four-point bend method to define the dynamic crack initiation toughness in ceramics. They used a modified Kolsky setup with the specimen loaded in four-point bending amongst the nose and the supporting rollers. They used a pulse shaping technique to carefully control the loading pulse to certify not only continuous loading rate, but dynamic equilibrium of the sample as well. Quartz force transducers where imbedded in the ends of the nose and supporting rollers to measure the sample in equilibrium. Because the specimen was shown to be in dynamic stress equilibrium, quasi-static analysis was used to discover the dynamic crack initiation toughness.

In one of the most recent works to date, Jiang *et* al. (2007) have devised a new experimental technique using what they call two-bar/three-point bending. This is a much improved technique over the incident bar Charpy scheme by the same authors reviewed earlier. Similar to work by Weerasooriya *et* al. (2006) these investigators use a traditional two bar Kolsky apparatus experimental setup with a three-point bending mechanism attached to the incident and transmission bars as shown in Figure 2.1. They use pulse shaping techniques to control the incidence pulse and investigate the loss of contact issue between the impact pins and the specimen. They use a clever voltage scheme to monitor the contact at the pins and show that the loss of contact occurs well after the crack initiates in the sample. The authors do not actually report any calculated values for dynamic stress intensity factor.

As from the above, we can conclude that the dissimilarities between 3-point bending and 4-point bending test is that the highest or maximum stress is applied under the load of a 3-point bending test while the stress in 4-point bending test is spread out across the beam over a large region avoiding premature failure between the loading points. Three-point bending test is also applied for homogeneous materials while 4-point bending test is for non-homogeneous materials. The deflection in three-point bending test is easier to analyse