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EFFECT OF GLASS POWDER ON THE PROPERTIES OF CLAY MIXTURE FOR PORCELAIN STONEWARE TILES.

MUHAMMAD SYAZWAN BIN ZAINOL ABIDIN

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DECLARATION

I declare that this thesis entitled "The Effect of Glass Powder on The Properties and Microstructure of Clay Mixture For Porcelain Stoneware Tiles" is the result of my research, apart from the references listed. The thesis has not been approved for any degree and is not presently being considered for any other degree.

Signature : ____________________

Student's name : MUHAMMAD SYAZWAN BIN ZAINOL ABIDIN

Date : 28/2/2024

Verified by,

Signature : ____________________

Supervisor's name : DR. NORFADHILAH BINTI IBRAHIM

Date : ____________________

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THE EFFECT OF GLASS POWDER ON THE PROPERTIES OF CLAY MIXTURE FOR PORCELAIN STONEWARE TILES.

ABSTRACT

Glass waste is nonbiodegradable and consumes valuable landfills. This study examined the utilization of discarded glass powder and clay to make porcelain stoneware walls and floor tiles. Raw materials were characterized by their mineral and chemical makeup. Glass compositions were fired at 1000-1100 °C for 1 hour. The effects of waste glass content on technological parameters such as linear shrinkage, water absorption, bulk density, and porosity were investigated. X-ray diffraction was used to do a microstructural investigation of the burned samples. Experiments show that waste glass can improve the physico-mechanical properties of materials with up to 35 wt% glass content at 1100°C. The final product (KC50CC15G35) at 1100 °C showed a weak absorbed water value (21.037%). The XRD spectra of KC50CC15G35 were measured in the range of 2ϴ = 10° to 90°. KC50CC15G35 with COD 1011176 which is quartz low and the crystalline structure is hexagonal. The lattice parameters for KC50CC15G35 of a and c are 4.9 and 5.4 respectively. that the silicon (Si) has a higher peak than aluminum (Al).

KESAN SERBUK KACA TERHADAP SIFAT-SIFAT DAN STRUKTUR MIKRO CAMPURAN TANAH TANAH UNTUK JUBIN PORSELIN PERANGKAT BATU.

ABSTRAK

Sisa kaca tidak boleh terbiodegradasi dan menggunakan tapak pelupusan yang berharga. Kajian ini mengkaji penggunaan serbuk kaca dan tanah liat yang dibuang untuk membuat dinding batu porselin dan jubin lantai. Bahan mentah dicirikan oleh solek mineral dan kimia mereka. Komposisi kaca dibakar pada 1000-1100 °C selama 1 jam. Kesan kandungan kaca sisa pada parameter teknologi seperti pengecutan linear, penyerapan air, ketumpatan pukal, dan keliangan telah disiasat. Difraksi sinar-X digunakan untuk melakukan penyiasatan struktur mikro terhadap sampel yang dibakar. Eksperimen menunjukkan bahawa kaca sisa boleh meningkatkan sifat fiziko-mekanikal bahan dengan kandungan kaca sehingga 35% berat pada 1100°C. Hasil akhir (KC50CC15G35) pada suhu 1100 °C menunjukkan nilai air serapan yang lemah (21.037%). Spektrum XRD KC50CC15G35 diukur dalam julat 2ϴ = 10° hingga 90°. KC50CC15G35 dengan COD 1011176 iaitu kuarza rendah dan struktur kristal adalah heksagon. Parameter kekisi untuk KC50CC15G35 a dan c masing-masing ialah 4.9 dan 5.4. bahawa silikon (Si) mempunyai puncak yang lebih tinggi daripada aluminium (Al).

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LIST OF ABBREVIATION

XRD	X-ray Diffraction
XRF	X-ray Fluorescence
FTIR	Fourier Transform Infrared Spectroscopy
TGA	Thermogravimetric Analysis
Al	Aluminium
Si	Silicon
O	Oxygen
OH	Hydroxy group
Fe	Iron
Ca	Calcium
Mg	Magnesium
K	Potassium
Ti	Titanium
Mn	Manganese
CH	Methane (hydrocarbon)
CO	Carbon monoxide

LIST OF SYMBOLS

%	Percentage
wt.%	Weight percentage
min	Minutes
°C	Degree Celsius
°F	Degrees Fahrenheit
°	Diffraction angle
θ	Theta
cm^{-1}	Centimeter inverse
g/m^3	Gram per cubic meter
MPa	Megapascal
µm	Micrometer
kV	Kilovolt
mA	Milliamperes
s	Second

CHAPTER 1

INTRODUCTION

1.1 Background of Study

One major issue with glass is its one-time-use function for usages such as containers for drinks, that is one of its primary uses. In 2016, waste glass was responsible for 5% of the worldwide waste generation. Glass waste is nonbiodegradable and consumes valuable landfill space. Glass trash dumping towards landfills is a result of poor recycling as it raises dependency on natural resources, diminishing resources like the seashore to make more glass items. As the need for junkyard space increases, taxes are anticipated to rise in order to encourage greater recycling practices. Discovery new solutions to recycle junk glass can reduce disposal costs while protecting landfills and the environment. Glass can be recycled in either an open-loop or closed-loop, as a substitute for waste recycling. A closed loop recycles glass by reusing glass bottles through a reverse program or making advanced glass items from recycled glassware. The open-looped system repurposes waste glass into alternate items (Harrison et al. 2020).

Thus, the recycling process is an essential eco-friendly and economic substitute for all waste class. It is not just applied in the procedure related to their creation, but also in further activity section such as the ceramic tile field, particularly for the waste that had a low decay rate in atmospheric or by environment precipitation over a few decades like the glass waste. The recycling process allows for the achievement of several essential goals, including disposal area, the management of short quantities of mineral deposits, and, as a result, environmental protection.

Various types of waste have been combined into tiles and bricks. Higher-grade ceramics necessitate a huge number of resources. As an example, clay gives the composition its flexibility, then feldspar reacts as a fluxing agent to form a liquid phase during inert materials and sintering. It will aid in product dimension restriction after firing. This makes the demand for raw materials to create ceramics increase thus the raw materials are not always available since they need to be extracted from nature. With the higher demand and the shortage of raw materials, it creates another problem which is increasing costs.

It is necessary to recompose the combined formation of raw materials using different raw materials that must be very low price and easily available, such as waste glass. There will be no problem reformulating the composition using glass waste since the quality and properties of the ceramic will be unchanged. Using waste glass can also reduce the use of electrical energy and increase the quality of the ceramic.

1.2 Problem Statement

Because of its remarkable properties, such as optical clarity, chemically inertness, high intrinsic strength, and low permeability, glass is one of the most adaptable materials on the planet. Although glass can potentially be totally recycled, there are still constraints in satisfying the necessary requirements for glass remanufacturing. As a result, the non-recyclable portion is often discarded and disposed of in landfills. With a very poor recycling rate, the projected amount of landfilled glass worldwide is over 200 million tons per year (Yi Jiang, 2019).

There was previous research studying the effect of glass powder with the clay mixture to create porcelain tiles (O. Njindam et al. 2018). The result shows that linear shrinkage increases up to 30% with glass powder loading. Products melted and began to spread after being burned at 1150 °C with 40% glass. Water absorption properties of tiles fall as waste glass and firing temperature rise. As a result, burned goods with 30% glass had the lowest water absorption rating (0.4%) (O. Njindam et al. 2018). The result shows that the research was successful with the enhanced properties of porcelain tiles. But for this study, the composition and the firing temperature was changed to find a better solution for porcelain tiles. In other words, the major focus of this study is to exceed the enhanced qualities of the previous study.

In this research, to make sure the idea of mixing the waste glass to make the ceramic can enhance the quality and lower the cost process, the glass powder was mixed with clay to form porcelain tiles. There are various compositions for the glass powder and the clay. It is to make sure that a perfect composition can be found in order to achieve the best quality of the ceramic. The result of the mixture was observed by using X-ray diffraction (XRD), apparent porosity, Water absorption, Bulk density, and Linear firing shrinkage. For this study, glass powder will be mixed with clay to make porcelain tiles to examine their properties of it. The glass powder utilized in this study has a composition of 0g, 5g, 15g, 25, and 35g, and the clay has a composition of 50g, 45g, 35g, 25g, and 15g, while the kaolinite clay has a composition of 50g for each sample. After the preparation of the samples, they was examined with various types of characterization techniques.

1.3 Expected Outputs.

In this research project, glass waste was mixed with clay to produce porcelain tiles. The mixture of glass waste and clay is expected to produce great properties to porcelain tiles such as low water absorption and enhance strength while reducing the impact on the environment, thus improving the quality of our nature.

1.4 Objectives

1. To study the effects of glass powder on the properties of the clay mixture for porcelain stoneware tiles.
2. To determine the percentage of glass waste and clay mixture to use to achieve the best properties of the porcelain tiles.

1.5 Scope of Study

. Material selection is used to identify appropriate clay substances and glass powder mixtures for the investigation. Consider various clays and glass powders are used. In this study, the result was affected by different glass composition used in producing porcelain tiles stoneware. This may include evaluating the final porcelain stoneware tiles' shrinkage, density, porosity, and water absorption. Microstructural Analysis, such as X-ray diffraction (XRD) are also required to analyze the microstructure of the clay-glass composite. Examine the glass particle distribution, clay-glass interactions, and any phase transitions that occur.

The surface texture will be evaluated to determine any enhancements or alterations caused by the glass powder. Compare the characteristics and microstructure of the clay mixture with glass powder to that of a reference sample without the addition of glass powder. All of the things that have been stated are the scope of the study for the effect of glass powder on the properties of clay mixture for porcelain stoneware tiles.

1.6 Significance of Study

The increasing waste around the world has caused many sorts of pollution due to the population of humans increasing from year to year. Humans generate a wide range of garbage as a result of their daily activities. The demand for raw materials also increased since the growth of human population was growing unexpectedly especially in the ceramic industry since it was required to build the building. With all of these problems, the researchers decided to use the waste as a replacement for the raw materials to create the ceramic. This is to ensure that the waste growth will decrease while making sure that the raw materials will not be depleted.

Porcelain tile possesses a water-absorbing rate that is less than 0.5 percent. To attain this density, a finer and purer kaolin clay mixture over most ceramic clay is needed. It usually has significant amounts of feldspar and quartz blended in. To the average consumer, porcelain is a thick, fine-grained, polished tile that is more resistant to water than conventional ceramic tile. The impact of glass powder on the characteristics and morphology of clay combination for porcelain stoneware tiles may assist enhance the performance of the porcelain tiles while preserving raw material resources and decreasing glass waste.

From an economic perspective, glass powder as a raw material mixed with clay can greatly decrease the cost of producing porcelain tiles. The preparation of raw materials is no longer needed since glass waste is easy to get. The price for kaolin as raw materials can be cut from the budget. Glass powder also can increase the quality of porcelain tiles. In general, it reduces the cost for those involved with producing the porcelain tiles industries and also reduces the cost for those who are involved in waste management.

As the previous research stated, the help of the glass powder mixed with clay for the porcelain tiles will increase its properties of it. The water absorption for the porcelain tiles decreases as the glass has a low water absorption rate. Water absorption properties of tiles fall as glass waste and firing temperature rise. Bulk density also rises as glass waste increases and the temperature of firing increases. The study also discovered that ceramic products' flexural strength increased. The formation of numerous crystalline forms like mullite, enstatite, anorthite, and cristobalite enhances sintered glass composites due to their high mechanical properties.

The application of glass waste powder mixed with clay to create porcelain tiles is recommended. The process of making porcelain tiles with the use of this mixture is suitable for the environment and can greatly reduce the cost. The quality of the porcelain tiles will also be improved. Thus, this research is to investigate the effect of glass powder whether it is true or not that it can enhance the quality of porcelain tiles as stated above.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the definition of porcelain tiles was introduced along with its structure. The function and characteristics of kaolinite clay, plastic clay, and glass powder are next explained in detail. Parameters such as temperature and composition was also be discussed in this chapter. The appropriate characterization approach utilized to analyze the clay mixture after burning was also investigated.

2.2 Porcelain Tiles

Ceramic tiles, often known as porcelain tiles, are commonly used as flooring floors and walls. Specific gravity, absorption of water (%), and impact values (%) were determined to be 2.36, 0.94, and 12.5 respectively (Denesh et al. 2022). In general, the clay used to make porcelain tiles is denser.

Porcelain, sometimes known as triaxial porcelain, is made up of three separate basic materials: clay or kaolin, feldspar, and quartz. Porcelain is typically composed of around 50% kaolin, 25% quartz, and 25% feldspar. In terms of application, porcelain tiles are one of the newer goods compared with other ceramic tiles, and it has lately shown an increase in market trends. Porcelain tile offers a high-quality product that stands out from the competition due to its superior technical qualities. It is a ceramic material with very little porosity (less than 0.5%), as well as an extremely small amount of closed porosity (less than 10%)(Nur Azureen, 2020).

Although the composition of the porcelain can influence the end-product characteristics, one of the most critical aspects in the manufacturing of porcelain tiles is the sintering temperature. The sintering temperature influences modifications in morphology and vitrification behavior because it causes major changes in densification and enhances the toughness of the porcelain tiles.

Figure 2.1: Porcelain Tiles (google photos)

2.3 Kaolinite Clay

Kaolinite clay ($Al_2Si_2O_5(OH)_4$) is a widely utilized clay in a variety of applications. It is a clay mineral with 1:1 dioctahedral structure. This category also includes dickite and halloysite. The sole distinction between dickite and kaolinite is their plates structure with flat layers. Because kaolinite layers are neutral in their ideal chemical composition, crystalline structural solidity is mostly because of hydrogen bonding and van der Waals forces among surround films (Daniel Tunega, Ali Zaoui, 2020). Kaolinite has a restricted shrink-swell ability and a low cation exchange capacity.

2.4 Glass Powder

Glass powders are frequently employed as temperature-resistant, non-aging 'glue' for the effective sealing, joining, or soldering of various materials. According to one study, water absorption, shape, and particle size of glass powder particles can have a considerable impact on the fresh qualities of concrete. When fairly big glass powder grains (d50 = 204 m) were used, there was a considerable decline in flow value. It was determined that the lower fluidity was caused by the huge particle size and shape diversity of glass powder, as well as a high aspect ratio. To account for the physical properties of glass powder cullet, the size of glass powder must be properly selected. When a positive effect on workability is established, it can be used to lower the effective consumption of water or reduce the cement content to mitigate heat and shrinkage issues. The advantages of utilizing glass cullet in ceramic products are as follows: Reduce electrical energy usage, improve material quality, reduce HF emissions, and reduce CO_2 emissions. According to certain studies, wasted glass bottles contain a great number of silica, SiO_2 (70-74%), as well as a significant number of alkaline earth oxides: Na_2O (12-16%), CaO (5- 11%), and MgO (1-3%). Waste glass has fluxing capabilities due to its mineralogy and chemical makeup and, as a result, can be utilized in place of the fluxing agent utilized by traditional ceramics (Njindam et al. 2018).

2.5 Firing temperature

It revealed that first rate porcelain floor tiles may be produced using materials acquired easily. There is a study about the properties of porcelain tiles made from resources in Uganda. It was made from sand, ball clay, feldspar, and kaolin. The tile specimens were tested at various temperatures and combination compositions. The formulation of the resources had no effect on the water absorption of the samples, but the firing temperature did. The firing temperature used for this study was 1150 °C to 1250 °C. The water absorption rates were less than 0.5% at 1200 °C for all samples examined. It met the ISO 13006 porcelain floor tile specifications (Ochen et al., 2021).

2.6 Characterization techniques

The porcelain tiles created from a clay-glass powder mixture will be characterized using several characterization techniques to identify the specimen's chemical composition, structure, element, compound, and bonding, as well as physical and mechanical qualities.

2.6.1 X-ray diffraction (XRD)

Nondestructive X-ray diffraction (XRD) offers accurate data regarding the crystalline structure, chemical structure, and mechanical characteristics of materials. The previous study's figure demonstrates that only mullite and quartz emerge as crystalline stage in the porcelain tiles sample. The patterns nearly all show similar peaks for all compositions burned at 1200 °C. As a result, the crystalline part produced possesses identical proportions in the burned specimens. There is a spike at 2Θ = 20-30° for all glass stage compositions. As a result, the same amount of glass should be found in all samples (Ochen et al. 2021)

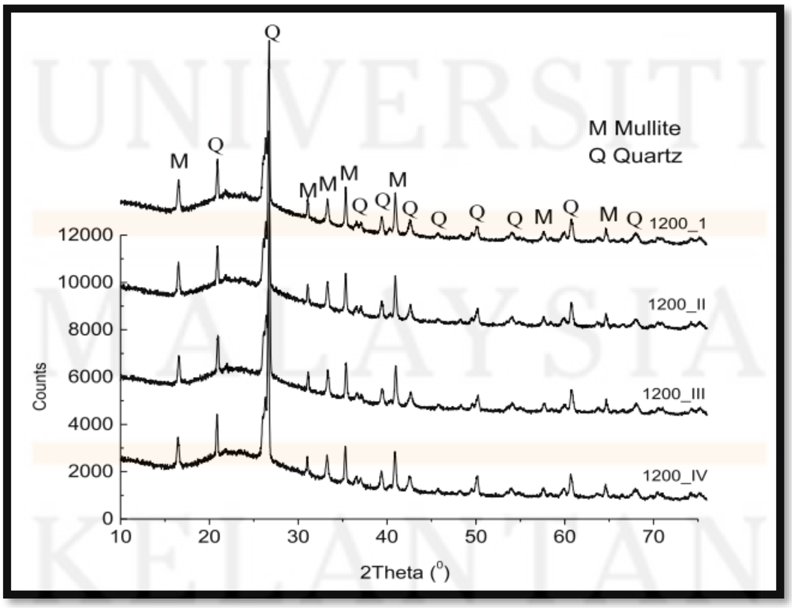

Figure 2.2: XRD patterns for all specimens fired at 1200 ◦C (Ochen et al. 2021).

2.7 Physical Properties of porcelain tiles.

This is the literature review of the physical properties of porcelain tiles after the result of glass powder on the clay mixture.

2.7.1 Water absorption

Water absorption is important to measure the durability of concrete. Reduced water absorption may significantly enhance for a long-time concrete endurance under demanding service conditions. According to one study (Ibrahim, 2021), when the WGP level increased, the degree of water absorption decreased. Water absorption was discovered to be considerable in concrete, but it was minimized by utilizing milled WG as a replacement to cement in combinations. The use of conductive WG instead of cement lowers the number of gaps in the concrete. (Ibrahim, 2021).

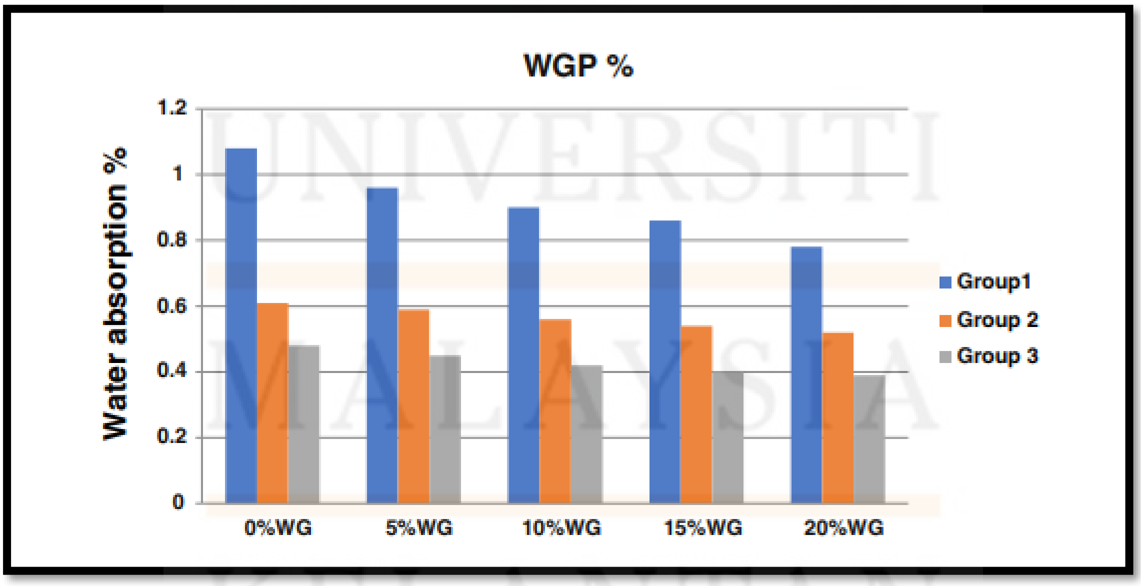

Figure 2.3: the value of water absorption (%) (Ibrahim, 2021).

2.7.2 Linear Shrinkage

Studying the linear shrinkage behavior of a clay product after sintering is crucial in the ceramic field. It enables you to adjust the dimensions of the finished object. Less linear shrinkage remains desirable if certain physical-mechanical qualities can be achieved. The shrinkage behavior of separate compositions with different glass cullet percentages and firing temperatures. Linear shrinkage increases with GP concentration and fire temperature for all specimens. The increased linear shrinkage suggests that the clay and GP experienced more heat fluctuations. Increasing the temperature promotes this behavior. It is possible that the existence of a greater concentration of fluxing oxides derived from waste glass aids in the formation of a fluid phase that close the pores and supports the bringing of grains closer together, resulting in less linear shrinkage during firing. In one study, when the quantity of powder glass supplied reaches 40 wt% (R_{50}(kaolinite clay) G_{10}(plastic clay) C_{40}(glass cullet)) at 1100 °C, a following fall in shrinkage value is seen; this could be related to a reduce in raw clay (Njindam et al. 2018).

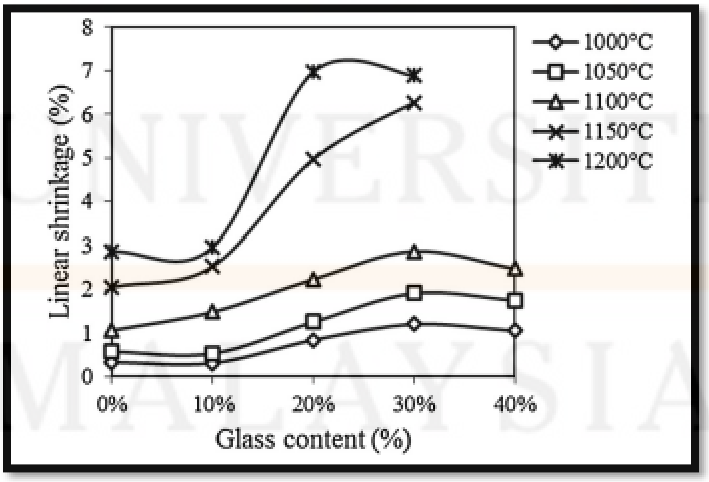

Figure 2.4: Linear Shrinkage of the fired mixture from 1000 °C to 1200 °C (Njindam et al. 2018).

2.7.3 Bulk density

According to one study (Njindam et al. 2018), the heating reaction rate increases as the amount of glass powder increases. As a result, a large amount of liquid phase is produced, which enters and falls into the pores of burned items. This contributes to higher consolidation, which raises the bulk density of ceramic products. When the firing temperature is raised to 1200 °C, the bulk density rises. Conversely, the sample's bulk density increases to a high of 1150 °C before decreasing as the firing temperature increases (Njindam et al. 2018).

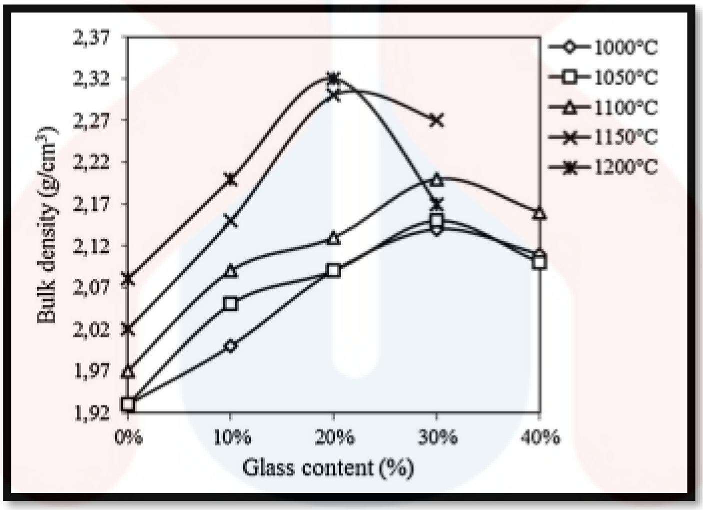

Figure 2.5: Bulk density of the fired mixture from 1000 °C to 1200 °C (Njindam et al. 2018).

CHAPTER 3

MATERIAL AND METHOD

3.1 Material

3.1.1 Raw material

In this study, there are three main components for porcelain tiles which are kaolinite clay, plastic clay, and glass powder. The glass powder will be obtained from the glass waste (colorless bottle). To prepare the glass powder, the glass waste must be washed first before being crushed into small pieces. Then the small pieces of the glass waste will be grounded into powder using the ball mill. Glass and both clay will be sieved through a 100 µm mesh sieve and a 125 µm mesh sieve, respectively. The five various porcelain tile compositions are made by altering the composition of glass powder as shown in Table 3.1.

Table 3.1: The composition of raw materials with varying plastic clay and glass powder

Raw Materials	*Kaolinite clay (wt. %)*	*china Clay (wt. %)*	*Glass powder (wt. %)*
Control	*50*	*50*	*0*
Sample 1	*50*	*45*	*5*
Sample 2	*50*	*35*	*15*
Sample 3	*50*	*25*	*25*
Sample 4	*50*	*15*	*35*

3.2 Research Flowchart

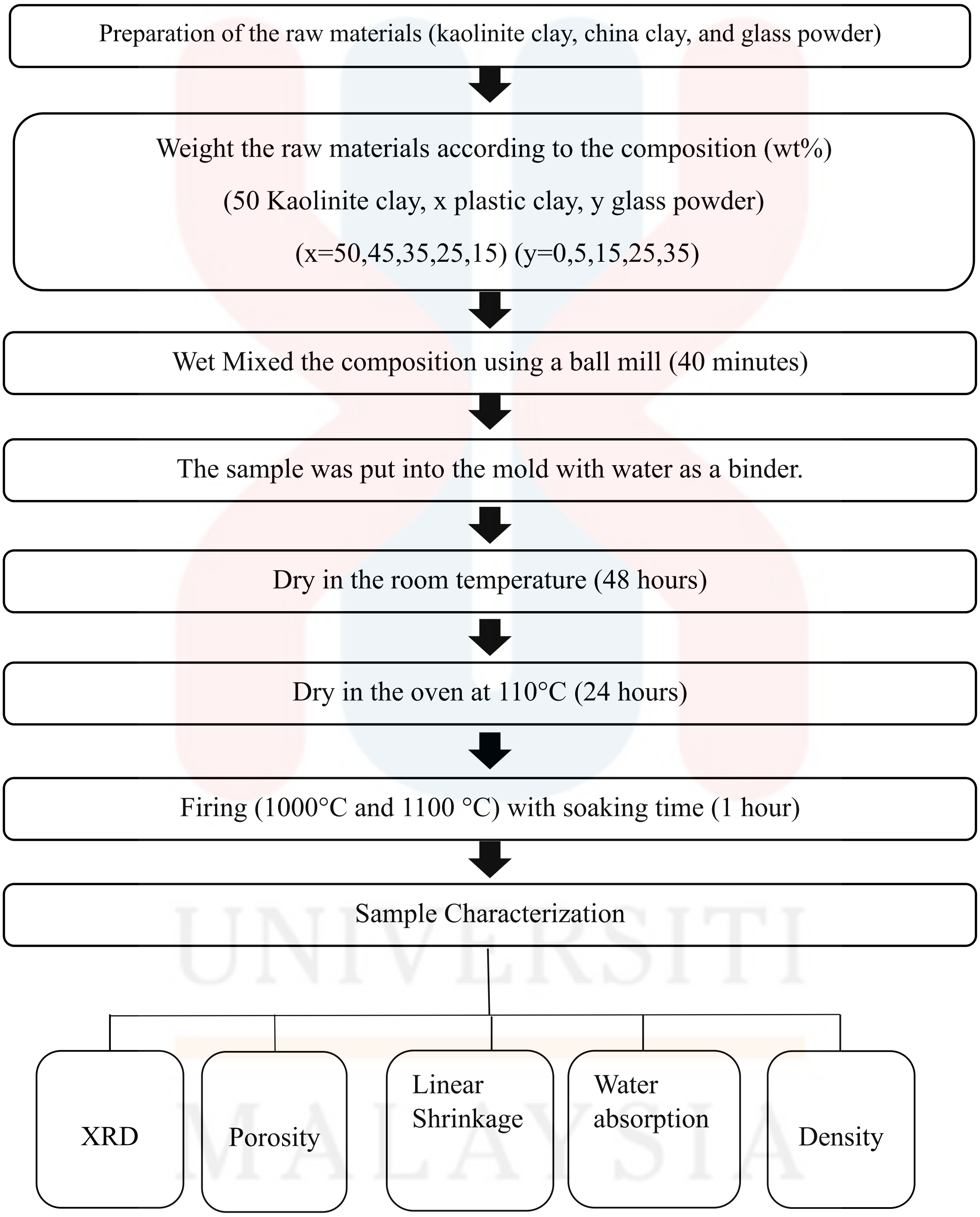

Figure 3.1: Research flow for ceramic brick sample preparation and characterization.

3.3 Method

3.3.1 Mixing

All the raw materials (kaolinite clay, plastic clay, and glass powder) were weighted as listed in Table 3.1. The clay mixture will be wet-mixed using the stand mixer for 40 minutes. Water was added as a binder with 60% of total weighted.

3.3.2 Molding

After the mixing process, put the sample into the mold with water as a binder and dry it at room temperature for 48 hours. Then, the sample must be put in the oven to dry for 24 hours at a temperature of 100 °C.

3.3.3 Firing

The five different composition samples are fire at three different temperatures, 1000 °C and 1100 °C, with fire rates of 5 °C per minute and a soaking period of one hour. The firing temperature is important since different temperatures can create different results for the properties of the sample.

3.4 Sample Characterization

3.4.1 X-ray Diffraction (XRD)

X-ray Diffraction (XRD) was used to identify the material's various phases and crystalline structures. The XRD machine that was used in this thesis was the Bruker D2-Phaser XRD machine. The crystalline makeup of a burnt sample can also be determined using XRD. Following the firing process, samples are subjected to XRD analysis. The sample will be crushed into a fine powder before being put into the sample stage or holder to analyze it.

3.4.2 Water Absorption, porosity, density, and bulk density determination

Water absorption, porosity, density, and bulk density will be determined by using MS ISO 10545-3: 1995. After this process removes the air from the chamber, the specimens are going to be immersed in water. The specimens are going to be weighed prior to and after being submerged in water to calculate porosity, density, and bulk density using the water absorption Equation 3.1, 3.2, and 3.3.

Water Absorption (%) =

$$\left(\frac{\mathbf{m2(b,v)-m1}}{\mathbf{m1}}\right) \times \mathbf{100\%} \qquad \text{Equation 3.1}$$

m1: is the mass of the dry porcelain tiles.

m2: is the mass of wet porcelain tiles.

Apparent Porosity (%) =

$$\pi_a = \left(\frac{m_3 - m_1}{m_3 - m_2}\right) \times 100\% \qquad \text{Equation 3.2}$$

π_a: porosity

m_1: mass of dried sample

m_2: mass of saturated sample in water

m_3: mass of saturated sample in air

Bulk Density Equation =

$$\rho_s = \rho_{fl} \frac{m_{(a)}}{m_{(a)} - m_{(fl)}}$$ Equation 3.3

ρ_s: Density of Body

ρ_{fl}: Density of Liquid

$m_{(a)}$: Mass of body

$m_{(fl)}$: mass of liquid

3.4.2 Linear Shrinkage

Linear shrinkage refers to the reduction in the dimension of a sample. All the sample 's dimension will be measured by the digital calipers. All the data that were collected will determine the shrinkage of the sample by the linear shrinkage Equation 3.4.

Linear Shrinkage Equation =

$$\in L = \frac{L_m - L_o}{L_0} \ x \ 100\%$$ Equation 3.4

∈L: Linear Shrinkage

L_m: The dimension before the firing process

L_0 : The dimension after the firing process

CHAPTER 4

RESULT AND DISCUSSION

4.1 Raw Material Characterizations

In this search, the sample of porcelain tiles (kaolin clay, china clay and glass powder) has been characterized using X-Ray Diffraction (XRD). In this testing, the samples are examined to identify the characteristics and elements. The XRD spectra of KC50CC50G0 were measured at range of 2ϴ = 10° to 90°. According to Figure 4.1 it is stated that KC50CC50G0 with COD 1011176 (Quartz low) as primary phase and COD 1000442 (aluminum oxide) as secondary phase. The crystalline structure for KC50CC50G0 is hexagonal.

On Figure 4.1, it shows a few peak that have weak and sharp diffraction peak. The highest peak that contains in the graph was at 2ϴ = 26.69° (101) while the lowest peak was at 2ϴ = 68.27° (203).

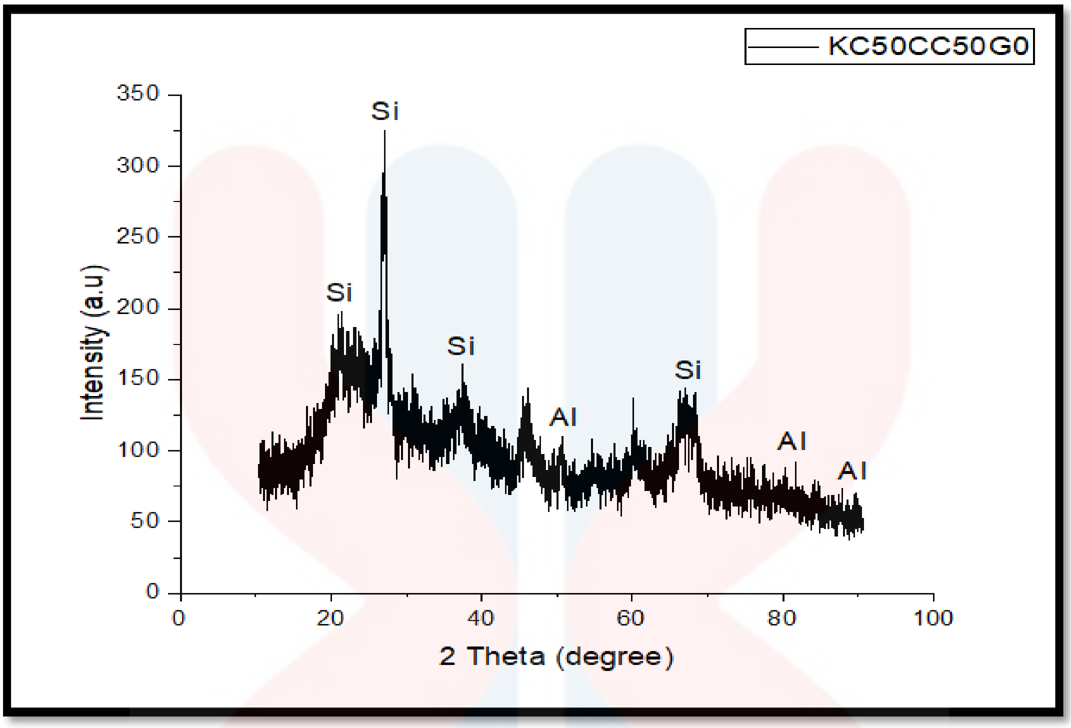

Figure 4.1: XRD pattern of KC50CC50G0

In Figure 4.2, the XRD spectra of KC50CC15G35 was measured in range if 2ϴ = 10° to 90°. KC50CC15G35 with COD 1011176 which is quartz low and the crystalline structure is hexagonal. The lattice parameter for KC50CC15G35 of a and c are 4.9 and 5.4 respectively. according to Figure 4.2, the highes peak recorded was at 2ϴ = 26.69° (101) while the lowest peak recorded is at 2ϴ = 40.39° (111).

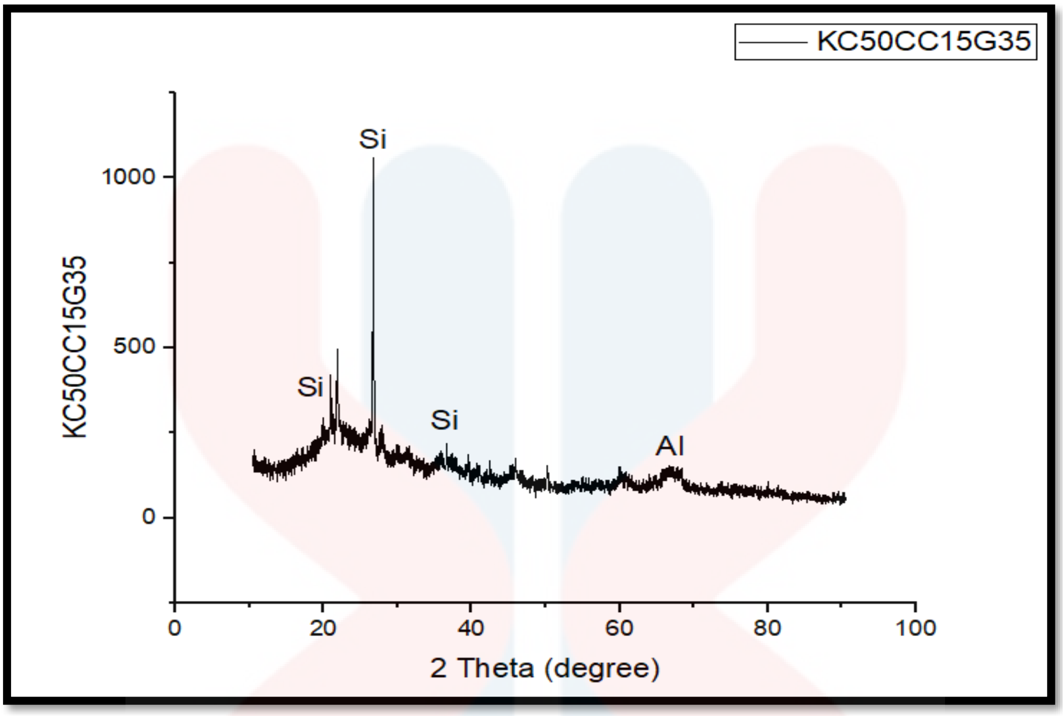

Figure 4.2: XRD pattern of KC50CC15G35

4.2 Sample of porcelain tiles Characterization

After the samples of porcelain tiles were produced, a few testing techniques were conducted to identify and determine the characterization of the final product such as XRD, water absorption, density, and porosity measurement. Figure 4.3 shows the sample of porcelain tiles after the firing process at 1000 °C and 1100 °C.

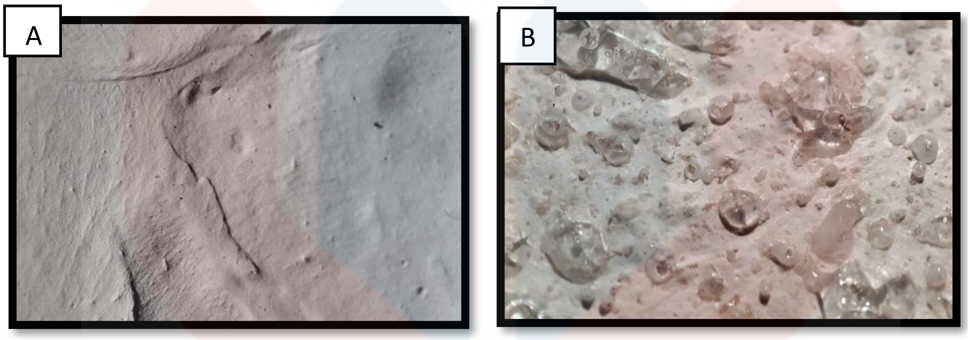

FIGURE 4.3 : The sample of porcelain tiles after firing process, (a) at 1000 °C, (b) at 1100 °C.

4.2.1 Phase Identification of Porcelain Tiles samples

In Figure 4.4, it shows XRD pattern of all porcelain tiles samples with various of composition. According to the graph, all samples peak patterns for the porcelain tiles sample have the same pattern, although there were a slight diffenrent that occurred because of the composition. Figure 4.4 illustrates that the silicon (Si) has higher peak than aluminum (Al). All of the highest peak was from Si while the remaining peak is from aluminum.

The XRD testing was measured in range of 2Θ = 10° to 90° which shown that COD 1011176 (Quartz low) as primary phase and COD 1000442 (aluminum oxide). All five samples have the same highest peak containing COD 1011176 with lattice parameter a and c are 4.9 and 5.4 respectively while the crystalline structure is hexagonal.

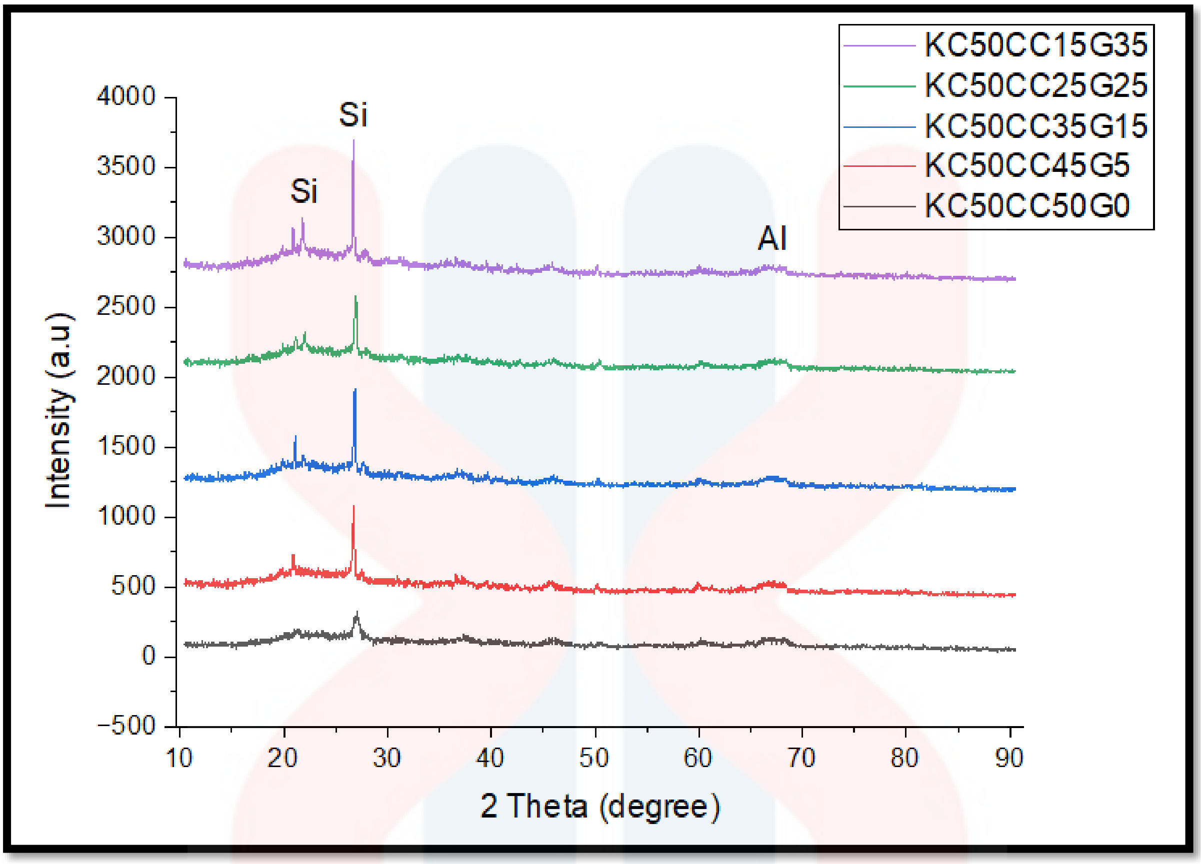

Figure 4.4: XRD pattern of all porcelain tiles samples.

4.3 Water Absorption, Bulk density, and Porosity

All the sample's water absorption, density and porosity were evaluated using measurement of density and porosity. To describe the weight under various situations as described in Equation 3.1, 3.2 and 3.3, each sample needs to be tested under three conditions which is dry weight and saturated weight in water and air for each firing temperature.

Table 4.1: Water absorption, bulk density, and porosity of the porcelain tiles samples at 1000°C firing temperatures.

Glass content (%)	Dried (g)	In air (g)	In water (g)	Water absorption (%)	bulk density(g/cm3)	Porosity (%)
0	8.505	12.053	4.826	41.64	1.176	49.13
5	5.881	8.275	3.434	40.799	1.214	49.554
15	6.849	9.195	3.964	34.28	1.308	44.86
25	7.028	9.160	4.2	30.37	1.41	42.93
35	7.954	10.219	4.663	28.474	1.432	40.806

Table 4.2: Water absorption, bulk density, and porosity of the porcelain tiles samples at 1000°C firing temperatures

Glass content (%)	Dried (g)	In air (g)	In water (g)	Water absorption (%)	Bulk density (g/cm3)	Porosity (%)
0	8.156	11.342	4.717	39.025	1.23	48.012
5	5.573	7.661	3.263	37.494	1.265	47.452
15	8.756	11.318	4.674	29.341	1.316	38.554
25	8.084	10.08	4.402	24.779	1.42	35.211
35	10.484	12.829	5.235	21.037	1.406	29.604

4.3.1 Water absorption

According to Figure 4.5, it shows that the samples with 0 wt% glass content in both firing temperature have the highest rate of water absorption which are 41.64% and 39% respectively. For the lowest rate of water absorption in both firing temperatures are at 35 wt% of glass content which are 28.474% and 21.307% respectively. It shows that with the presence of the glass content, the water absorption rate of the clay mixture decreased. It is because the glass properties were added to the clay mixture which is non-absorbent making the samples less absorbent with water as the glass content increased. The reason why the water absorption is lower when firing at 1100 °C temperature compared to 1000 °C temperature is because of the shrinkage and sintering effect. As the firing rate increases, the clay shrinks, and its particles become more compact and less absorbent.

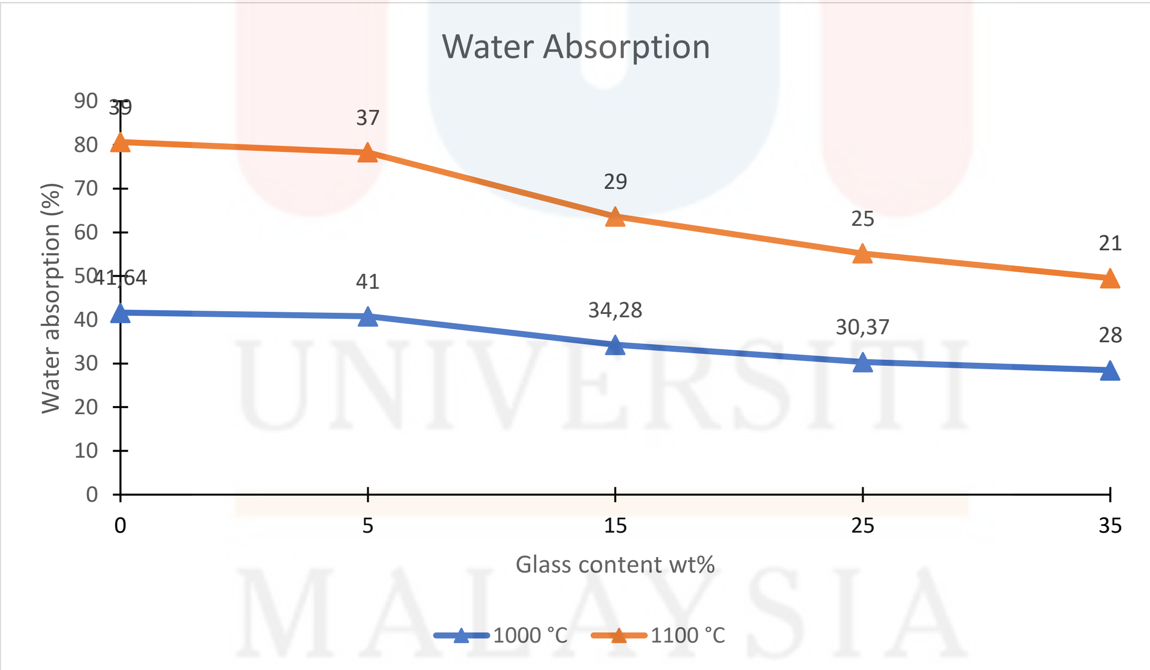

Figure 4.5: Water absorption of the porcelain tiles sample at 1000 °C and 1100 °C firing temperatures.

4.3.2 Bulk Density

In figure 4.6, the graph shows the lowest bulk density recorded for both firing temperatures are at 0 wt% glass content which are 1.176 and 1.230 respectively. The highest bulk density for 1000 °C firing temperature is at 35 wt% glass content which is 1.432 g/cm3 and for 1100 °C firing temperature is at 25 wt% glass content which is 1.420 g/cm3. The reason why the bulk density increases as the glass content wt% increases is because there is less organic matter, the subsurface layers are more compressed with less pore space. The reason why the density is higher on the 1000 °C firing temperature is because as the temperature increases, the density decreases.

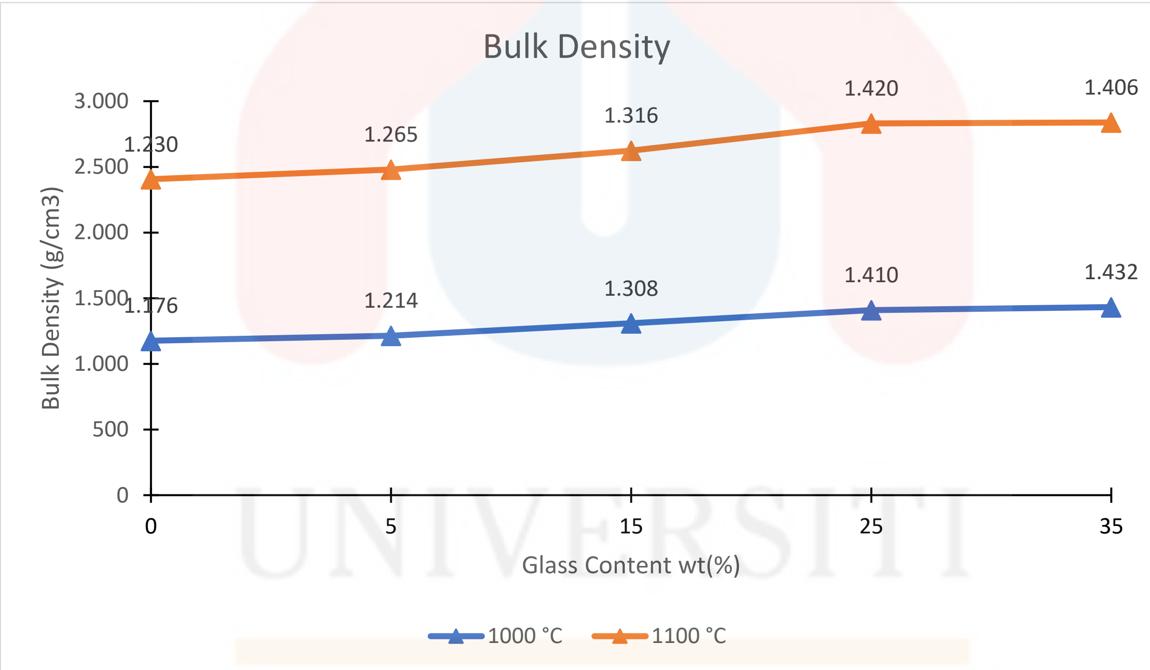

Figure 4.6: Bulk density of the porcelain tiles samples at 1000 °C and 1100 °C firing temperatures.

4.3.3 Porosity

The figure below shows the data of porosity. The highest porosity recorded was at 0% wt glass content for both firing temperature which are 49% and 48% respectively. The lowest porosity was at 35% wt for both firing temperature which are 41% and 30% respectively. The reason for the decreasing of the porosity is because of the mineral precipitation such as silica contained in grain boundaries, known as cementation. The reason why 1100 °C firing temperature has lower porosity than 1000 °C firing temperature is because the clay mixture became more compacted with the increased of the firing rate making the sample less porosity.

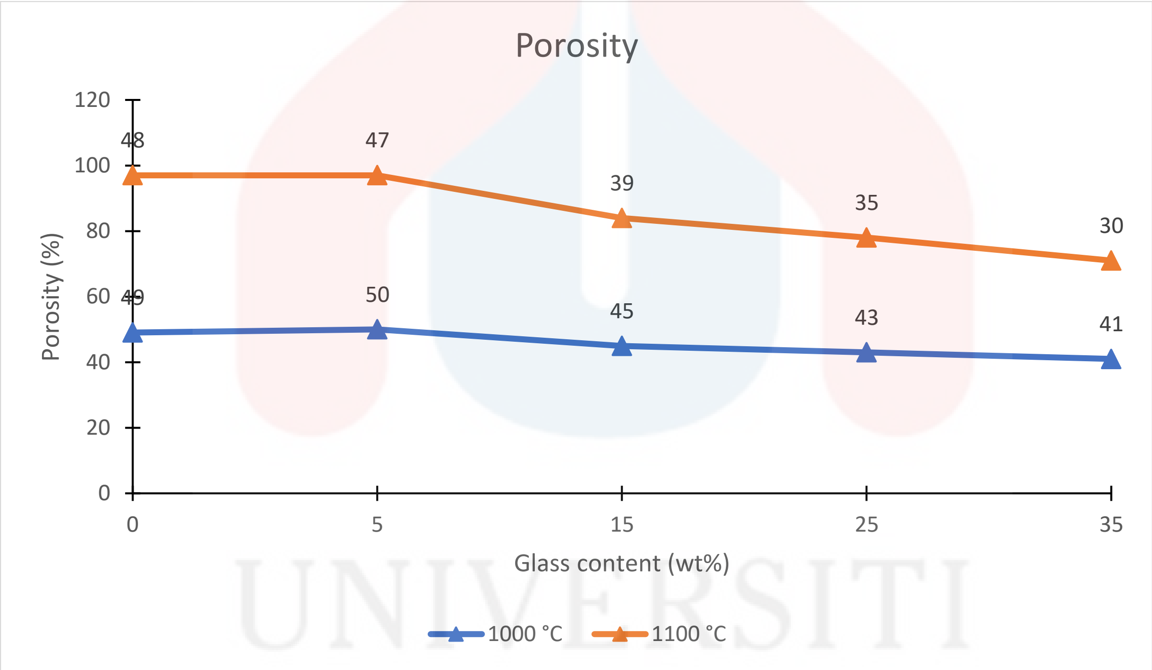

Figure 4.7: Porosity percentage of the porcelain tiles sample at 1000 °C and 1100 °C firing temperature.

4.4 Linear Shrinkage

All the sample's linear shrinkage were evaluated using the measurement of linear shrinkage. The sample dimensions are measured using caliper and the shrinkage will be calculated using Equation 3.4.

According to Figure 4.8, the highest linear shrinkage recorded was at 0% wt glass content for both firing temperatures which are 11.805 mm/m and 23.349 mm/m respectively. For the lowest linear shrinkage is at 35% wt glass content for both firing temperatures which are 2.866 mm/m and 3.881 mm/m respectively. The reason why the linear shrinkage decreased as the glass content increased is because of moisture content. When the glass was added to the clay mixture, the mixture became less absorbent with water thus rendering the moisture content. Linear shrinkage at 1100 °C has higher shrinkage than 1000 °C because of the increased in temperature.

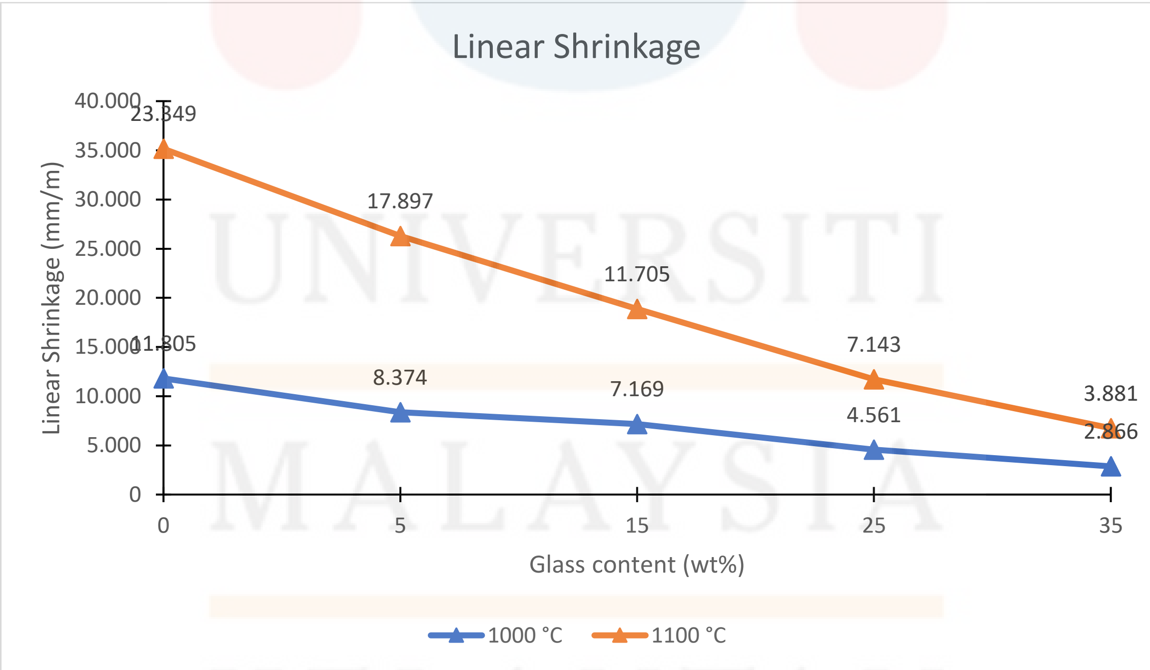

Figure 4.8: Linear shrinkage of the porcelain tiles sample at 1000 °C and 1100 °C firing temperature.

5.0 CONCLUSION

5.1 Conclusion

In this study, glass powder was added into the clay mixture of kaolin clay and china clay to make the porcelain tiles samples. The glass powder was added to see its effect on the properties and microstructure of the clay mixture.

According to the first objective of this study which is to study the effects of glass powder on the properties and microstructure of the clay mixture for porcelain stoneware tiles. When the glass was added into the clay mixture, the water absorption and porosity of the mixture decrease. The clay mixture become less absorbent with water as the glass content increase making the mixture more suitable for porcelain tiles.

For the second objective last objective which is to determine the percentage of glass waste and clay mixture to use to achieve the best properties of the porcelain tiles. As the result, the best composition recorded was clay mixture with 35 wt% glass content at 1100 °C firing temperature, which demonstrated the best result throughout all of the testing.

Every composition was examined using water absorption, density, porosity, linear shrinkage and XRD measurement to study more about the properties and characteristics of the clay mixture with glass powder added based on various composition. As a result, it demonstrates that it has the potential to produce result for any other application in the future.

In conclusion, based on all the research that have been done, all the objectives of this thesis were all successfully fulfilled. With a solid proof, it can be stated that the porcelain tiles sample with 35 wt% glass content at 1100 °C is the best. This research finding indicates that it has potential to be commercialized for industrial applications because of the enhancement of the properties.

5.2 Recommendation for a Future Research

There are a few recommendations of experiments that can be recommended for future research. Firstly, X-ray Fluorescence testing which is a non-destructive analytical method can be used for determining the constituent elements of materials. Next, Thermogravimetric analysis (TGA) which is a powerful approach for determining the thermal stability of materials, particularly polymers. This approach measures variations in the weight of a specimen as its temperature increases. TGA can quantify a sample's moisture and volatile content. Additionally, it is more conventional to use at least three different firing temperatures to produce finer results in the future. Last recommendation suggest is to use compressive test. Compression tests are used to examine a material's behavior under crushing loads. They are normally performed by applying compressive pressure to a test specimen (usually of a cuboid or cylindrical geometry) with platens or specific fixtures on a universal testing machine.

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APPENDIX A

Pattern: COD 1537396 Radiation: 1.54060 Quality: Quality Unknown

Formula O3
Name
Name (mineral)
Name (common)
Status Status Unknown
Ambient Yes

Lattice: Cubic
S.G.: I -4 3 d (220)

a = 9.86000
a/b = 1.00000
c/b = 1.00000
Z = 4

Mol. weight =
Volume [CD] = 958.59
Dx =
Dm =
I/Icor = 3.180

Primary Reference
Helms A., Klemm W., "Ueber die Kristallstrukturen der Rubidium- und Caesiumsesquioxyde", Zeitschrift fuer Anorganische und Allgemeine Chemie 242 (1939) 201-214.

Wavelength: 1.54060
SS/FOM:
Filter: Not specified
d-spacing:

d	2θ	I fix	h	k	l
4.02530	22.065	1000	1	2	1
3.48600	25.532	111	2	0	2
3.11800	28.606	316	3	0	1
2.63520	33.993	181	3	1	2
2.46500	36.419	18	0	4	0
2.20480	40.898	186	4	0	2
2.10220	42.991	115	3	2	3
2.01270	45.004	32	2	4	2
1.93370	46.951	162	5	0	1
1.80020	50.668	39	5	1	2
1.74300	52.455	8	4	0	4
1.59950	57.578	101	6	1	1
1.55900	59.221	10	6	0	2
1.52140	60.837	35	4	5	1
1.45380	63.991	14	6	1	3
1.42320	65.537	19	4	4	4
1.36730	68.579	20	6	0	4
1.34180	70.070	56	7	1	2
1.31760	71.553	8	6	2	4
1.29470	73.020	8	7	0	3
1.25220	75.927	13	7	2	3
1.23250	77.363	7	0	8	0
1.17850	81.631	15	5	6	3
1.16200	83.044	3	8	2	2
1.14620	84.450	21	8	1	3
1.11640	87.258	4	7	2	5
1.10240	88.653	2	8	0	4
1.07580	91.455	13	8	2	4
1.06320	92.856	23	9	1	2
1.05110	94.252	1	6	4	6
1.03930	95.663	14	9	0	3
1.01700	98.475	5	9	2	3

Pattern: COD 1101168 Radiation: 1.54060 Quality: Quality Unknown

Formula Al2O3
Name
Name (mineral)
Name (common)
Status Status Unknown
Ambient Yes

Lattice: Cubic
S.G.: F d -3 m (227)

Mol. weight =
Volume [CD] = 499.05
Dx =
Dm =
I/Icor = 0.990

a = 7.93200
a/b = 1.00000
c/b = 1.00000
Z = 1

Primary Reference
"St210499->St100gnn".

Wavelength : 1.54060
SS/FOM:
Filter: Not specified
d-spacing:

d	2θ	I fix	h	k	l
4.57950	19.367	115	1	1	1
2.80440	31.885	117	2	0	2
2.39160	37.578	150	1	3	1
2.28980	39.316	228	2	2	2
1.98300	45.716	994	0	4	0
1.81970	50.088	23	3	1	3
1.61910	56.817	32	2	4	2
1.52650	60.612	47	1	5	1
1.40220	66.645	1000	4	0	4
1.34080	70.130	10	5	1	3
1.25420	75.784	10	6	0	2
1.20960	79.111	10	3	5	3
1.19580	80.207	7	2	6	2
1.14490	84.569	115	4	4	4
1.11070	87.820	4	1	7	1
1.06000	93.221	10	6	2	4
1.03270	96.474	15	7	1	3
0.99150	101.956	121	0	8	0
0.96900	105.300	1	3	7	3
0.93480	110.980	4	6	0	6
0.91590	114.498	10	5	7	1
0.90990	115.682	1	6	2	6
0.88680	120.599	185	8	0	4
0.87070	124.427	3	1	9	1
0.84560	131.274	3	6	4	6
0.83150	135.760	11	9	1	3
0.80960	144.149	525	4	8	4
0.79720	150.147	3	7	1	7