UNIVERSITI
MALAYSIA
KELANTAN

Effect of Adding Sugarcane Bagasse Ash and Glass Powder on the Performance of Refractory Bricks

Bibi Intishaar Binti Abdul Hakim
J20A0425

A report submitted in fulfillment of the requirements for the degree of Bachelor of Applied Science (Materials Technology) with Honours

FACULTY OF BIOENGINEERING AND TECHNOLOGY
UMK

2024

DECLARATION

I declare that this thesis entitled Effect of Adding Sugarcane Bagasse Ash (SCBA) and Glass Powder (GP) on the Performance of Refractory Bricks is the result of my own research except as cited in the references.

Signature : ______________________________

Student's Name : BIBI INTISHAAR BINTI ABDUL HAKIM

Date : ______________________________

Verified by:

Signature : ____________________________

Supervisor's Name : DR. NORFADHILAH BINTI IBRAHIM

Stamp : ____________________________

Date : ____________________________

ACKNOWLEDGEMENT

First and foremost, I would like to express my deep gratitude to my Creator, Allah S.W.T, for His unwavering guidance and abundant blessings that enabled me to carry out this Final Year Project (FYP) effectively, despite the challenges I faced. I offer my heartfelt praise to Him for granting me the opportunity, good health, and mental acuity to complete this significant project.

Furthermore, it is with great pleasure that I acknowledge and extend my gratitude to those who have played pivotal roles in shaping my knowledge and practical skills, particularly within the realm of research. My utmost appreciation is reserved for my supervisor, Dr. Norfadhilah Binti Ibrahim, whose continuous guidance, and unwavering support have been instrumental from the inception of this FYP until its successful conclusion. Even amidst her busy schedule, she consistently made time to provide guidance, facilitating the effective completion of my FYP.

I would also like to extend my heartfelt gratitude to the lab assistants at UMK for their invaluable assistance and guidance in laboratory work and the operation of characterization machines. I extend my thanks to all the dedicated laboratory assistants who helped me conduct the necessary tests. A profound thank you goes out to my FYP partner, who has been accompanying me on this journey and collaborating to successfully finish this report.

Last but by no means least, I wish to express my deep appreciation to my parents, family members, and friends for their unwavering support and motivation throughout the course of this FYP. My heartfelt gratitude is extended to everyone who has directly and indirectly contributed to the successful completion of my Final Year Project.

Effect of Adding Sugarcane Bagasse Ash and Glass Powder on the Performance of Refractory Bricks

ABSTRACT

This study investigates the influence of incorporating Sugarcane Bagasse Ash (SCBA) and Glass Powder (GP) on the performance of refractory bricks. As industries seek sustainable and cost-effective solutions for high-temperature applications, the potential of alternative materials in refractory brick production becomes increasingly relevant. Combinations of refractory bricks were formulated by introducing varying proportions of SCBA and the same proportions of GP. Their effects on crucial properties including mechanical strength, physical properties, porosity, and high-temperature resistance were rigorously assessed. The primary objective was to determine whether the integration of SCBA and GP could enhance these properties while maintaining the overall integrity of the refractory bricks. Results indicate that the inclusion of SCBA and GP has a significant impact on the properties of refractory bricks. This research provides insights into opportunities for developing environmentally friendly and high-performance refractory brick materials. It emphasizes the potential of SCBA and GP to improve sustainability and cost-efficiency in high-temperature industrial processes.

Keywords: Sugarcane Bagasse Ash, Glass Powder, Refractory Bricks, High-Temperature Applications, Mechanical Strength, Physical Properties, Porosity

ABSTRAK

Kajian ini menyiasat pengaruh menggabungkan Abu Tebu (SCBA) dan Serbuk Kaca (GP) ke atas prestasi bata tahan api. Apabila industri mencari penyelesaian yang mampan dan kos efektif untuk aplikasi suhu tinggi, potensi bahan alternatif dalam pengeluaran bata refraktori menjadi semakin relevan. Gabungan bata tahan api telah dirumuskan dengan memperkenalkan perkadaran SCBA yang berbeza-beza dan dengan perkadaran yang sama GP. Kesannya terhadap sifat penting termasuk kekuatan mekanikal, sifat fizikal, keliangan, dan rintangan suhu tinggi telah dinilai dengan teliti. Objektif utama adalah untuk menentukan sama ada penyepaduan SCBA dan GP boleh meningkatkan sifat-sifat ini sambil mengekalkan integriti keseluruhan bata tahan api. Keputusan menunjukkan bahawa kemasukan SCBA dan GP mempunyai kesan yang ketara ke atas sifat-sifat bata tahan api. Penyelidikan ini memberikan pandangan tentang peluang untuk membangunkan bahan bata tahan api yang mesra alam dan berprestasi tinggi. Ia menekankan potensi SCBA dan GP untuk meningkatkan kemampanan dan kecekapan kos dalam proses industri suhu tinggi.

Kata kunci: Abu Ampas Tebu, Serbuk Kaca, Bata Tahan Api, Aplikasi Suhu Tinggi, Kekuatan Mekanikal, Sifat Fizikal, Keliangan,

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

WSGB	Waste sugarcane bagasse
WP	Waste glass
SCBA	Sugarcane bagasse ash
GP	Glass powder
XRD	X-ray diffraction
SEM	Scanning electron micrograph
XRF	X-ray Fluorescence
WBA	Waste bagasse ash
CS	Clayey soil
WSCBA	Waste sugarcane bagasse ash
WG	Waste glass
SLS	Soda lime silicate
SCB	Sugarcane bagasse
SiO_2	Sillicon oxide
Al_2O_3	Aluminium oxide
Fe_2O_3	Ferric oxide
CaO	Calcium oxide
MgO	Magnesium oxide
TiO_2	Titanium oxide
MnO	Manganese (II) oxide
Na_2O	Sodium oxide
K_2O	Potassium oxide

LIST OF SYMBOLS

%	Percentage
wt.%	Weight percentage
°	Diffraction angle
°C	Degree Celsius
θ	Theta
ρ	Density
cm^{-1}	Centimeter inverse
g/m^3	Gram per cubic meter
µm	Micrometre
cm^3	Cubic centimetre
Mpa	Megapascal

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Refractory bricks, often colloquially known as fire bricks, represent a class of specialized construction materials engineered to withstand extreme temperatures and harsh environmental conditions. The manufacturing of refractory bricks has been a crucial aspect in various industries such as steel, cement, glass, and petrochemicals. It is produced specifically to withstand extreme heat conditions and an essential material in industries (Wang et al., 2023). Traditional refractory bricks are often manufactured using raw materials like clay, silica, alumina, and magnesia. However, the increasing demand for sustainable materials and the need to reduce environmental impact have led to the exploration of alternative materials in refractory brick production. Additives can be added to improve its performance in certain applications. Additives can improve the strength, thermal shock resistance, and other properties of bricks, making it more suitable for high-temperature applications (Chindaprasirt et al., 2021).

Previous research, as reported by Hamada et al., (2023), has demonstrated the beneficial use of recycling waste materials such as waste sugarcane bagasse (WSGB) and waste glass (WP) in the production of bricks. In terms of environmental benefits, recycling waste helps reduce the amount of waste directed to landfills and incinerators, thereby mitigating potential negative impacts on the environment. By using waste materials to make bricks, the virgin materials can be reduced, conserve natural resources, and minimize the carbon footprint associated with traditional brick-making methods (Assamoi 2012). Cost-effective, Recycling waste materials can be a cost-effective way to produce fire-clay bricks. Waste materials can often be obtained at a lower cost than virgin materials, which can reduce the overall cost of production (Abbas et al., 2017).

Besides that, by incorporating waste materials to the brick-making process was shown an improvement in the properties of the bricks (Andiç-Çakır, et al., 2021) as such improvement of traditional clay bricks' thermal insulation characteristics by using waste materials. Case Studies in construction materials demonstrated the additional of glass waste can increase the insulation properties of the bricks and make it more durable. To facilitate the widespread production and application of waste materials, including their utilization as a viable alternative in the construction and building materials industry, it is essential to consider economic and environmental factors, government policies, and public education that promote waste reuse and sustainable development. These factors play a crucial role in creating a supportive framework for the effective incorporation of waste materials into various industries (Arbelaex Perez et al., 2022).

Basically, there has been a study about adding sugarcane bagasse fiber only, but the research reported a reduction of the compression strength of fire clay brick after adding fibre waste to the specimens (Michael & Moussa 2022, Abdullatif et al., 2020). In contrast, Salih et al., (2018) prove that after adding fibres in the form of ash or after muddling clay bricks without burning the bricks. The incorporation of ash particles, which may still retain remnants of fibrous material even after the burning process. Although the original fibrous structure is destroyed during burning, the residual ash plays a significant role in enhancing the overall strength of the bricks. This interpretation underscores the unique contribution of ash particles, even in their altered state, to the mechanical properties of the resulting clay bricks (Salih et al., 2018)

In the previous research, the effect of adding waste bagasse ash and glass powder was identified are 100, 80, 70, 60, 50 g, and same amount of glass powder which is 10 g. Based on that, the effect on adding additive waste bagasse ash and glass powder were observed. The fire-clay bricks analysed by using x-ray diffraction (XRD), scanning electron micrograph (SEM), x-ray fluorescence (XRF), linear firing shrinkage, bulk density, water absorption and apparent porosity and compressive test (Artbumrung et al., 2022).

1.2 Problem Statement

The expansion of different industries and the excessive utilization of raw materials have led to a heightened focus on the reuse and recycling of agricultural and industrial waste. With the growing population, there has been an increase in the consumption of disposable and returnable materials, resulting in a larger volume of waste generated in societies. To promote the widespread production and application of these waste materials, it is necessary to consider economic and environmental factors, government policies, and public education pertaining to waste reuse and sustainable development. One potential solution is the utilization of waste materials as a viable alternative in the construction and building materials industry (Sutcu et al., 2015). Re-utilization waste materials in the production of bricks can be an effective strategy, as it reduces waste generation and decreases the need for clay in brick manufacturing. This approach not only contributes to waste reduction but also enhances the overall properties of the bricks (Arbelaex Perez et al., 2022).

One potential application includes utilizing these waste materials as viable alternatives in the construction and building materials industry (Artbumrung et al., 2022). Due to waste output reduction and decreased clay replacement in brick manufacturing, re-using waste materials in brick production can be a successful method test (Artbumrung et al., 2022). Extensive research has been conducted by numerous scholars exploring the utilization of diverse waste materials as additives in the production of clay bricks. These waste materials encompass a wide range, such as paper trash, sugarcane bagasse ash, tea waste, fly ash, waste glass, wastewater sludge, water treatment sludge, glass, marble debris, agro-waste, and sugarcane bagasse fibers (Artbumrung et al., 2022).

The utilization of sugarcane bagasse fibers, along with other waste materials, in brick production has certain limitations. These limitations arise from the ineffective utilization and inadequate disposal practices of agricultural wastes that are not effectively used and are either poorly disposed of or burnt, having adverse to the human health environment. However, reusing agricultural fiber by-products make the compression testing drop after burning the clay brick. This happened because the fiber burn so it may reduce the compressive strength (Micheal et al., 2022).

Previous studies, as reported by Artbumrung et al., (2022), have shown different result in improving properties of brick. Therefore, further addition of waste sugarcane bagasse ash and glass powder were used in the bricks by considering the burning and the research procedure to evaluate its effect on bricks properties. The different amounts between clay are 100, 80, 70, 60, and 50 g, and then waste bagasse ash which are 0, 10, 20, 30, 40 g, and the same amount of glass powder which is 10 g. After the brick samples were treated, observation of the effect of adding the waste sugarcane bagasse ash and glass powder was obtained.

The current studies as reported by Artbumrung et al., (2022), introduces notable modifications in the composition of bricks by incorporating sugarcane bagasse ash and glass powder. The rationale behind these changes lies in addressing limitations identified in prior investigations. Previous studies, as reported by Artbumrung et al., (2022), have shown certain challenges, such as increased porosity and water absorption. Building upon this knowledge, the current formulation seeks to overcome these challenges by adjusting the composition of sugarcane bagasse ash within the range of 0, 2.5, 5.0, 7.5, and 10 wt.%. This strategic variation aims to optimize characteristics like strength, durability, thermal insulation, and shrinkage control.

Moreover, the proposed changes align with the objective of determining the ideal ratio that offers improved performance in refractory bricks. The inclusion of sugarcane bagasse ash and glass powder not only addresses the limitations observed in previous research but also aligns with the broader goal of sustainable waste utilization. By incorporating these byproducts, the current formulation not only provides an eco-friendly method of disposal but also enhances the physical and mechanical properties of the refractory bricks.

1.3 Objectives

1. To investigate the effect adding different composition of waste sugarcane bagasse ash with same composition of glass powder in refractory bricks.
2. To study the effect of firing temperature of mechanical and physical properties of refractory bricks.

1.4 Scope of Study

In this study, the effect of adding waste sugarcane bagasse ash and glass powder in refractory bricks were investigated. The refractory bricks were prepared by combination with ball clay, waste sugarcane bagasse ash, and glass powder. There was different mix amount of three materials to be incorporated to make the refractory bricks and will were to identify the optimum value for the mechanical properties in the refractory bricks. The study aimed to investigate the influence of temperature and composition on refractory bricks. The bricks were subjected to different firing temperatures (900 °C, 1000 °C, 1100 °C), and their properties were evaluated using various techniques including x-ray diffraction (XRD), scanning electron microscopy (SEM), density, water absorption, porosity, compressive testing, fourier transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA) (Artbumrung et al., 2022).

1.5 Significance of Study

High demand in refractory brick industries makes this study significant. The advanced refractory bricks were widely used and applied in a many application. They are commonly used in the construction of high-temperature industrial furnaces, kilns, and chimneys due to their ability to withstand high temperatures and resist thermal shock. They are also used in residential fireplaces, ovens, and barbecues, as well as in the lining of blast furnaces and reactors. In recent years, there have been advancements in the development of advanced refractory bricks. These bricks are produced by incorporating a range of additives, including waste materials or nanomaterials.

These bricks offer improved mechanical, thermal, and chemical properties, making them suitable for a wider range of applications. For example, adding waste materials such as sugarcane bagasse ash (SCBA) or glass powder (GP) can improve the insulation properties of bricks (Artbumrung et al., 2022). Overall, refractory bricks have a long history of use and have been widely applied in various high-temperature and fire-resistant applications. With the development of advanced refractory bricks, they continue to offer new opportunities for use in a wide range of applications, including sustainable building practices.

The effect of adding waste sugarcane bagasse ash (WSCBA) and glass powder in refractory bricks can help society in several ways which are environmental benefits, by using waste materials in brick production, the study can help reduce the amount of waste sent to landfills, conserving natural resources, and reducing environmental pollution. This can help create a cleaner and healthier environment for society. Sustainable building practices, the study can promote the use of waste materials in construction and help develop sustainable building practices. This can lead to reduced environmental impact, improved building performance, and lower energy costs for building occupants (Maza-ignacio et al., 2021).

Then, economic benefits, using waste materials in brick production can be a cost-effective alternative to traditional brick-making methods, reducing the cost of production and creating a potential revenue stream for waste management companies. This can help stimulate economic growth and create job opportunities in the waste management and construction industries. Next, improved building performance. In addition, adding WBA and GP to fire-clay bricks can improve their physical properties and compressive strength. This can lead to better building performance, increased comfort, and reduced energy costs for building occupants (Artbumrung et al., 2022).

The research on adding Waste Sugarcane Bagasse Ash (WSCBA) and clay soil to clay bricks holds significant implications for various stakeholders, including construction and waste management companies, environmental organizations, and society at large. This study contributes to improving the understanding of material properties, determining optimal mechanical strength values, enhancing energy efficiency, and promoting environmentally friendly brick production (Kumar Swarnakar et al., 2016).

The methodology and results offer valuable insights for future experimentation with different waste materials and additives, potentially identifying new opportunities to enhance brick properties. For instance, the combination of Waste Bagasse Ash (WBA) and Glass Powder (GP) was examined in this study, revealing positive effects on physical properties and compressive strength. Previous findings also indicate that higher firing temperatures enhance compressive strength and reduce water absorption in burnt clay bricks (Artbumrung et al., 2022).

Research by Tonnayopas (2013) emphasizes the importance of sintering at a fixed temperature of 1,050 °C, demonstrating that the resulting strength can surpass that of conventional clay bricks when incorporating WSCBA. This practice not only improves strength but also reduces environmental impact, aligning with sustainable and eco-friendly brick manufacturing practices. While existing studies highlight the potential of different compositions and formulations in enhancing fire-clay brick properties, the optimal formulation remains inconclusive. This study specifically aims to investigate the most effective formulation of refractory bricks by incorporating waste materials, such as sugarcane bagasse and glass powder.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the definition and structure of refractory bricks were introduced. Additionally, detailed explanations were provided regarding the function and properties of incorporating waste sugarcane bagasse ash and glass powder as additives. Furthermore, the impact of varying the amount of waste sugarcane bagasse ash and glass powder was investigated. The influence of different firing temperatures on the composition and temperature of waste sugarcane bagasse ash and glass powder was also discussed. Suitable characterization techniques for analyzing the waste sugarcane bagasse ash and glass powder after firing were thoroughly examined.

2.2 Refractory Bricks

Refractory bricks, also known as fire bricks or heat-resistant bricks, are bricks made from ceramic materials that can withstand high temperatures without degrading or melting (Del Rio et al., 2022). Refractory bricks are commonly used in applications where high temperatures are involved, such as in furnaces, kilns, and incinerators. Refractory bricks are made from ceramic materials that are capable of withstanding temperatures of up to 3000 °C (Sequeira 2019). The materials used to make refractory bricks can vary depending on the intended application and temperature requirements, but they often include silica, alumina, and magnesia (Cardarelli 2008).

Refractory bricks can be classified into several different types, including acidic, basic, and neutral refractory bricks. Acidic refractory bricks are made from silica and alumina materials and are suitable for use in acidic environments, such as in the chemical industry (Jadeha and Saradava 2014). Basic refractory bricks, on the other hand, are made from magnesia or dolomite and are used in basic environments, such as in the steel industry (Sugita 2008). Neutral refractory bricks are made from materials such as chromite or alumina-silica and are used in environments that are neither acidic nor basic (Achaw and Danso-Boateng 2021).

Refractory bricks are widely used in various industries due to their excellent thermal shock resistance, high-temperature strength, and resistance to abrasion and corrosion. Refractory bricks play a critical role in ensuring the safe and efficient operation of high-temperature processes in industries such as steel, cement, and glass production (Kumarasamy et al., 2022).

2.3 Glass

Glass is a fluid substance that solidifies in an amorphous state. Glass recycling in construction materials has lately been discovered as a replacement for traditional materials. When introduced into a clay body mixture as an additive, glass powder (GP) might cause vitrification in fire-clay bricks after sintering. Previous research, as reported by Artbumrung et al., (2022), using soda-lime-glass indicated that including up to 10% waste glass (WG) in bricks improved the mechanical qualities of fire-clay bricks. When scrap glass was added up to 5% of the clay body, mechanical properties improved.

2.4 Soda lime silicate glass

Soda lime silicate glass (SLS) is widely employed as a common glass composition and is utilized in various glass products (Aktas et al., 2017). The vitreous silicate known as GP soda-lime-glass is generated during the maturation process of clay brick bodies. It serves the purpose of reducing the firing temperature required and improving the sustainability of clay brick production. However, the effects of GP on the porosity, shrinkage, and compressive strength properties of fired brick bodies have yet to be investigated and understood (Artbumrung et al., 2022).

Characterized by its light permeability and smooth, fine-pored surface, soda-lime glass offers easy cleanability. However, it is crucial to handle with care when introducing hot water into a container made of soda-lime glass, as it expands rapidly when exposed to heat. For reference, Table 2.1 provides an approximate overview of compositions commonly found in soda-lime-silica glass (Abdeen and Shihada 2016).

Table 2.1: Approximate compositions of Soda-Lime-Silicate

Type of Glass	Composition (by weight)
Soda-Lime-Silica	73% Silica – 14% Soda – 9% Lime – 4% Magnesia – 0.1% Alumina

(Source: Shelby, 2005)

2.5 Agriculture waste

Agricultural waste poses a significant environmental challenge. The primary objective of this study is to explore the feasibility of manufacturing fired clay bricks using a blend of agricultural waste and other waste materials. The focus is on identifying the most effective technique for partially replacing cement with sugarcane without compromising the standard properties of the resulting cement bricks. Numerous studies, as reported by Roushdy (2021), have examined the potential of substituting cement with sugarcane to create environmentally friendly cement bricks with suitable structural characteristics in the construction industry.

2.6 Properties of waste sugarcane bagasse ash and glass powder

SCBA and GP are waste materials that have the potential to improve the properties of refractory bricks. Refractory bricks are commonly used in high-temperature applications such as kilns, furnaces, and chimneys. These bricks are typically made from a mixture of clay and other materials, such as sand, to improve their properties.

Artbumrung et al., (2022) studied the effect of SCBA and GP on the properties of bricks. The researchers found that the addition of SCBA and GP led to a significant improvement in the compressive strength of the bricks. They also noted that the addition of these materials reduced the porosity and water absorption of the bricks, which improved their durability occupants.

In a separate study, as reported by Micheal and Moussa (2022), the impact of incorporating sugarcane bagasse fibers solely on the compressive strength of bricks was examined. They discovered that the inclusion of this material resulted in favourable compression strength across various loadings. However, it should be noted that agricultural wastes are currently not being effectively utilized, leading to improper disposal, or burning, which has detrimental effects on human health and the environment. The researchers further observed that the addition of sugarcane bagasse fibers to clay bricks in concentrations of 0.5% contributed to a reduction in surface cracks.

Overall, these studies suggest that the addition of SCBA and GP can improve the properties of refractory bricks, including their compressive strength, durability, and thermal conductivity. The combination of these materials may provide even greater benefits than using either material alone.

2.7 Characterization technique

Characterization is the process of examining and describing the properties, qualities, or behavior of a material, substance, or system through various tests, measurements, and observations. It helps researchers understand the composition, structure, physical properties, and performance of the subject being studied. Kazmi et al., (2016) studied, the bricks analysed by using x-ray diffraction (XRD), scanning electron micrograph (SEM), linear firing shrinkage, bulk density, water absorption and apparent porosity and compressive test.

2.7.1 Scanning Electron Microscopy (SEM)

SEM is an advanced imaging technique used to examine the surface of materials at high resolution (Falsafi et al., 2020), It involves scanning a focused beam of electrons over the sample's surface and collecting signals to generate detailed images and gather information about the microstructure of materials, morphology and particle size, pore structure of the samples which contain ball clay, SCBA and GP. SEM allows for the visualization of the morphology and particle size distribution of sugarcane bagasse ash and glass powder. The SEM images can reveal the shape, surface texture, and agglomeration of individual particles (Artbumrung et al., 2022).

2.7.2 X-Ray Diffraction (XRD)

X-ray diffraction (XRD) is a technique employed to determine the inherent crystal structure of a material. Its primary purpose is to confirm the presence of crystallinity and assess the sample's structural characteristics. However, it should be noted that XRD does not provide any chemical information about the material (Oganov et al., 2019). In another research study, as reported by Artbumrung et al., (2022), the influence of Waste Bagasse Ash (WBA) and Groundnut Powder (GP) on the microstructure and thermal properties of bricks was examined using X-ray diffraction (XRD). They observed that the incorporation of WBA, GP, and clay resulted in changes in the microstructure of the bricks. The X-ray diffraction analysis is depicted in Figure 2.1 (a).

The clay sample revealed the presence of several crystalline phases, primarily consisting of quartz, along with minor quantities of kaolinite, orthoclase, hematite, and muscovite. Conversely, WBA (Waste Bagasse Ash) predominantly consists of cristobalite and quartz, as depicted in Figure 2.1 (b). Lastly, for Figure 2.1 (c) presented for GP contains only a glassy phase (Artbumrung et al., 2022).

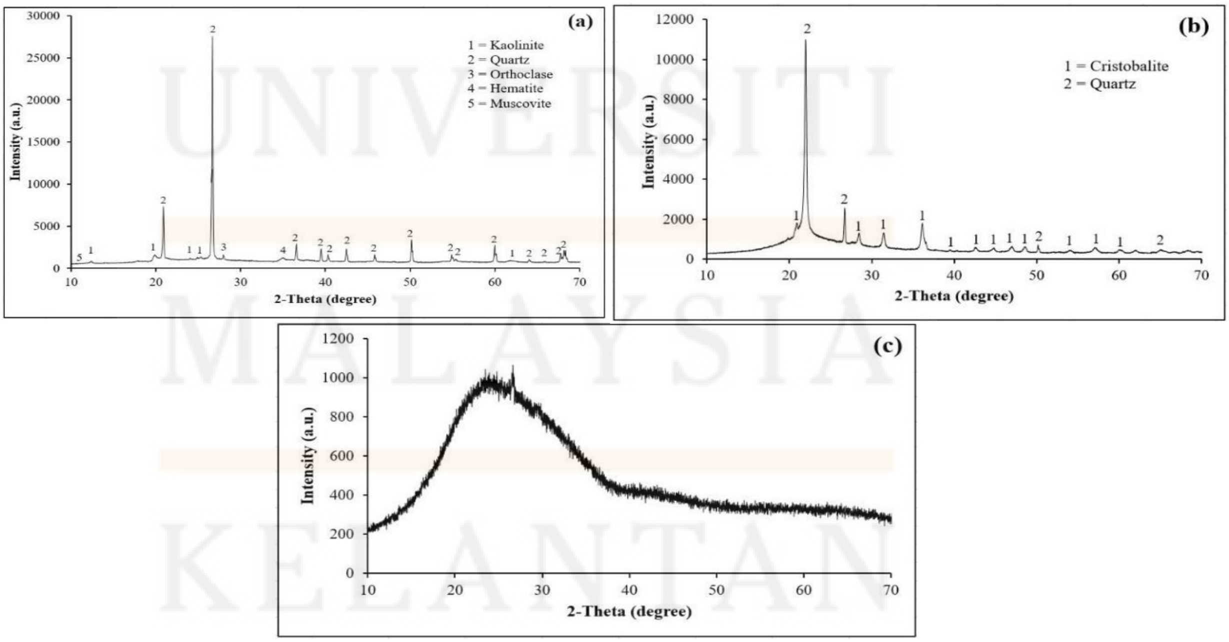


Figure 2.1: XRD pattern of (a) clay, (b) WBA and (c) GP.

(Source: Artbumrung et al., 2022)

2.7.3 X-ray Fluorescence (XRF)

X-ray Fluorescence (XRF) is a non-destructive explanatory technique that is used to determine the natural composition of clay, WBA, and GP. It is a technique used to analyze the elemental composition of materials by irradiating them with high-energy X-rays and detecting the characteristic X-ray fluorescence emitted by the atoms in the sample (Wen et al., 2023). The chemical analysis of the raw materials such as clay, WBA, GP could be described from XRF. From the result it shown that the raw materials are having different chemical constituents such as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, MnO, Na_2O, K_2O which can be identified as shown in Table 2.2.

Table 2.2: Chemical analysis of the raw materials
(Source: Artbumrung, S., et al. 2022)

Components	Clay (wt.%)	WBA (wt.%)	GP (wt.%)
SiO_2	59.43	84.58	71.43
Al_2O_3	20.67	1.84	0.87
Fe_2O_3	4.81	4.26	1.85
CaO	0.72	2.11	7.65
MgO	-	-	-
TiO_2	0.95	-	0.15
MnO	1.05	-	-
Na_2O	-	0.31	18.59
K_2O	2.86	0.25	0.43
LOI	12.37	7.90	-

2.8 Firing temperature

The firing temperature is an important parameter in brick production, as it can affect the microstructure, mechanical properties, and chemical composition of the bricks. In such an experiment, refractory bricks with different proportions of sugarcane bagasse ash and glass powder can be fired at different temperatures, such as 900, 1000 and 1100 °C, or higher, depending on the desired properties.

In accordance with ASTM C62-13a standards, the compressive strength requirement for burned clay bricks is set at a value exceeding 17.2 MPa. This threshold was successfully achieved by incorporating 10 wt.% WBA (Waste Bagasse Ash) and GP (Glass Powder) content, resulting in a compressive strength of 17.85 MPa after firing at 1100 °C. The combination of WBA and GP powder as additives exhibited a synergistic effect, enabling the production of fired clay bricks with significantly high strength levels (Artbumrung et al., 2022).

This happened because a firing temperature of 1100 °C, the clay mix may undergo full vitrification, resulting in a glassy matrix that is fully fused together. This can result in high strength and low porosity of the bricks, but it may also result in a more brittle material that is less resistant to thermal shock or other stresses (Artbumrung, et al., 2022).

CHAPTER 3

MATERIALS AND METHODS

3.1 Raw Materials

There is crucial aspect of raw materials in ceramic composite manufacturing. The primary focus was an in-depth exploration of the composition of raw materials, specifically examining variations in ball clay, sugarcane bagasse, and glass powder. A detailed table accompanied the research, providing a comprehensive overview of these variations and offering valuable insights into the material characteristics essential for the successful production of refractory bricks. The ball clay was used in the production of refractory bricks, varying the weight percentages of silica and alumina. Ball clay ($Al_2O_32SiO_22H_2O$) acted as the primary binder in the ceramic composition, while silica (SiO_2) and alumina (Al_2O_3) functioned as fillers, maintaining the shape of the ceramic structure during the firing process.

The sugarcane bagasse was obtained from stall that sold sugarcane juice. Subsequently, employed a method to transform the sugarcane bagasse into ash. Following this process, the resulting ash was used as a component, and its composition is detailed in the Table 3.1. Glass waste was collected from shops selling glass-based materials. The collected glass was cleaned of any impurities and then crushed using a hammer until it became glass cullet. Next, it was ground and filtered using a mesh sieve with a size of 150 µm. By adjusting the composition of ball clay, SCBA, and GP given in Table 3.1, five distinct compositions of refractory bricks were created.

Table 3.1: The composition of raw materials with varying of ball clay, SCBA and GP

Brick Series	Ball clay wt.%	SCBA wt.%	GP wt.%
Control	100.0	0.0	0
1	87.5	2.5	10
2	85.0	5.0	10
3	82.5	7.5	10
4	80.0	10.0	10

3.2 Research Flowchart

The research flow chart shows the sample preparation, evaluation and characterization steps as shown in Figure 3.1.

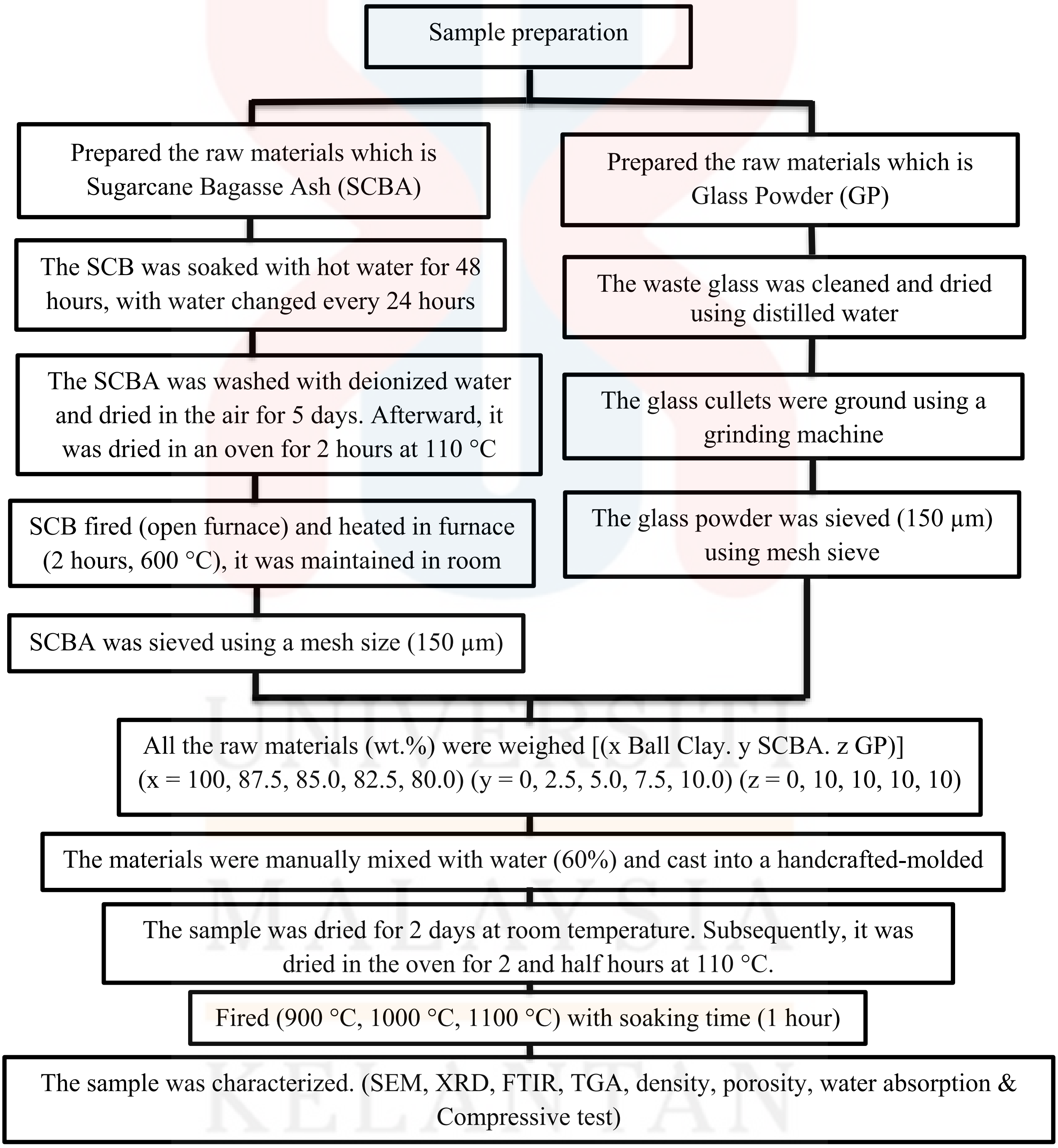


Figure 3.1: Research flow for Refractory Bricks

3.3 Sample Preparation

3.3.1 Ash Formation

In the investigation of sugarcane bagasse ash formation, the process involved The SCB was soaked with hot water for 48 hours, with water changed every 24 hours. The SCBA was washed with deionized water then dried the SCB by exposing it to ambient air for a duration of 5 days, followed by additional drying in an oven at 110 °C for 2 hours. The sugarcane bagasse was fired in an open furnace to initiate the transformation process. When sugarcane bagasse is burned in an open furnace, the resulting black ash is commonly referred to as "unburned" or "raw" sugarcane ash.

To achieve grey ash, a secondary step involves further heating in a furnace at a higher temperature at 600 °C for 2 hours and was thereafter left to naturally cool to room temperature. Finally, the resulting sugarcane bagasse ash (SCBA) was sieved using a mesh size of 150 µm to ensure the desired particle size and uniformity for further analysis or applications. The Figure 3.2 illustrates the comprehensive process involved in investigating sugarcane bagasse ash formation 1-6.

Figure 3.2: Process involved in investigating sugarcane bagasse ash formation.

3.2.2 Mixing

All the raw materials, including ball clay, sugarcane bagasse ash (SCBA), and glass powder (GP), were weighed according to their respective compositions as listed in Table 3.1. The materials were manually mixed, and water was added in a quantity of 60%.

3.2.3 Molding

The mixture was mixed and stirred manually for 3 minutes until blended, the mixture was cast into the prepared mold according to the specified size. The handcrafted mold size was 25 mm x 25 mm x 20 mm for compressive strength while 60mm x 15mm x 10mm for water absorption, porosity and density was shown in Figure 3.6. Figures 3.3, 3.4 and 3.5 shown the samples were allowed to dry for 2 days at room temperature, and then they were dried in the oven for 2 and half hours under a temperature of 900, 1000, 1100 °C.

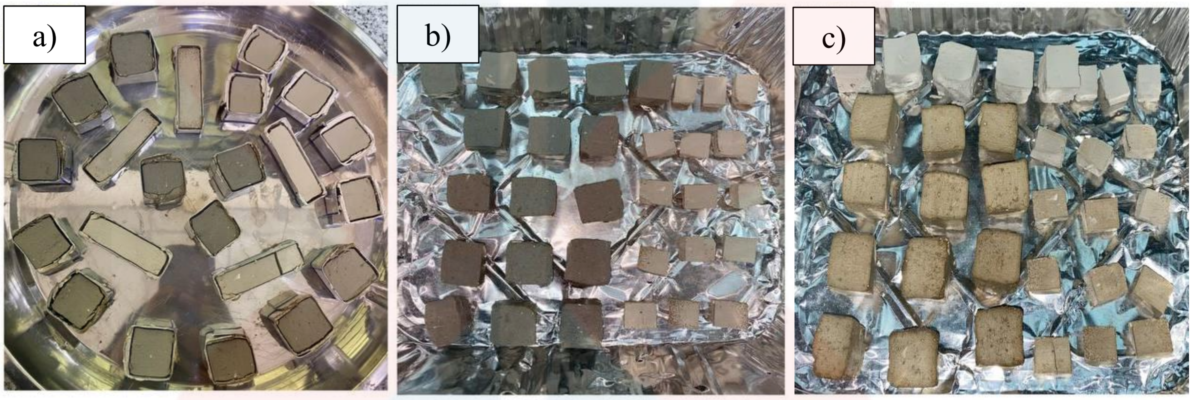


Figure 3.3: (a) **s**amples molded, (b) samples dried in air for 2 days at room temperature (c) samples dried in oven for 120 °C in 2 hours at 900 °C.

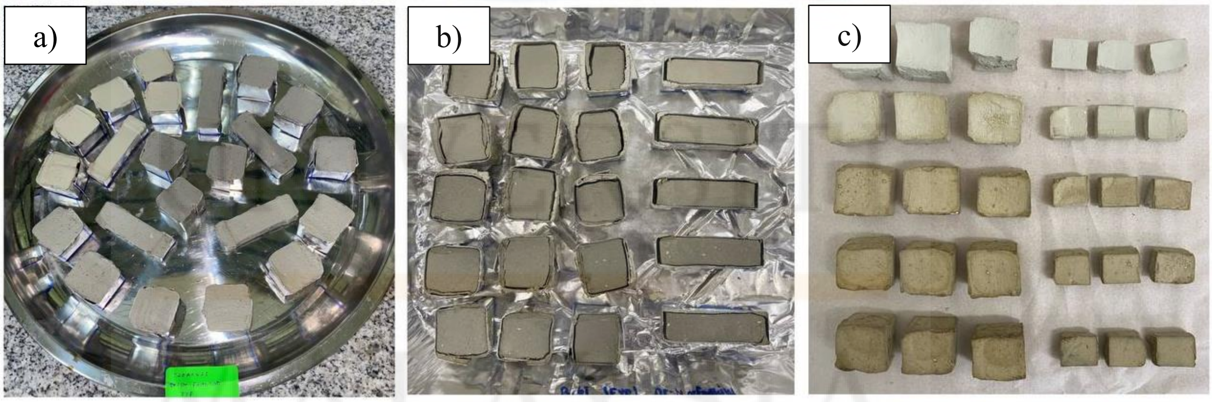


Figure 3.4: (a) **s**amples molded, (b) samples dried in air for 2 days at room temperature (c) samples dried in oven for 120 °C in 2 hours at 1000 °C.

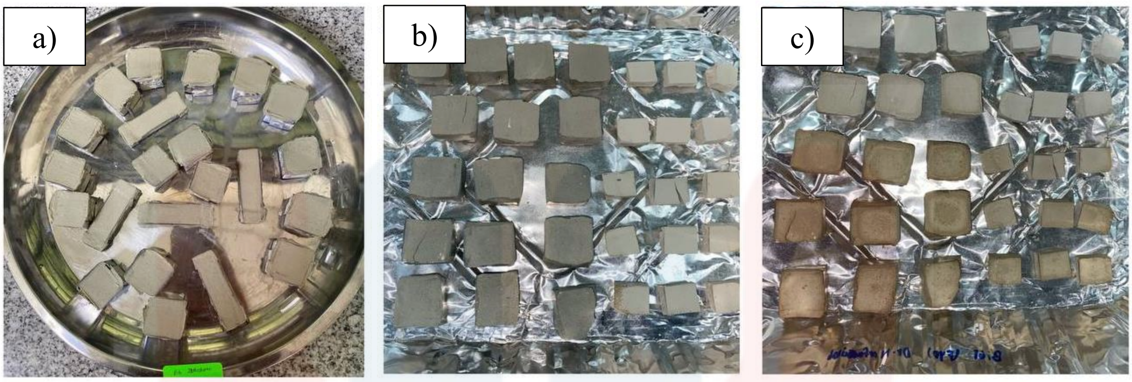


Figure 3.5: (a) **s**amples molded, (b) samples dried in air for 2 days at room temperature (c) samples dried in oven for 120 °C in 2 hours at 1100 °C.

Figure 3.6: Two size of handcrafted mold (60mm x 15mm x 1mm) and (25mm x 25mm x 20mm).

3.2.4 Firing

The next step involved firing the five samples with different compositions in a furnace at temperatures of 900, 1000 and 1100 °C with a heating rate of 5 °C /min with soaking time for 1 hour. The Figure 3.7 illustrates a temperature increase of 5 °C per minute, reaching 900 °C within 1 minute, where it remains for 1 hours to complete the ion exchange process. Subsequently, the samples were left at room temperature and proceeded to the characterization process. The uniform firing temperature could produce different structures for samples with varying compositions. Figures 3.8, 3.9 and 3.10 shows the samples after 2 hours and half hour in oven for 120 °C, samples placed in furnace and samples after firing processed at 900, 1000, 1100 °C.

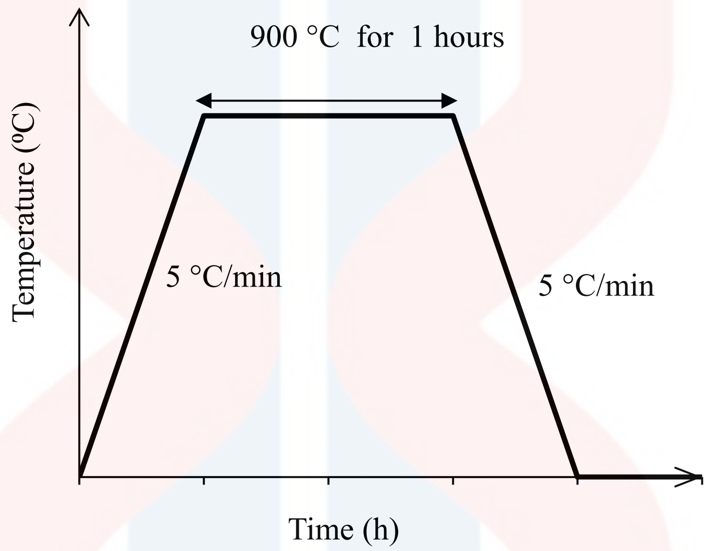


Figure 3.7: The temperature of ion exchange process and the heating rate of process.

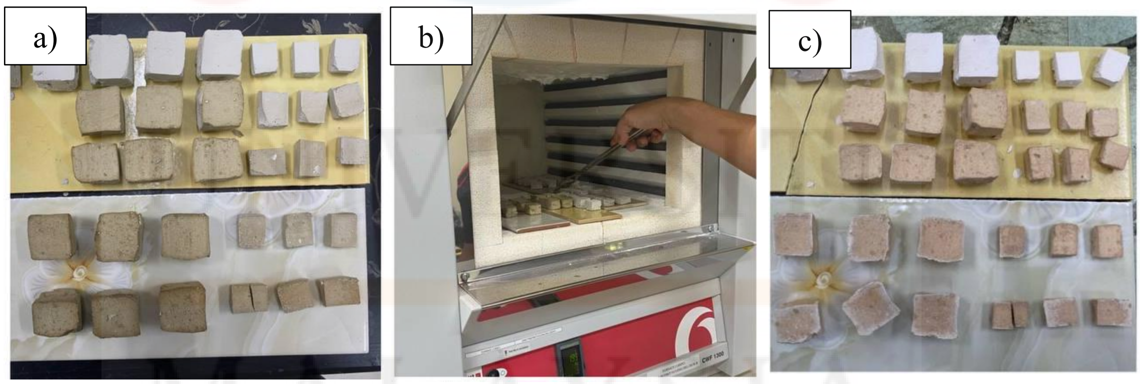


Figure 3.8: (a) samples after 2 hours and 30 minutes in oven for 120 °C, (b) samples placed in furnace and (c) samples after firing processed at 900 °C.

Figure 3.9: (a) samples after 2 hours and 30 minutes in oven for 120 °C, (b) samples placed in furnace and (c) samples after firing processed at 1000 °C.

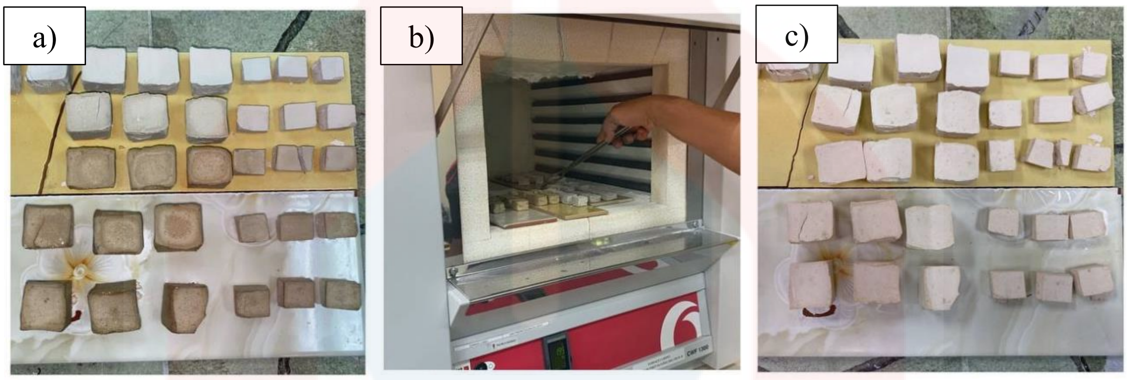


Figure 3.10: (a) samples after 2 hours and 30 minutes in oven for 120 °C, (b) samples placed in furnace and (c) samples after firing processed at 1100 °C.

3.3 Sample Characterization

3.3.1 Scanning Electron Microscopy (SEM)

The Scanning Electron Microscope (SEM) was used to analyze the surface of the sample microstructure as shown Figure 3.11. The scanning electron microscopy (SEM) analysis was conducted at the University Malaysia Kelantan (UMK) using the JSM IT200 InTouchScope SEM model. The SEM images revealed the shape and surface texture of individual particles for each material, namely ball clay, SCBA, and GP. The grain structure, grain boundaries, and pore structure of the sample were identified. The magnifications used was 1400x. SEM was employed to examine the sample's outer surface and microstructure. The accelerating voltage of the SEM was set at 15 kV.

Figure 3.11: The sample are being test using SEM machine.

3.3.2 X-Ray Diffraction (XRD)

X-ray Diffraction (XRD) was a technique employed to analyze the phase structure of a sample. Ultilized the X-ray diffraction (XRD) machine, specifically the D2 Phaser model manufactured by Bruker, for my analysis XRD enabled the identification of the crystal structure of a material, allowing for verification of its crystallinity and structure.

To ensure a uniform distribution of crystalline phases during powder XRD analysis, the ceramic brick sample was first crushed into a fine powder using a mortar. The powder was then placed in a sample stage or container for analysis. Powder XRD was commonly used to analyze the crystallographic structure and phase identification of ceramic materials. Data were captured in continuous scan mode at a rate of 2 °/min for 2θ ranging from 5 ° to 60 °. Peak intensities in XRD patterns indicated the amount or concentration of a specific crystalline phase in a ceramic brick. The analysis of this characterization was conducted using the DIFRAC.EVA software.

3.3.3 Water Absorption

ISO 10545-3 is an international standard that can be referred to for water absorption testing. For water absorption testing in ceramic bricks, ASTM C373 is a commonly referenced ASTM standard. The study focused on examining water absorption in ceramic bricks using a desiccator vacuum method. Placed ceramic brick samples suspended on a glass rod into a beaker shown as Figure 3.12, ensuring no contact between them, distilled water has been poured into the beaker and let the samples submerged completely and put it in the vacuum chamber shown as Figure 3.13. The chamber was evacuated to a pressure of (100 ± 1) kPa and maintained for 30 mm. Subsequently, while sustaining the vacuum, distilled water was slowly introduced until it covered the tiles. The vacuum was then released for 30 minutes, allowing the ceramic bricks to remain submerged as shown as Figure 3.7. Tissues was prepared by wetting and wringing out by hand. It was placed on a flat surface, and each side of every ceramic was lightly dried in succession. Any relief surfaces were dabbed with the chamois leather. Following this procedure, each brick was weighed immediately, and the results were recorded with the same accuracy as for the dry state.

The desiccator vacuum method allowed for controlled testing, highlighting the influence of tile composition and surface finish on water absorption. These findings underscored the importance of manufacturing processes and surface treatments in reducing water permeability in ceramic bricks, providing valuable insights for optimizing tile production and enhancing their resistance to moisture-related damage. To calculate the water absorption, use the following formula:

$$Water\ Absorption\ (\%) = \frac{M_2 - M_1}{M_1} \times 100$$

M_1: dried mass

M_2: saturated mass

Figure 3.12: Ceramic brick sample suspended on a glass rod into a beaker.

Figure 3.13: Distilled water has been poured into the beaker and let the samples submerged completely.

3.3.4 Compressive Strength

Ceramic brick compressive strength testing is usually performed in accordance with international standards such as ASTM C67 as shown as Figure 3.14. During a compressive test, the sample is completely crushed, allowing the juvenile rupture modulus to be measured. This test used to calculate the sample's young modulus, maximum force, stress, and strain. Compressive strength values vary from 4.35 MPa to 18.2 MPa.

Figure 3.14: Compression strength test machine and Computer generated result.

3.3.5 Density

The density of the samples underwent examination utilizing a density determination set (PS 210.R2), demonstrated in Figure 3.15. All the sample from 5 compositions samples underwent a distilled water rinse to eliminate any potential contaminants. Subsequently, these samples were uniformly divided using a glass cutter into equally sized parts, each sample being quartered. The density determination utilized the Archimedes water immersion technique. This measurement process was repeated four times for each sample, and an average was computed to enhance the data's reliability.

Figure 3.15: The density of sample was measured using density determination set.

3.3.6 Porosity

During the drying and firing process, the added particles underwent combustion, resulting in the formation of voids due to their breakdown. Additionally, gas emissions occurred due to the decomposition of substances such as water and carbon dioxide. It was important to note that there was no specific maximum porosity value for refractory bricks.

Porosity, expressed as a percentage, represented the proportion of the volume of open pores in the specimen to its total volume. The formula used to calculate the apparent porosity was:

$$P\ (\%) = \frac{M - D}{V} \times 100$$

where V (cm3) is the exterior volume (V = M – S).

D: dried mass

M: saturated mass

S: suspended mass in water

3.3.7 Fourier transform infrared (FTIR)

The FTIR NICOLET iZ10 was employed for recording FTIR spectra. To facilitate fourier transform infrared (FTIR) analysis, the glass sample was transformed into a powder form. This involved crushing and grinding the glass sample using a mortar and pestle until it reached a size of <75 µm. Approximately 1 mg of the finely ground sample was analyzed in a mortar. The examination revealed the presence of various characteristic functional groups in the samples, providing insight into the elemental functional groups present (Prasad, 2013). The effectiveness of FTIR in detecting functional groups and covalent bonds within the sample was attributed to its capability. Furthermore, FTIR generated an infrared absorption spectrum, aiding in the identification of chemical bonds within the sample. The characterization analysis was performed using the OMNIC software.

3.3.8 Thermogravimetric Analysis (TGA)

Thermogravimetric Analysis (TGA) was performed on ball clay, sugarcane bagasse, and sugarcane bagasse ash to evaluate their thermal behaviours and decomposition characteristics. Each material underwent controlled heating in an inert atmosphere, and their weight changes were monitored with increasing temperature. Each sample are weighed between 0.0025 to 0.0030 gram for run the analysis.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Microstructure and porosity determination by SEM

The morphology of the raw materials was investigated by the scanning electron microscope (SEM). The SEM images of the samples refractory bricks revealed in morphologies. It is also showing the occurrence of pores that are 10 μm wide. An in-depth analysis was conducted on the morphological characteristics of a series of bricks, considering varying proportions of sugarcane bagasse ash and firing temperatures. The comprehensive investigation of the microstructures revealed consistent improvements in the bulk properties of the bricks. These enhancements align with the attributes of highly porous materials, playing a significant role in the observed high porosity, density, elevated compressive strength, and extensive water absorption values within this specific brick series.

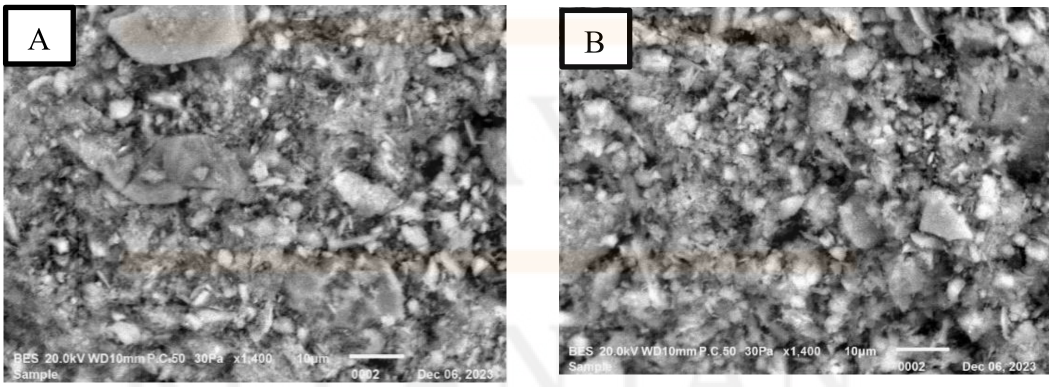


Figure 4.1: Morphologies of refractory bricks at 900 °C contains sugarcane bagasse ash (A) 7.5% and (B) 10% at magnification 1400x.

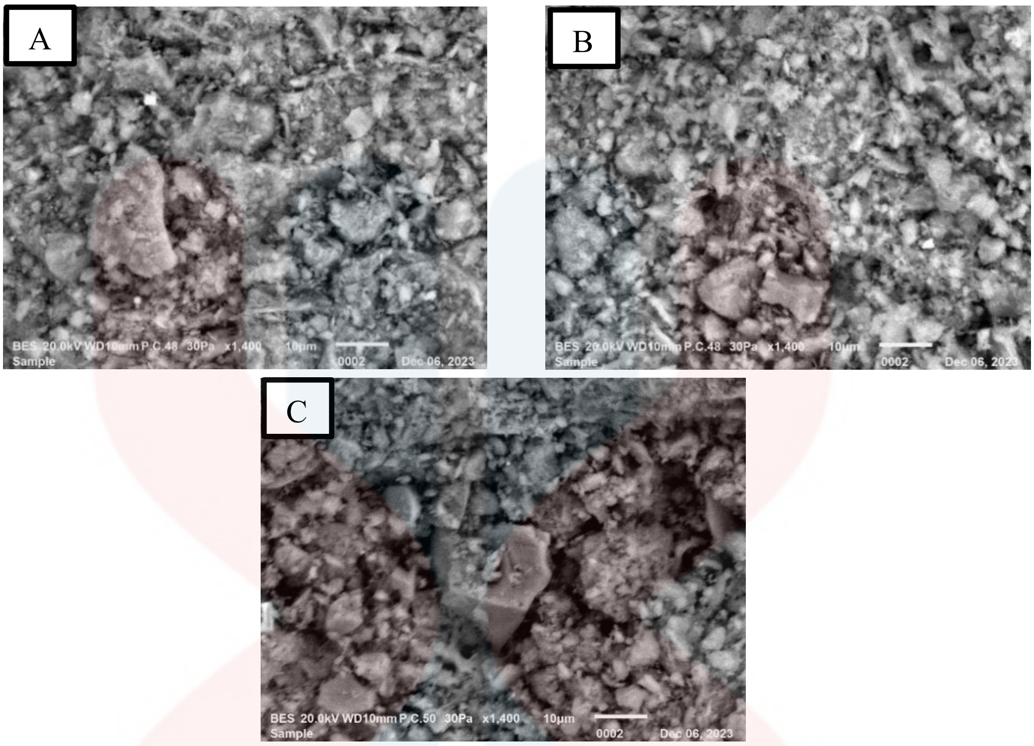


Figure 4.2: Morphologies of refractory bricks at 1000 °C contains different amount of sugarcane bagasse ash (A) 5.0% (B) 7.5% and (C) 10.0% at magnification 1400x.

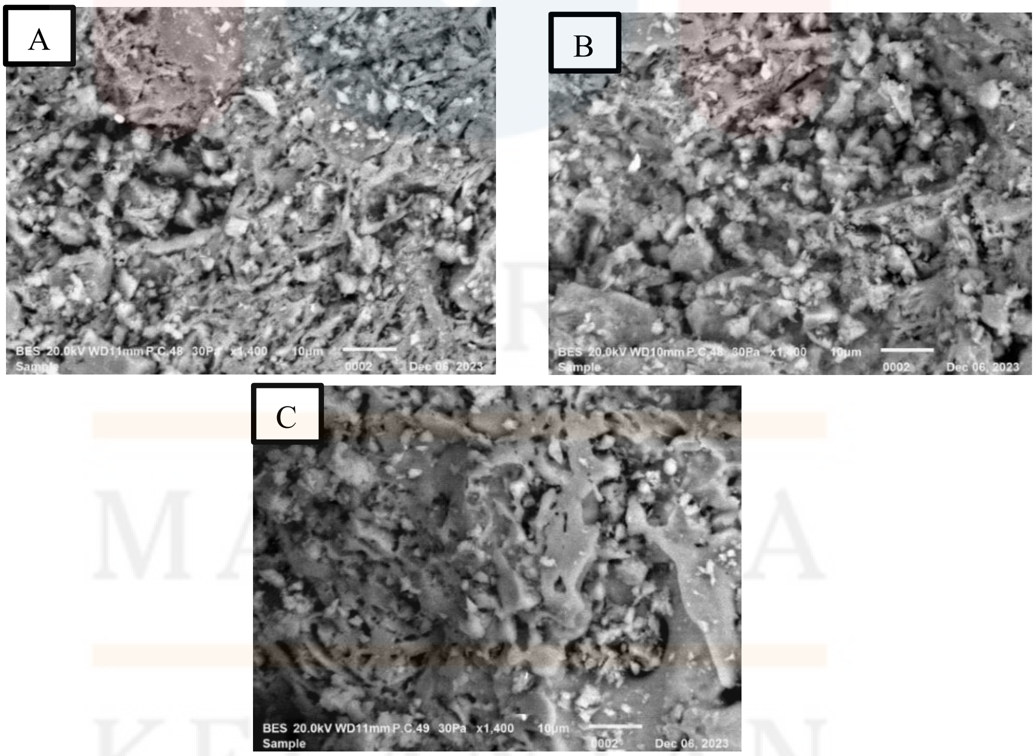


Figure 4.3: Morphologies of refractory bricks at 1100 °C contains different amount of sugarcane bagasse ash (A) 5.0% (B) 7.5% and (C) 10.0% at magnification 1400x.

Figure 4.1 (a)(b) shown the pore structure in the 900 °C refractory brick samples were an evident correlation emerged between the increasing proportion of sugarcane bagasse ash (7.5%, and 10%) and the augmentation of pores within the ceramic matrix. Figure 4.2 (a)(b)(c) illustrates the morphology of refractory bricks, for pore structure there is a significant difference at 1000 °C. A significant relationship was observed between the percentage of sugarcane ash (5.0, 7.5, and 10%) where with the increase in SCBA, the pore structure increased.

Figure 4.3 (a)(b)(c) visually represents the morphological changes in refractory bricks fired at 1100 °C with varying proportions of sugarcane bagasse ash (5.0, 7.5, and 10%), revealing an augmented presence of vitreous glassy phases. The interconnectivity among the pores formed within the clay matrix appears to be somewhat restricted. A noticeable decrease in the number of pore structures is observed, attributed to the partial filling by the glassy phases. The presence of these vitreous glassy phases serves as evidence of enhanced densification reactions, facilitating the coalescence of clay particles and contributing to an overall higher density. In addition, the vitrified glassy phases disrupted the pore-circuitry within the clay matrices there by impeding the water intrusion. This might have resulted in the much-lowered water absorption values as exhibited by the 1100 °C fired clay ceramic bricks (Adazabra et al.2023).

4.2 Phase examination using XRD.

4.2.1 XRD Pattern results on soda lime silicate glass

In Figure 4.4, the X-ray diffraction (XRD) pattern for soda lime silicate glass demonstrates an amorphous structure. Amorphous materials lack a long-range ordered arrangement, exhibiting varying degrees of short-range ordering, which renders the detection of peaks challenging during XRD characterization. The absence of long-range periodic order is attributed to the potential changes in bond lengths and angles, as explained by (Hasanuzzaman et al. 2016). Conversely, glass, being an amorphous material, lacks a regular three-dimensional arrangement of atoms, with atoms exhibiting a non-repeating pattern and lacking periodic packing. This phenomenon arises from complex structures and rapid cooling. Moreover, amorphous structures can be induced by the addition of impurities such as Na^+, Mg^+, Ca^+, and Al^+, which interfere with the formation of a crystalline structure.

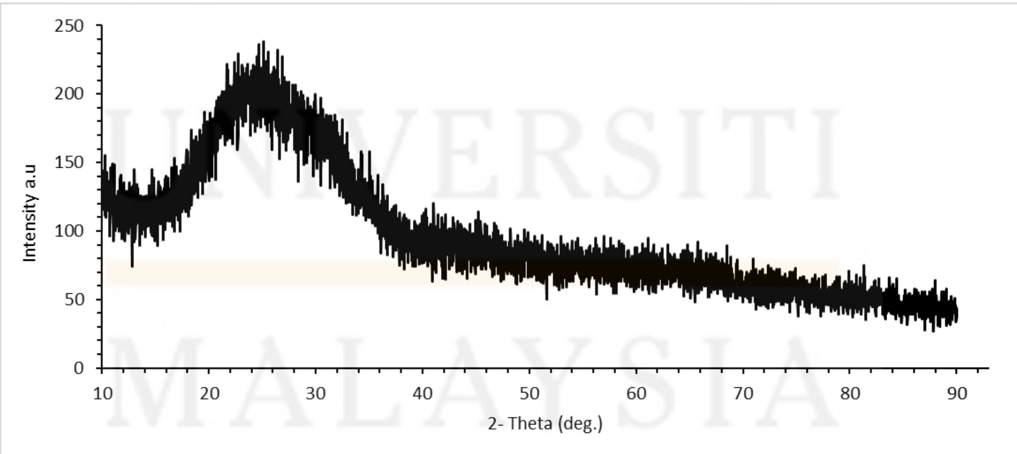


Figure 4.4: XRD pattern results on soda lime silicate glass

4.2.2 XRD pattern results on 5 compositions of refractory bricks.

XRD analysis results of refractory bricks with addition different ratios of sugarcane bagasse ash (SCBA) (0.0%, 2.5%, 5.0%, 7.5% and 10.0%) at 1000ºC samples were given in Figure 4.5. Figure 4.5 was examined, the peaks of quartz, indicated by Q, were evidently observed from the 0.0% -10.0% of SCBA samples.

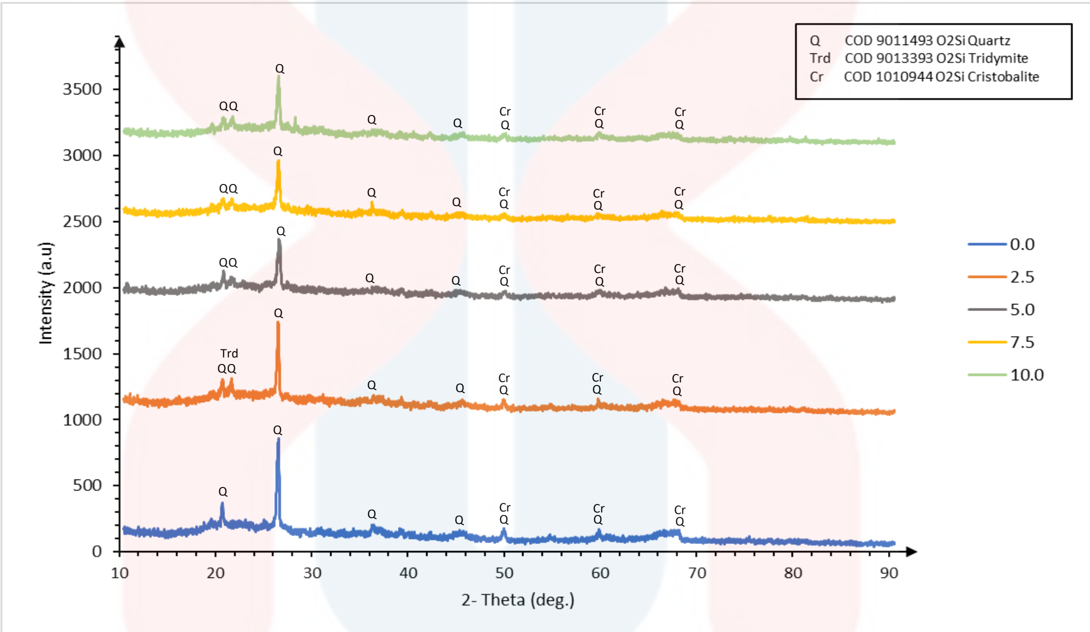


Figure 4.5: XRD pattern results on 5 compositions of refractory bricks (0.0,2.5,5.0,7.5,10.0% of SCBA.)

The highest crystallinity is 5.0% of SCBA which is 45.4%. The range of the crystallinity 0.0 to 10.0% of SCBA is the samples are 39.5 to 45.4%. It was examined, there are quartz peaks were detected in addition of SCBA the to the prominent peak of the sample are at 2θ = 26.56 °. In addition to the Cristobalite (Cr) peaks, and Tridymite (Trd) peaks were evidently observed. The decreases in the intensities of all peaks were recorded with increasing addition of SCBA with the mechanical activation process. The reason for this was the intense deterioration and partial amorphization of the structure due to mechanical activation. These reductions were consistent with the literature. The decrease in quartz peak despite the increasing sugarcane bagasse ash content in refractory bricks could be attributed to specific interactions and reactions occurring during the firing process.

When sugarcane bagasse ash is introduced, it might act as a fluxing agent, altering the chemical environment during firing. This change could lead to the formation of new phases or reactions that affect quartz. The increased ash content might promote reactions that consume or transform the quartz phase, reducing its detectable quantity in the refractory bricks. Additionally, the ash might induce structural modifications or phase changes in the quartz particles, resulting in decreased intensity of the quartz peak observed in the XRD analysis of the refractory bricks. Quartz (SiO_2), a common mineral found in ball clay and certain ashes, typically exhibits distinct diffraction peaks in XRD analysis.

Next, the quantity of cristobalite, a crystalline form of silica is observed in analysis at 2θ = 50.10 °, 59.78 ° and 67.72 °. SCBA contains silica and various compounds. When introduced into the ceramic mixture, the silica content in SCBA might interact with the existing silica components from ball clay or other materials. This interaction during the firing process can influence the formation, transformation, or reduction of cristobalite. As the proportion of SCBA increases in the mix, it could dilute the concentration of cristobalite that might be present in the raw materials, leading to a decrease in its detectable presence in XRD analysis. Tridymite is a mineral form of silica that can be present in certain ceramic compositions, especially if the raw materials used contain high levels of silica and undergo specific firing conditions and observed at 2θ = 21.74 °.

In a refractory brick made from sugarcane bagasse ash, ball clay, and soda-lime silicate glass powder, the presence of tridymite through XRD analysis. Tridymite is a polymorph of silica (SiO2) that typically forms under specific temperature and pressure conditions. If the raw materials, particularly the ball clay or other components, contain high levels of silica, and the firing process involves elevated temperatures within the range conducive to tridymite formation.

4.3 Water absorption

Water absorption, a critical parameter influencing the durability of fired clay bricks, is closely tied to their high porosity. Typically, the water absorption of fired bricks exhibits a decrease with elevated firing temperatures, attributed to the increased local liquid phase and subsequent reduction in pores (Chindaprasirt et al., 2021), contributing to enhanced strength. Infiltration of water into clay bricks leads to diminished durability (Phonphuak et al., 2016). As illustrated in Figure 4.6, the water absorption of refractory bricks is significantly influenced by the quantity of added sugarcane bagasse ash (SCBA) and the firing temperature. The data is represented by three fitted curves, indicating the impact of SCBA addition and firing temperature on brick water absorption.

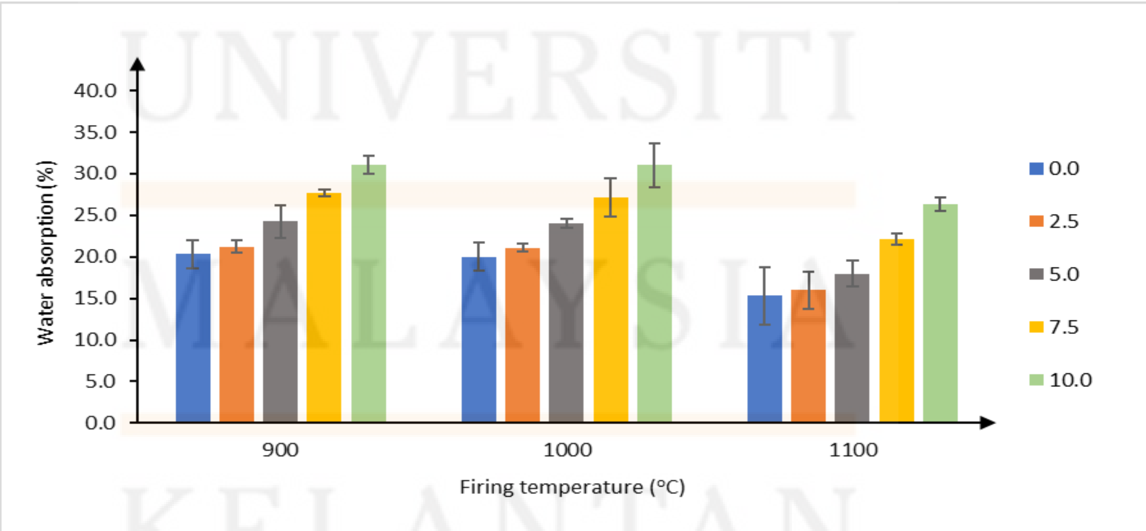


Figure 4.6: The relationship between water absorption for different ratios of SCBA and different firing temperature.

Throughout the experiment, water absorption values marginally increased with rising amounts of sugarcane bagasse ash, ranging from 0.0% to 10.0%, while the glass powder content remained constant at 10%. Control refractory bricks without SCBA-GP exhibited water absorption percentages of 20.32, 20.00, and 15.33% for sintering at 900 °C, 1000 °C, and 1100 °C. An elevation in water absorption could render clay bricks undesirable and compromise wall strength (Phonphuak N. et al., 2011). For instance, at 1100 °C, water absorption values for the brick were 15.33%, 15.99%, 17.98%, 22.13%, and 26.32% for 0.0%, 2.5%, 5.0%, 7.5%, and 10.0% of SCBA, respectively. The incorporation of 0.0% SCBA resulted in reduced porosity compared to the 2.5% SCBA brick, attributed to lesser water retention in the former.

The water absorption results generally aligned with porosity outcomes (Figure 4.9), indicating an increase in water absorption with the use of 2.5% to 10.0% SCBA for all firing temperatures, owing to the hand-shaping of refractory bricks using a relatively wet clay mixture. SCBA particles oriented themselves, forming continuous pores and causing increased water absorptions. However, the inclusion of 2.5% and 5.0% SCBA only slightly elevated water absorption values, exerting minimal adverse effects on brick properties. Notably, a significant disparity in water absorption values was observed between 900 °C and 1000 °C (20.32% to 31.04% and 20.00% to 31.01%) compared to 1100 °C (15.33% to 26.34%). This disparity is attributed to the temperature increase at 1100 °C, facilitating the formation of a local liquid phase within the ceramic material. The liquid phase promotes particle rearrangement, densification, reduced porosity, and increased impermeability to water. Higher temperatures energize particles, enabling closer packing through sintering, leading to improved bonding, decreased pore spaces, and subsequently, lower water absorption. Hence, the water absorption value for 1100 °C is the lowest in this context.

4.4 Compressive Strength

Figure 4.7 illustrated the compressive strength of refractory bricks is significantly influenced by the quantity of added sugarcane bagasse ash (SCBA) and the firing temperature.

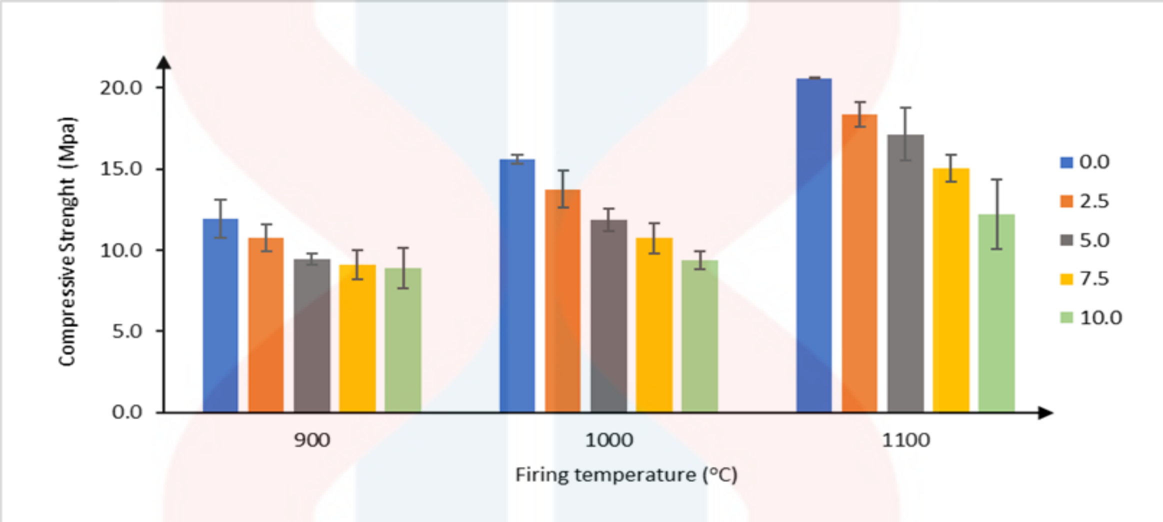


Figure 4.7: The relationship between compressive strength for different ratios of SCBA and different firing temperature.

The data is represented by three fitted curves, indicating the impact of SCBA addition and firing temperature on brick compressive strength. The compressive strength is the most important index for assuring the engineering quality of a building material because with a higher compressive strength, other properties also improved. Results demonstrate a range of compressive strengths from 8.90 to 20.59 MPa, corresponding to 0.0% to 10 wt.% SCBA across firing temperatures from 900 °C to 1100 °C. Notably, bricks with 2.5% SCBA fired at 1100 °C exhibited a commendable strength of 18.33 MPa, surpassing the ASTM standard requirement of 17.2 MPa. At 900 °C, strengths for 2.5%, 5.0%, 7.5%, and 10% SCBA were 10.78, 9.46, 9.11, and 8.90 MPa, respectively, differing slightly from the strengths at 1000 °C, which were 13.76, 11.87, 10.74, and 9.39 MPa. However, at 1100 °C, strengths increased significantly to 18.33, 17.79, 15.03, and

12.18 MPa for 2.5%, 5.0%, 7.5%, and 10% SCBA, surpassing those at 900 °C and 1000 °C.

Elevated temperatures contributed to increased compressive strength by reducing porosity and enhancing density through sintering, a process was particles bond together. The study underscores the substantial influence of added SCBA and firing temperature on the compressive strength of refractory bricks. Strength augmentation was observed with higher firing temperatures and lower SCBA amounts. Optimal results were achieved with a 2.5wt% SCBA mixture for bricks fired at 1100 °C, yielding compressive strengths ranging from 18.33 MPa. The addition of SCBA significantly contributed to vitrification, enhancing strength by sealing internal pores with a glassy phase. The findings underscore the dependence of compressive strength on the SCBA-GP content in clay bricks and the firing temperature, revealing an increase in strength due to decreased porosity (Figure 4.9) and increased density (Figure 4.8) with rising temperature during sintering.

4.5 Density

Figure 4.8 illustrated the density of refractory bricks is significantly influenced by the quantity of added sugarcane bagasse ash (SCBA) and the firing temperature.

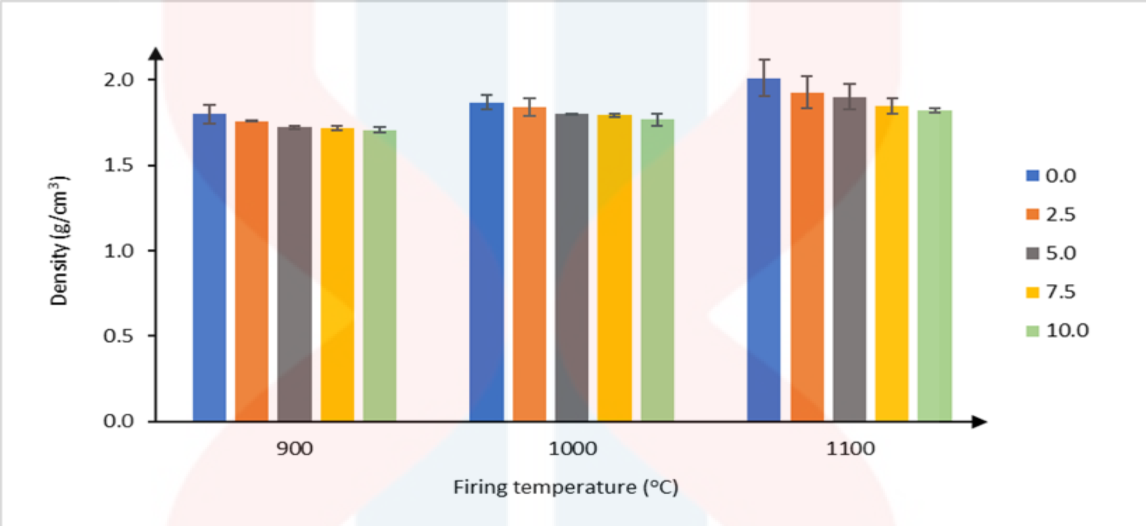


Figure 4.8: The relationship between density for different ratios of SCBA and different firing temperature.

The density of refractory bricks (in Figure 4.8) exhibits a decrease with an escalating content of sugarcane bagasse ash (SCBA). This observed trend aligns with expectations, attributed to the introduction of open porosity generated during the combustion of SCBA. Enhanced sintering temperature and the incorporation of glass powder contribute to an increase in the density of the refractory bricks. The density of refractory bricks is directly proportional to both the firing temperature and the quantity of SCBA introduced into the mixture. Test results reveal density values for specimens containing SCBA-GP ranging from 1.71 to 1.93 g/cm³. As the sintering temperature rises and GP is added, the GP undergoes melting, forming a liquid phase. This results in tightly bonded clay particles and a subsequent increase in density (Benlalla A. et al. 2015). Refractory bricks without the addition of SCBA-GP, fired within the range of 900 to 1100 °C, exhibit densities in the range of 1.79 to 2.01 g/cm³.

The correlation between firing temperature and density is evident as an increase in firing temperature corresponds to an increase in density. This phenomenon is attributed to increased consolidation or vitrification between particles within the body as the temperature rises. At 900 °C, the density of refractory bricks ranges from 1.71 to 1.79 g/cm³, with no marked effect. The impact becomes more pronounced at 1000 °C, where densities vary from 1.76 to 1.87 g/cm³, demonstrating an improvement in density proportional to the increase in sugarcane bagasse ash. At a firing temperature of 1100 °C, the density of refractory clay bricks ranges from 1.82 to 2.02 g/cm³. Consequently, it can be inferred that the addition of SCBA at relatively low temperatures results in densification of the mixture. At higher temperatures, the observed bloating effect likely leads to a reduction in density as the quantity of SCBA increases. It's important to note that density is linked to the durability and water absorption characteristics of refractory bricks, as illustrated in Figure (3.6), which depicts the density device.

4.6 Porosity

The relationship between the porosity of fired clay bricks and their water absorption capacity has been established (Mao, L et al. 2019). Elevated porosity in clay bricks offers advantages in terms of thermal properties bricks with higher porosity exhibit low thermal conductivity and excellent insulating properties. Increased brick porosity corresponds to higher brick humidity (Maza-Ignacio, O.T. et al. 2020). As illustrated in Figure 4.9, porosity in refractory bricks is linked to the levels of SCBA-GP addition.

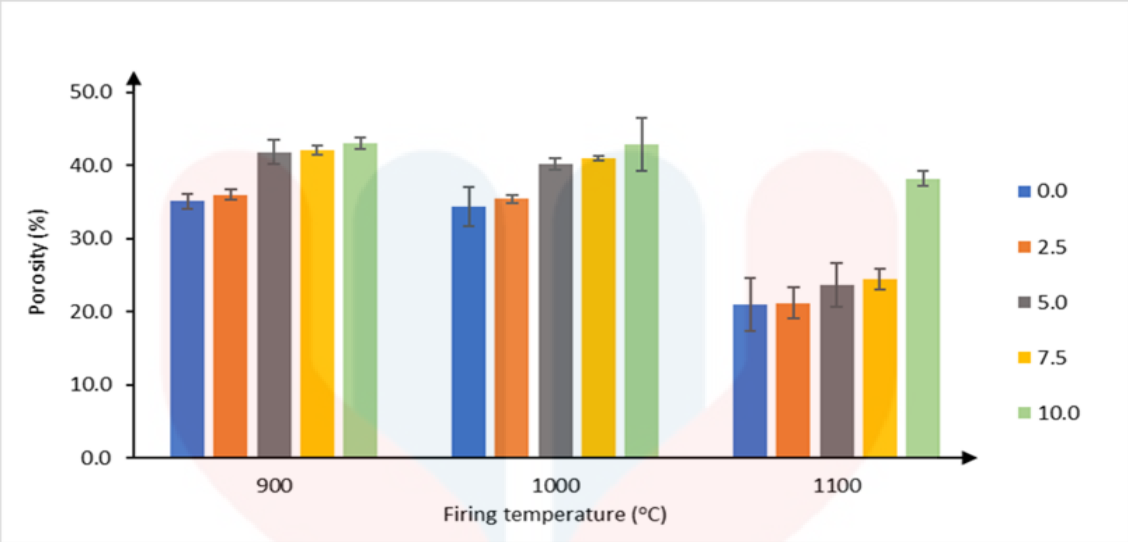


Figure 4.9: The relationship between porosity for different ratios of SCBA and different firing temperature.

The outcomes of this study reveal that porosity is contingent on the quantity of SCBA present in the refractory bricks. The highest porosity, reaching 43.02%, was observed in refractory bricks containing 10.0% SCBA and fired at 900 °C. This observation suggests that higher SCBA content results in increased porosity due to the combustion of SCBA during the firing process. In contrast, the lowest porosities of 21.04% and 21.23% were recorded in refractory bricks containing 0.0% and 2.5% SCBA, respectively, and fired at 1100 °C (as depicted in Figure 4.9).

Therefore, the higher the amount of SCBA in refractory brick, the higher the open porosity and hence the more porous clay brick as a result. The control specimens without any SCBA-GP addition had 21.04 - 35.13% comparable porosity. There is also a significant difference in the porosity value between 900 °C and 1000 °C with 1100 °C. There is slightly different value of porosity for 900 °C and 1000 °C the value of porosity is 35.13 - 43.02% and 34.37 - 42.86%, while for 1100 °C are 21.04 - 38.24 %. The porosity value for the temperature of 1100 °C has a significant difference between the temperature of 900 °C and 1000 °C.

This happened often attributed to the increased formation of a local liquid phase and enhanced particle bonding, resulting in a denser structure with reduced pores (Rahaman 2017). At 1100 °C, the ceramic material might fully vitrify, meaning the particles fuse together to form a glass-like structure. This complete vitrification can significantly diminish the number and size of pores, rendering the material highly impermeable to water. Then, the particles might achieve the closest possible packing arrangement at this temperature, leading to strong bonding between them. This close packing minimizes pore spaces, contributing to a substantial decrease in porosity.

4.7 Relationship between compressive strength (Mpa) and porosity (%) fired at 900, 1000 and 1100 °C.

The Figure 4.10 provided illustrates the relationship between the compressive strength and the porosity of refractory brick samples with varying amounts of sugarcane bagasse ash (SCBA) content, ranging from the control group with no SCBA to 2.5%, 5.0%, 7.5%, and 10% SCBA content.

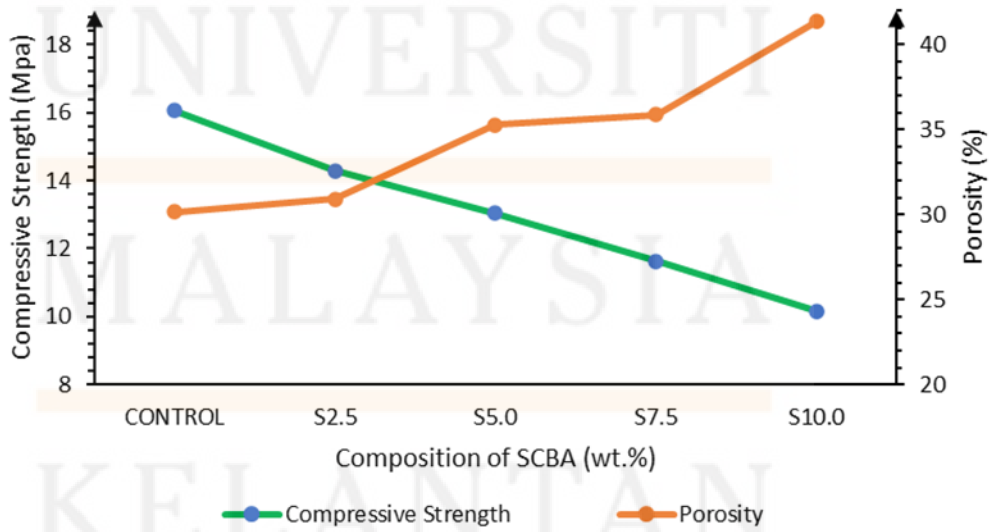


Figure 4.10: The relationship between compressive strength (Mpa) and porosity (%) fired at 900, 1000, 1100 °C.

The data on the graph suggests a noteworthy pattern. As the SCBA content in the brick's mixture increases, there is a noticeable decrease in the compressive strength of the concrete, while simultaneously, there is an increase in porosity. This trend can be attributed to several factors. Firstly, the introduction of SCBA into the brick's mixture may disrupt the crystalline structure of the cementitious matrix, which subsequently weakens the overall strength of the material. Additionally, SCBA particles tend to have irregular shapes, which can create voids and interstitial spaces within the concrete, thereby increasing its porosity. The higher porosity indicates that there is a greater volume of interconnected air voids within the concrete, which reduces its density and, consequently, its compressive strength. Furthermore, the pozzolanic reaction of SCBA with calcium hydroxide may not fully compensate for the detrimental effects on the concrete's mechanical properties, especially at higher SCBA contents.

This observed relationship between compressive strength and porosity is crucial to consider in the context of using SCBA as a supplementary material in concrete production. While SCBA can be a sustainable alternative to traditional cementitious materials due to its agricultural waste origin, it's essential to strike a balance between incorporating SCBA for sustainability and maintaining the desired strength properties.

4.8 Relationship between water absorption (%) and porosity (%) fired at 900, 1000 and 1100 °C.

In the Figure 4.11, we can observe the relationship between water absorption and porosity as influenced by the varying amounts of sugarcane bagasse ash (control, 2.5%, 5.0%, 7.5%, and 10%) added to refractory bricks.

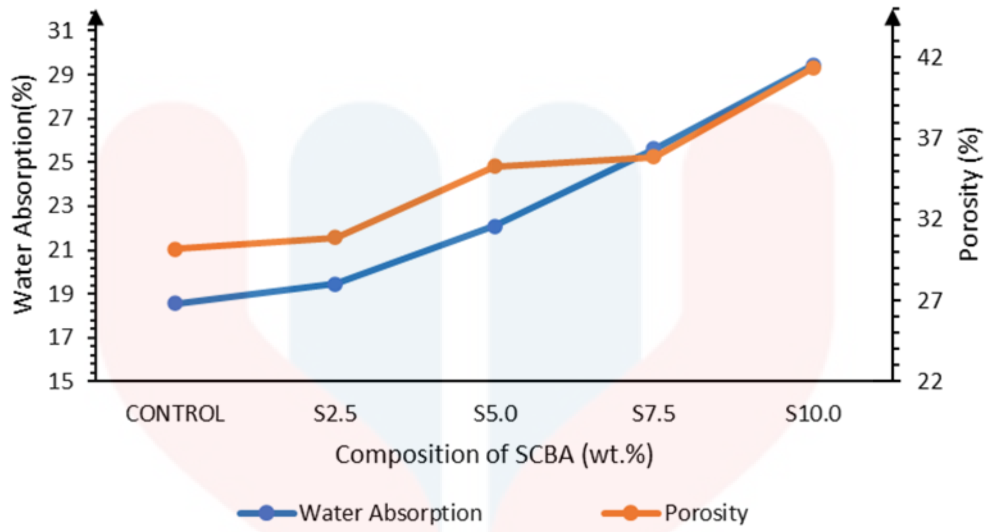


Figure 4.11: The relationship between water absorption (%) and porosity (%) fired at 900, 1000, 1100 °C

The key insight drawn from this graph is the clear trend of increasing water absorption with higher proportions of sugarcane bagasse ash. This trend suggests a direct correlation between the amount of ash incorporated into the material and its porosity, resulting in increased water absorption. The control sample, representing the material without any sugarcane bagasse ash, exhibits the lowest water absorption rate, which serves as a baseline for comparison. As we progress to higher percentages of SCBA content, we can observe a steady and significant rise in water absorption. This phenomenon can be attributed to the porous nature of sugarcane bagasse ash particles. As more ash is added, it increases the overall porosity of the material, creating more pathways for water infiltration. Consequently, the material becomes more susceptible to water absorption, which is a crucial factor to consider in applications where moisture resistance is essential.

This graph's findings are of paramount importance in various industries and applications, including construction materials, where water absorption can impact structural integrity and durability. Understanding the relationship between water absorption and porosity in materials containing sugarcane bagasse ash can guide engineers and researchers in optimizing the composition of composite materials to achieve desired water resistance properties. Additionally, it underscores the significance of careful material selection and proportions in engineering and construction practices, emphasizing the need for further research to fine-tune these relationships for specific applications.

4.9 Relationship between and density (%) and porosity (%) fired at 900, 1000 and 1100 °C.

In the Figure 4.12, we can observe a clear relationship between the density and porosity of materials containing different amounts of sugarcane bagasse ash (control, 2.5%, 5.0%, 7.5%, and 10%).

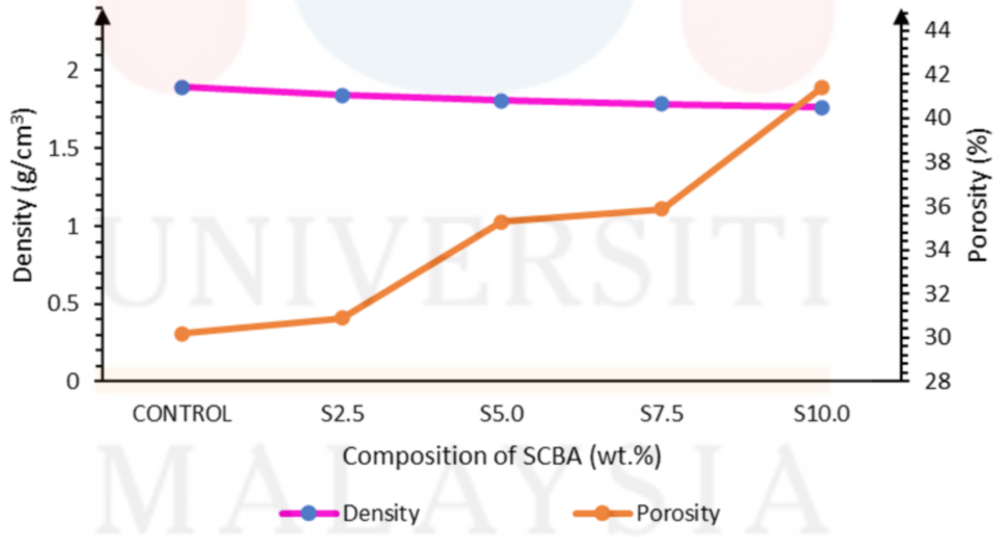


Figure 4.12: The relationship between density (g/cm^3) and porosity (%) fired at 900, 1000, 1100 °C.

As the amount of sugarcane bagasse ash in the mixture increases, there is a noticeable decrease in density and a corresponding increase in porosity. This trend can be attributed to the unique properties of sugarcane bagasse ash, which is a waste byproduct rich in amorphous silica and other reactive compounds. When added to a material matrix, it tends to displace some of the denser components, thus reducing the overall density of the mixture. Simultaneously, the introduction of sugarcane bagasse ash particles creates additional pore spaces within the material, leading to an increase in porosity. This phenomenon can have significant implications for various engineering and construction applications, as the control of density and porosity is crucial for achieving desired material properties such as strength, thermal conductivity, and permeability. Therefore, understanding this relationship between density and porosity in the context of sugarcane bagasse ash incorporation is essential for optimizing the performance and sustainability of composite materials in construction and other industries.

4.10 FTIR

4.10.1 FTIR pattern results on 5 compositions for 1000ºC firing temperature.

FTIR spectra obtained from the refractory bricks with addition different ratios of sugarcane bagasse ash (SCBA) (0.0%, 2.5%, 5.0%, 7.5% and 10.0%) at 1000 °C samples were given in Figure 4.13. Figure 4.13 was analyzed for FTIR, pattern result on 5 compositions of refractory bricks (0.0, 2.5, 5.0, 7.5, 10.0% of SCBA) for 1000 °C.

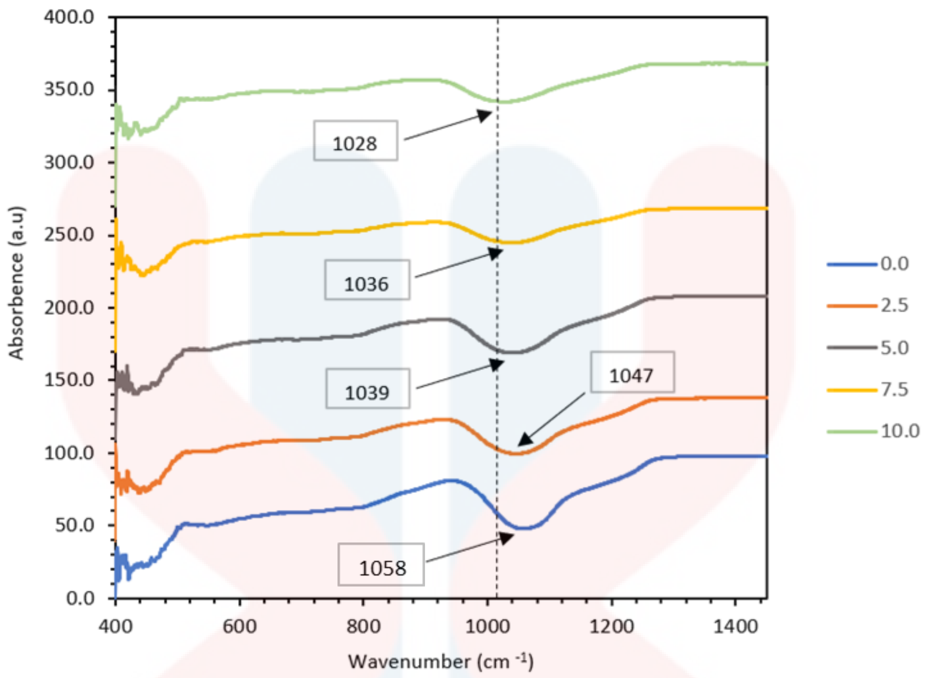


Figure 4.13: FTIR pattern result on 5 compositions of refractory bricks (0.0, 2.5, 5.0, 7.5, 10.0% of SCBA) for 1000 °C.

The FTIR spectra obtained from the refractory bricks, derived from distinct compositions of ball clay, sugarcane bagasse ash, and sodalime silicate glass powder, presented notable variations corresponding to changes in firing temperatures and material compositions. At lower firing temperatures (1000 °C), the infrared spectra of the samples were recorded in the range of 375 - 4000 cm^{-1}, but the most significant absorption bands were observed only in the range of 375 - 1300 cm^{-1}. It is indicative of O-H stretching vibrations from hydroxyl groups within the materials. The peak positions showed slight leftward shifts compared to the raw materials' spectra, suggesting increased hydrogen bonding and potential structural modifications induced by the firing process. This leftward shift was more pronounced in compositions with higher proportions of sugarcane bagasse ash, hinting at its influence on the molecular arrangement within the ceramic bricks.

Additionally, peaks in the range of 800 - 1200 cm^{-1}, attributed to Si-O stretching vibrations in silicates, displayed minor variations in intensity and position. These wavenumbers can be seen in Figure 4.13. As can be seen, the wavenumber of the hydroxyl group has decreased since the SCBA are increased from 1055 cm^{-1} for 0.0% SCBA, 1047 cm^{-1} for 2.5% SCBA, 1039 cm^{-1} for 5.0% SCBA, 1036 cm^{-1} for 7.5% SCBA and 1028 cm^{-1} for 10.0 % SCBA. These shifts, though subtle, indicated alterations in the bonding environment, particularly noticeable in compositions where sugarcane bagasse ash was introduced. The appearance of new peaks at higher wavenumbers might indicate the formation of new chemical species or crystalline structures due to the firing process. Comparing spectra from different compositions revealed distinct patterns. The increase in sugarcane bagasse ash content within the mixtures seemed to influence the intensity and positioning of peaks associated with Si-O and O-H stretching vibrations.

The observed shifts, changes in peak intensities, and the appearance of new peaks in the FTIR spectra provide valuable insights into the molecular alterations induced by variations in material compositions and firing temperatures. The presence of sugarcane bagasse ash notably affected the ceramic matrix, influencing the bonding environment and potentially contributing to structural modifications during firing. These findings underscore the importance of material composition and firing conditions in tailoring the molecular structure and properties of refractory bricks, offering valuable guidance for optimizing formulations to achieve desired characteristics for specific applications.

At 1000 °C, the firing temperature might not have been sufficient to induce complete chemical transformations or interactions between the components (ball clay, sugarcane bagasse ash, glass powder). As a result, certain functional groups or chemical bonds might have remained intact or only partially altered. Next, there air incomplete crystalliation he deeper curve at 1000 °C could indicate that certain bonds or crystalline structures were still forming or transitioning, resulting in a more prominent and distinct signal in the FTIR spectrum. This could suggest the presence of more intermediate states or partially reacted compounds. Next, increased homogeneity or uniformity. The higher intensity observed at 1000 °C might imply that certain molecular vibrations, characteristic of the raw materials or intermediate products, were more pronounced due to incomplete transformation or less efficient removal of certain functional groups.

4.10.2 FTIR pattern results on 5 compositions for 1100 °C firing temperature.

FTIR spectra obtained from the refractory bricks with addition different ratios of sugarcane bagasse ash (SCBA) (0.0%, 2.5%, 5.0%, 7.5% and 10.0%) at 1000 °C samples were given in Figure 4.14. Figure 4.14 was analyzed for FTIR, pattern result on 5 compositions of refractory bricks (0.0, 2.5, 5.0, 7.5, 10.0% of SCBA) for 1100 °C.

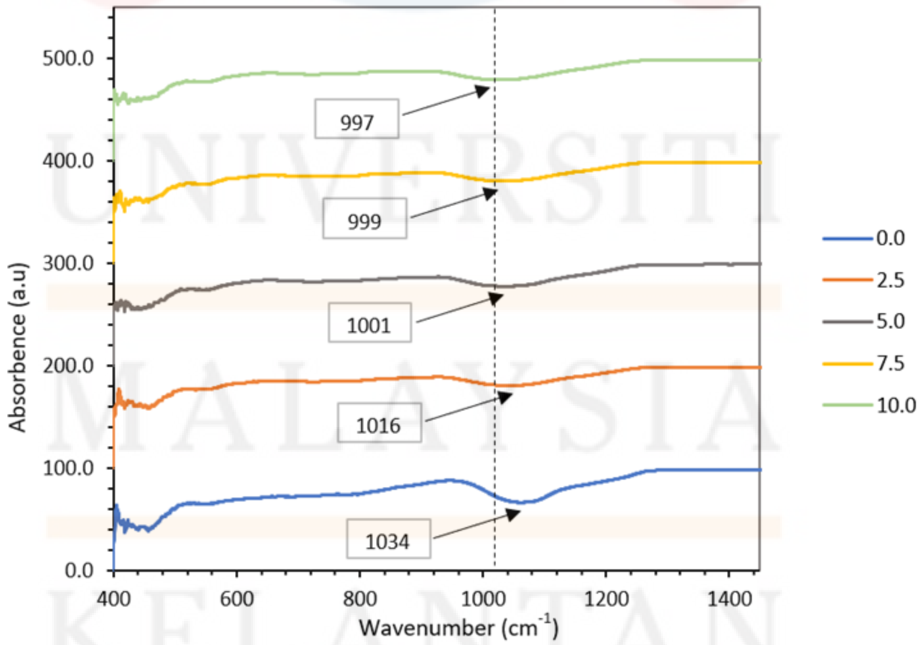


Figure 4.14: FTIR pattern result on 5 compositions of refractory bricks (0.0, 2.5, 5.0, 7.5, 10.0%) for 1100 °C.

At firing temperatures (1100 °C), the infrared spectra of the samples were recorded in the range of 4000 - 430 cm^{-1}, but the most significant absorption bands were observed only in the range of 375 - 1300 cm^{-1}. In this graph revealed distinctive patterns indicating significant molecular transformations induced by varied compositions. The spectra exhibited characteristic peaks in the range of 3000 - 3700 cm^{-1}, corresponding to O-H stretching vibrations present in hydroxyl groups within the materials. Notably, these peaks displayed leftward shifts, suggesting enhanced hydrogen bonding and potential structural rearrangements induced by the firing process. The degree of shift intensified with higher proportions of sugarcane bagasse ash, indicating its influence on the molecular configuration within the ceramic matrix.

Furthermore, peaks in the range of 900 - 1200 cm^{-1}, attributed to Si-O stretching vibrations in silicates, showed noticeable alterations in intensity and position. These wavenumbers can be seen in Figure 4.14. As can be seen, the wavenumber of the hydroxyl group has decreased since the SCBA are increased from 1034 cm^{-1} for 0.0% SCBA, 1016 cm^{-1} for 2.5% SCBA, 1001 cm^{-1} for 5.0% SCBA, 999 cm^{-1} for 7.5% SCBA and 997 cm^{-1} for 10.0% SCBA. These shifts implied changes in the bonding environment, particularly evident in compositions where sugarcane bagasse ash was introduced. Additionally, the appearance of new peaks at higher wavenumbers suggested potential formation of new chemical species or crystalline structures resulting from the firing process.

Comparing spectra across different compositions highlighted distinct trends. Increased proportions of sugarcane bagasse ash within the mixtures markedly influenced the intensity and positioning of peaks associated with Si-O and O-H stretching vibrations. This influence was magnified at the higher firing temperature (1100 °C), showcasing more pronounced shifts and alterations in peak intensities in samples with elevated amounts of sugarcane bagasse ash. There are less pronounce curve at 1100 °C. The firing temperature might have been adequate to drive more complete chemical reactions, resulting in the formation of desired crystalline phases and complete removal or transformation of specific functional groups. Therefore, fewer remaining or intermediate compounds might contribute to the FTIR signal.

It enhances the crystallization or bond formation. The reduced intensity could indicate that the material at 1100 °C underwent more complete crystallization or bond formation, leading to fewer remaining sites available for molecular vibrations that are typically detected by FTIR. Then, increased homogeneity or uniformity. Higher firing temperatures often promote better diffusion and homogenization of components, resulting in a more uniform structure with fewer distinct areas contributing to the FTIR signal.

4.11 TGA

4.11.1 TGA pattern results on sugarcane bagasse ash (SCBA).

To gain insights into the thermal characteristics, Thermogravimetric Analysis (TGA) was employed, specifically focusing on the utilization of sugarcane bagasse ash in the fired-clay brick compositions. The TGA results aim to elucidate weight loss events, temperature ranges, and decomposition stages associated with different SCBA proportions, providing valuable information about the thermal behavior of the fired bricks. Thermogravimetric Analysis (TGA) applied to sugarcane bagasse ash (SCBA) involves subjecting this residue to controlled temperature changes while measuring its weight alterations. Figure 4.15 illustrates the Thermogravimetric Analysis (TGA) curve of sugarcane bagasse ash.

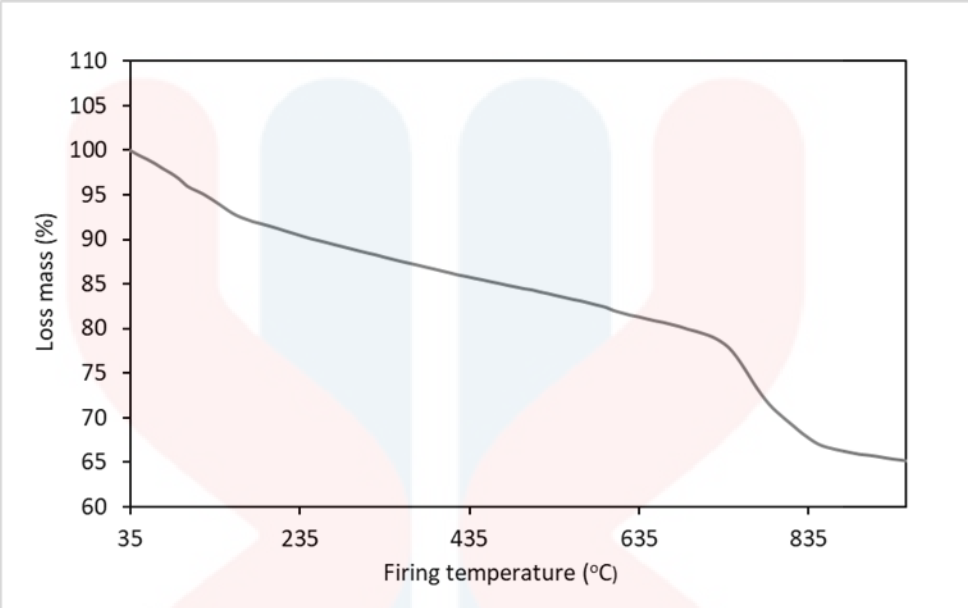


Figure 4.15: TGA pattern results on sugarcane bagasse ash (SCBA).

Through TGA, SCBA's thermal behavior is unveiled in stages initially, a slight weight decrease occurs as moisture and volatile compounds evaporate at lower temperatures. As the temperature rises, organic components within the ash, such as carbonaceous matter, undergo decomposition, resulting in further weight loss. However, the inorganic components, including silica, calcium oxide, potassium oxide, and magnesium oxide, tend to exhibit stability or gradual changes at elevated temperatures. The high-temperature regime may lead to additional reactions or combustion of remaining organic residues, contributing to continued weight reduction. Interpreting the TGA curve assists in comprehending SCBA's thermal stability, decomposition kinetics, and the temperature ranges associated with significant transformations, crucial insights for optimizing its applications across diverse industries, from construction materials to environmental and manufacturing sectors.

Thermogravimetric analysis (TGA) was conducted on the samples under a nitrogen atmosphere, employing a heating rate of 10 °C/min. The weight loss curves

(TGA) and thermal analysis (DTA) are presented in Figure 4.15. The figure illustrates the weight loss of SCBA, reaching 35.29% as the temperature increases to 1000 °C. The TGA curve records a mass loss of 35.29% at 731 °C, leaving a total residue of 64.71%. The tetrahedral characterization of silica mineral, specifically cristobalite mineral, is evident, and a significant mass change occurs after 720 °C, indicating the presence of α-cristobalite mineral. The change in dimension is gradual between 200 °C and 730 °C, reflecting the metastable nature of quartz minerals, but becomes more stable with an increase in crystallization temperature. The tetrahedral reorganization, occurring above 730 °C, signifies that the pozzolanic activity of SCBA is solely influenced by temperature.

Cristobalite, a high-temperature phase of silica, undergoes a phase transformation from a cubic to a tetrahedral structure around 220 °C. This high-temperature phase of silica, SiO2, remains stable within the temperature range of 1000 °C, with a melting point at 1728 °C. It is important to note three distinct stages of rapid weight loss attributed to moisture drying, volatile organic matter, and the swift decomposition of hemicellulose and cellulose.

4.11.2 TGA pattern results on ball clay.

Thermogravimetric Analysis (TGA) conducted on ball clay involves subjecting this specific type of clay to controlled temperature variations while monitoring its corresponding weight changes. Initially, during TGA, as the temperature gradually increases, ball clay typically undergoes a minimal decrease in weight due to the elimination of any moisture or volatile compounds present within the material. Subsequently, as the temperature continues to rise, the organic matter within the ball clay, such as residual plant material or carbonaceous compounds, begins to decompose, resulting in further weight loss. The key stages observed through TGA enable an understanding of the thermal stability and decomposition behavior of ball clay, providing insights into its composition and the temperature ranges associated with significant transformations. Figure 4.16 illustrates the Thermogravimetric Analysis (TGA) curve of ball clay, revealing two distinct events.

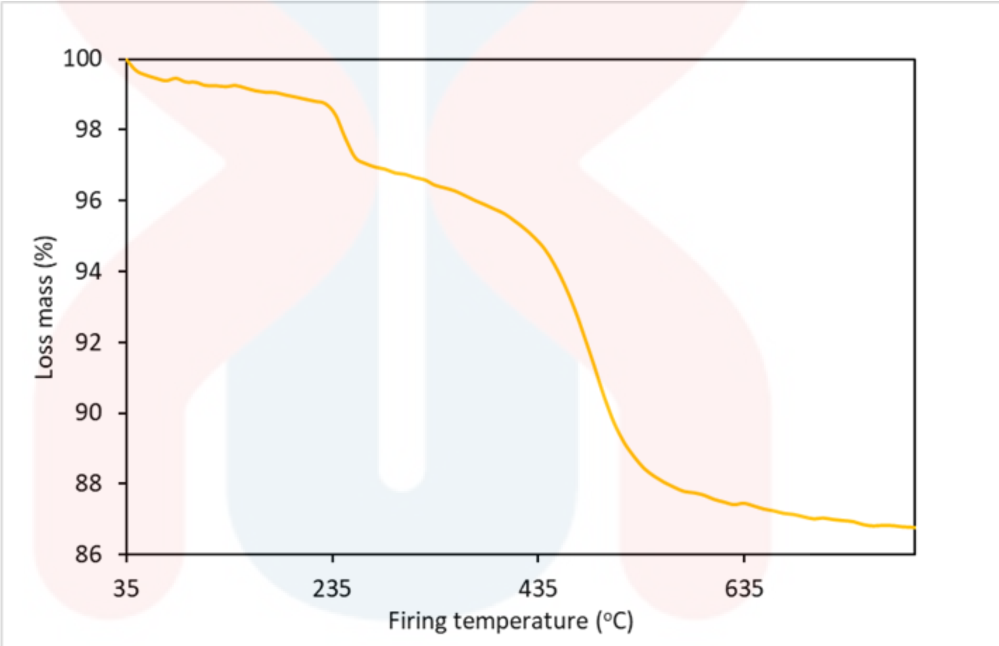


Figure 4.16: TGA pattern results on ball clay

The first event, initially at 45 °C, corresponds to water loss, as evidenced by the TGA curve displaying an initial weight loss around 110 °C due to the release of adsorbed water. The second peak, exhibiting the highest mass loss between 500 and 600 °C, is associated with the dehydroxylation of clay minerals and the formation of metakaolinite. Notably, the investigated ball clay displays characteristic endothermic peaks around 523 °C, linked to the removal of physically adsorbed water and the dehydroxylation of the silicate lattice leading to metakaolinite formation. Additionally, a marked exothermic reaction occurs between 900 °C and 1000 °C, with an exothermic peak in the Derivative Thermogravimetry (DTG) curve observed at 973 °C. This peak is likely due to the formation of new crystalline phases, such as Si-containing γ-Al_2O_3 with a spinel structure or a 2:1 mullite.

Throughout the entire heating process, the clay experiences a mass loss of approximately 9%. Previous studies have indicated that a mass loss close to 13% for ball clay contributes to improved plasticity and refractoriness, which are crucial factors for technological applications (Lopes et al. 2023). However, the observed 9% mass loss raises concerns about the suitability of using ball clay in the ceramic industry due to its exceptionally high weight loss. Ball clay, predominantly composed of quartz mineral may also pose challenges related to insufficient plasticity and refractoriness, especially when the proportion of clay mineral is relatively small (Suthee Wattanasiriwech 2019).

4.11.3 TGA pattern results on sugarcane bagasse.

Figure 4.17 illustrates the Thermogravimetric Analysis (TGA) curve of sugarcane bagasse.

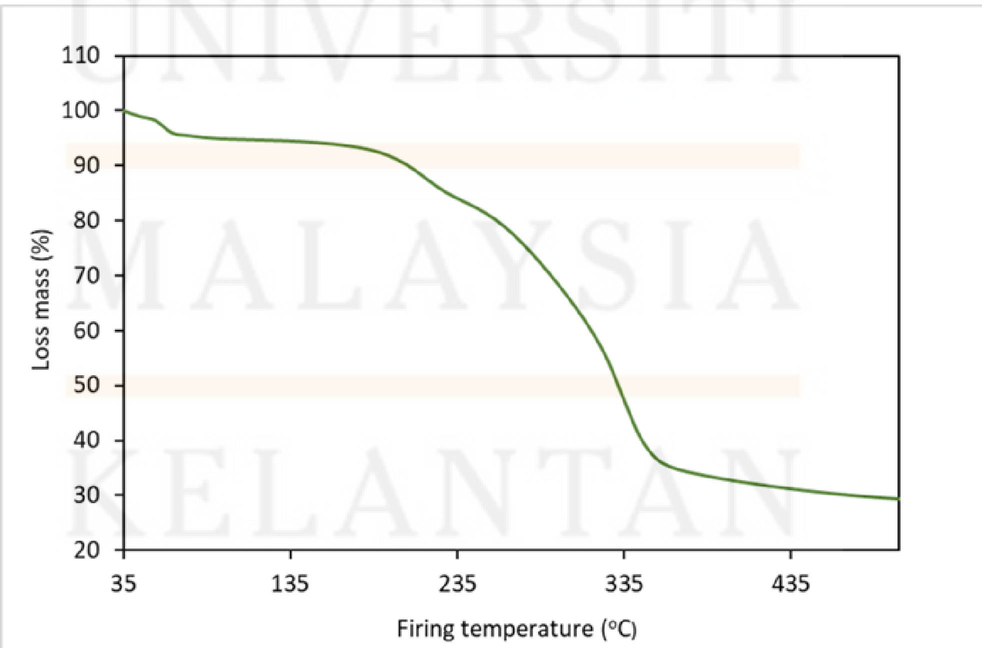


Figure 4.17: TGA pattern results on sugarcane bagasse (SB)

Thermogravimetric Analysis (TGA) is a method used to explore the thermal properties of sugarcane bagasse (SB), the fibrous residue remaining after the extraction of juice from sugarcane. When SB undergoes TGA, it involves gradually increasing the temperature while measuring its weight changes. Initially, as the temperature rises, SB experiences a decrease in weight attributed to the release of moisture and volatile compounds present within the material. Further heating leads to the decomposition of organic matter present in SB, including cellulose, hemicellulose, and lignin, resulting in additional weight loss.

Figure 4.17 presents the outcomes of thermal analysis for sugarcane bagasse at a heating rate of 10 °C/min, elucidating the stages of thermal decomposition. The weight loss, as depicted in Figure 4.17, unveils a three-stage process involving dehydration, volatilization, and carbonization. In Stage 1, occurring around 250 °C in sugarcane bagasse samples, the predominant process involves moisture evaporation due to crystallization within the internal structures and the presence of light volatiles in sugarcane bagasse ash. Stage 2 is the principal decomposition phase, primarily affecting cellulose, hemicellulose components, and partially decomposed lignin (Huynh Van Nam et al. 2019), with notable breakdown points at approximately 180 °C and 340 °C. Cellulosic breakdown specifically occurs in the temperature range of 250 °C to 450 °C. The rapid and nearly linear volume decrease with temperature in this stage aligns with the Arrhenius equation of first order, signifying that the energy of the thermal decomposition process is predominantly utilized for Stage 2. Stage 3 involves the decomposition of lignin (>400 °C), characterized by a gradual and insignificant weight loss progressing slowly from 200 °C to 800 °C.

An increase in the heating rate corresponds to heightened degradability of sugarcane bagasse. Nevertheless, the ash content and the fixed carbon remaining after heat decomposition also increase. The observed rapid weight loss on the Thermogravimetric Analysis (TGA) curve is attributed to the decomposition of hemicellulose and cellulose. The residue after thermal decomposition is determined to be 21.36%.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the effect of firing temperature of mechanical and physical properties of refractory bricks also have been studied. The effect of adding different composition of sugarcane bagasse ash with same composition of glass powder in fire-clay bricks were investigated by performing SEM, XRD, Water Absorption, Compressive Strength, Density, Porosity, FTIR and TGA. The study aimed to assess the effect of incorporating different composition of waste sugarcane bagasse ash with same composition of glass powder in refractory bricks, as well as to investigate the influence of firing temperature on the mechanical and physical properties. The results indicated the potential of SCBA in creating lightweight, low thermal conductivity, and high-strength bricks. However, recommendations for improvements in manufacturing methods were provided, considering the use of handcrafting molds for casting are recommended. The SEM analysis revealed varying porosity levels with different SCBA contents, and XRD results showed structural changes influenced by mechanical activation. The study concluded that SCBA incorporation led to reduced compressive strength but enhanced lightweight properties. Optimal performance was achieved with 2.5% SCBA at 1100 °C, demonstrating superior compressive strength, ideal density, minimized porosity, and low water absorption. These findings underscore the effectiveness of SCBA in enhancing the overall performance and durability of refractory bricks.

5.2 Recommendations

Recommendation and suggestion for future research to further enhance and augment better understanding on the production of refractory brick with SCBA additive, further investigation or research on different aspect are suggested. For example, use in contrast to SEM, TEM employs electron beams passing through a sample to generate high-resolution images for studying the structure and properties of materials on a nanometer scale. This technique enables detailed examination of crystal structures, elemental concentrations, and particle relationships within materials. Next, apply coating agent on the bricks, sodium silicate to increase the physical strength of the refractory bricks. Then, the production of refractory brick can be link to industrial so that the refractory bricks production will be much complying to the standard procedure for example, molding the refractory bricks by using an extruder to obtain a much more compact and well shape bricks. Lastly, chemical treatment can be used to increase the particle bonding of the clay brick such as addition of sodium bicarbonate.

REFERENCES

Assamoi, B., & Lawryshyn, Y. (2012). The environmental comparison of landfilling vs. incineration of MSW accounting for waste diversion. *Waste management*, *32*(5), 1019-1030.

Cardarelli, F. (2008). Ceramics, refractories, and glasses. *Materials handbook: a concise desktop reference*, 593-689.

Sequeira, C. A. (2019). *High temperature corrosion: fundamentals and engineering*. John Wiley & Sons.

Jadeha, K. H., & Saradava, K. (2014). Property analysis of alumina refractory bricks–a review. *International Journal of Futuristic Trends in Engineering and Technology*, *1*, 1-3.

Jeschke, P. (1966). Texture analysis of basic refractory brick. *Journal of the American Ceramic Society*, *49*(7), 360-363.

Sugita, K. (2008). Historical overview of refractory technology in the steel industry. *Shinnittetsu Giho*, *388*, 8.

Achaw, O. W., & Danso-Boateng, E. (2021). Cement and Clay Products Technology. In *Chemical and Process Industries: With Examples of Industries in Ghana* (pp. 135-170).

Kumarasamy, K., Doss, M. V. S., & Anand, A. V. (2022). Evaluation of thermo mechanical and corrosion properties of uniaxially pressed refractory blocks used in the transition zone of cement rotary kilns. *Materials Today: Proceedings*, *64*, 455-458.

Tonnayopas, Danupon. (2013). Green Building Bricks Made with Clays and Sugar Cane Bagasse Ash.

Shelby, J.E. (2005). Introduction to Glass Science and Technology. (2nd ed.). British Library: The Royal Society of Chemistry (RSC).

Falsafi, S. R., Rostamabadi, H., Assadpour, E., & Jafari, S. M. (2020). Morphology and microstructural analysis of bioactive-loaded micro/nanocarriers via microscopy techniques; CLSM/SEM/TEM/AFM. *Advances in Colloid and Interface Science*, *280*, 102166.

Andiç-Çakır, Ö., Son, A. E., Sürmelioğlu, S., Tosun, E., & Sarıkanat, M. (2021). Improvement of traditional clay bricks' thermal insulation characteristics by using waste materials. Case Studies in Construction Materials, 15, e00560.

Hamada, H. M., Shi, J., Abed, F., Al Jawahery, M. S., Majdi, A., & Yousif, S. T. (2023). Recycling solid waste to produce eco-friendly ultra-high-performance concrete: A review of durability, microstructure and environment characteristics. Science of The Total Environment, 876, 162804.

Abdullatif, K. G., Guirguis, M. N., & Moussa, R. R. (2020). Analyzing the structural properties of Fire Clay bricks after adding cigarette filters.

Oganov, A. R., Pickard, C. J., Zhu, Q., & Needs, R. J. (2019). Structure prediction drives materials discovery. *Nature Reviews Materials*, *4*(5), 331-348.

Wen, Z., Liu, H., Zhou, M., Liu, C., & Zhou, C. (2023). Explainable machine learning rapid approach to evaluate coal ash content based on X-ray fluorescence. *Fuel*, *332*, 125991.

Abbas, S., Saleem, M. A., Kazmi, S. M. S., & Munir, M. J. (2017). Production of sustainable clay bricks using waste fly ash: Mechanical and durability properties. *Journal of Building Engineering*, *14*, 7–14.

Amin, M., Attia, M. M., Agwa, I. S., Elsakhawy, Y., el-hassan, K. A., & Abdelsalam, B. A. (2022). Effects of sugarcane bagasse ash and nano eggshell powder on high-strength concrete properties. *Case Studies in Construction Materials*, *17*, e01528.

Arbelaez Perez, O. F., Florez, D. R., Zapata Vergara, L. M., & Hernández Benavides, K. V. (2022). Innovative use of agro-waste cane bagasse ash and waste glass as cement replacement for green concrete. Cost analysis and carbon dioxide emissions. *Journal of Cleaner Production*, *379*, 134822.

Artbumrung, S., Srila, M., Srisuwan, A., Saengthong, C., Lawanwadeekul, S., Sittiakkaranon, S., Dakaew, S., & Phonphuak, N. (n.d.). *Combined effects of waste bagasse ash and glass powder on the physical properties and compressive strength of construction bricks*.

Del Rio, D. D. F., Sovacool, B. K., Foley, A. M., Griffiths, S., Bazilian, M., Kim, J., & Rooney, D. (2022). Decarbonizing the ceramics industry: A systematic and critical review of policy options, developments and sociotechnical systems. Renewable and Sustainable Energy Reviews, 157, 112081.

Chindaprasirt, P., Srisuwan, A., Saengthong, C., Lawanwadeekul, S., & Phonphuak, N. (2021). Synergistic effect of fly ash and glass cullet additive on properties of fire clay bricks. *Journal of Building Engineering*, *44*, 102942.

Micheal, A., & Moussa, R. R. (2022a). Evaluating the Effect of Adding Sugarcane Bagasse to the Fire Clay Brick's Properties. *Civil Engineering and Architecture*, *10*(1), 71–78.

Aktas, B., Albaskara, M., Yalcin, S., & Dogru, K. (2017). Mechanical properties of soda-lime-silica glasses with variable peanut shell contents. Acta Physica Polonica A, 131(3), 511–513.

Abdeen, Hisham, and Samir Shihada. “Properties of Fired Clay Bricks Mixed with Waste Glass.” *Journal of Scientific Research and Reports*, vol. 13, no. 4, 10 Jan. 2017, pp. 1–9.

Roushdy, M. H. “Recycling of Cullet, Waste Clay Bricks and Wastes Resulted from Wheat and Sugarcane Cultivations in the Manufacture of Fired Clay Bricks.” Wseas Transactions on Environment and Development, vol. 17, 16 Mar. 2021, pp. 192–200.

Maza-Ignacio, Olivia Teresa, et al. “Recycling Untreated Sugarcane Bagasse Ash and Industrial Wastes for the Preparation of Resistant, Lightweight and Ecological Fired Bricks.” *Construction and Building Materials*, vol. 234, Feb. 2020, p. 117314.

Kumar Swarnakar, Arvind, and Dr. Shweta Choubey. “A Short Review on “Utilizing Sugarcane Bagasse (SCB).” *International Research Journal of Engineering and Technology (IRJET)*, Aug. 2016, p. 5.

Wang, D., Dai, Y., Li, Y., Zhu, Q., Yin, Y., & Andreev, K. (2023). High temperature creep behavior of fireclay refractory and its masonry. Construction and Building Materials, 385, 131478.

Salih MM., Osofero AI. and Imbabi MS. (2018). Mechanical Properties of Fibre-Reinforced Mud Bricks‖. 2nd Conference of Civil Engineering.

N. Phonphuak, S. Kanyakam, and P. Chindaprasirt. (2016) “Utilization of waste glass to enhance physical-mechanical properties of fired clay brick*,” Journal of Cleaner Production*, vol. 112, pp. 3057-3062.

Chindaprasirt, P., Srisuwan, A. , Saengthong, C. , Lawanwadeekul, S. and Phonphuak, N. (2021). Synergistic effect of fly ash and glass cullet additive on properties of fire clay bricks. *Journal of Building Engineering*. 44, pp. 102942

Benlalla A., Elmoussaouiti M., Dahhou M. and Assafi M., Appl. Clay Sci., (2015) ; 118: 171-177.

Maza- Ignacio, O.T., Jiménez-Quero, V. G., Guerrero-Paz, J. and Montes- García, P. (2020). Recycling untreated sugarcane ash and industrial wastes for the preparation of resistant, lightweight and ecological fired bricks. *Construction and Building Materials*. 234, pp. 117314.

Kazmi, S.M.S., Munir, M.J., Patnaikuni, I., Wu, Y.F. and Fawad U. (2018). Thermal performance enhancement of ecofriendly bricks incorporating agro- wastes. *Energy and Building*. 158, pp. 1117-1129.

Mao, L., Wu, Y., Zhang, W. and Huang, Q. (2019). The reuse of waste glass for enhancement of heavy metals immobilization during the introduction of galvanized sludge in brick manufacturing. *Journal of Environmental Management*. 231, pp. 780-787.

Hasanuzzaman, M., Rafferty, A., Sajjia, M., & Olabi, A.-G. (2016). Properties of Glass Materials. *In Reference Module in Materials Science and Materials Engineering.*

Garcıa-Perez, M.; Chaala, A.; Yanga, J.; Roy, C. Co-pyrolysis of sugarcane bagasse with petroleum residue. Part I: Thermogravi-metric analysis.

Adazabra, Aaron N, et al. (2023). "Valorising Cassava Pomace Biosolid in Fired Clay Bricks Production: Physical, Mechanical and Thermal Evaluation." *Materials Chemistry and Physics*, vol. 309, pp. 128402–128402.

Seyoum, Redeat, et al. (2021). "Investigation on Control Burned of Bagasse Ash on the Properties of Bagasse Ash-Blended Mortars." *Materials*, vol. 14, no. 17, p. 4991.

Lopes, Ward, et al. (2023) "Development of a New Clay-Based Aerogel Composite from Ball Clay from Piauí, Brazil and Polysaccharides." *Polymers*, vol. 15, no. 11, pp. 2412–2412.

Suthee Wattanasiriwech, and Suthee Wattanasiriwech. (2019). "Examination of Ball Clays Derived from a New Seam in Northern Thailand." *IOP Conference Series*, vol. 351, no. 1, 1 Oct. 2019, pp. 012006–012006.

ASTM C62-13a (2023): Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale). *West Conshohocken, PA, USA*: ASTM International.

Huynh Van Nam, et al. (2019). "Kinetic Modelling of Thermal Decomposition of Sugarcane Bagasse in the Inert Gas Environment." *Vietnam Journal of Chemistry*, vol. 57, no. 5, pp. 574–580.

Rahaman, M. N. (2017). *Ceramic processing*. CRC press.

APPENDIX A

Aluminium Mold Shaping Process:

A) Designing Process, B) Cutting Aluminium Process with desire shape and size and C) Shaping Process


A)


B)


C)

APPENDIX B

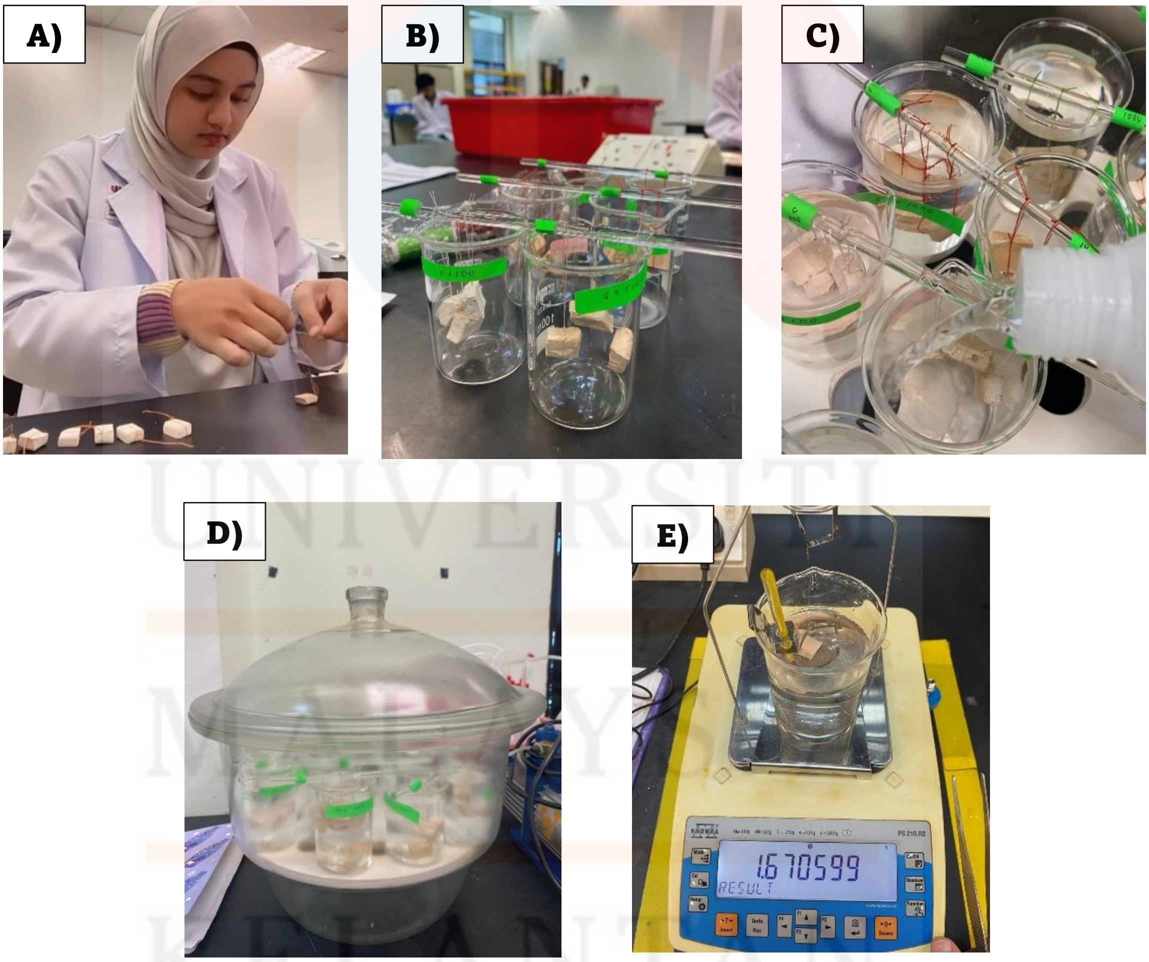
Sugarcane Bagasse Transformation Process to be an Ash:

A) Collected Waste SCB, B) Drying Process (in air condition) C), Drying Process (in oven at 110 °C for 2 hours) D) Fired Process (use open furnace), E) Resulted Black Ash, F) Fired/Heating Process in Furnace (at 600 °C for 2 hours) and G) Resulted SCBA Ash (grey ash)

APPENDIX C

Ultilizing Vacuum Indicator for Precise Measurement of Water Absorption, Density, and Porosity:

A) Tying Each Sample Using Threads, B) Hung Samples onto Glass Rods Inside Beakers, C) Poured Distilled Water Until All Samples Were Fully Submerged, D) Initiated Vacuum Indicator for 30 minutes, and E) Density Measurement



APPENDIX D

Ceramic brick sample was first crushed into a fine powder using a mortar for testing purpose in FTIR and XRD.