EFFECT OF DEFECT SINGGORA ROOF TILES WHEN MIXED WITH CLAY FOR RECYCLING

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DECLARATION

I declare that this thesis entitled "RECYCLED OF DEFECTED SINGGORA ROOF" is the results of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted of any other degree.

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ABSTRAK

Jubin bumbung Singgora adalah jubin lembaran bumbung tradisional yang digunakan secara meluas di Kelantan dan Pattani, Thailand. Bumbung Singgora mudah rosak kerana kekuatannya yang rendah. Matlamat kajian ini adalah untuk mengkaji sifat fizikal dan mekanikal bumbung Singgora dengan campuran serbuk bumbung Singgora yang rosak. Penyelidikan ini mengkaji proses pembangunan dan pembuatan jubin bumbung Singgora dengan membuat sampel bar. Dalam penyelidikan ini, saiz zarah serbuk Singgora dikawal pada 250 μm, sama seperti tanah liat mentah. Kedua-dua bahan dicampur bersama pada komposisi dan dilabelkan sebagai 10% berat, 20% berat, 30% berat, 40% berat, dan 50% berat. Sampel dibakar pada 900 ° C selama 6 jam. Pengujian sampel dijalankan dengan mengira peratus pengecutan, ketumpatan, keliangan, dan lenturan. Sampel menunjukkan pengurangan dalam pengecutan, dengan nilai 10% berat, 7.30%, dan 4.80% untuk 50% berat. Kekuatan lenturan meningkat disebabkan oleh serbuk Singgora yang rosak bertindak sebagai pengikat, yang menghalang kerosakan daripada merebak melalui liang. Peningkatan ketara dalam kekuatan lenturan sebanyak 3.8 MPa dilihat pada 30 wt%. Walau bagaimanapun, kekuatan berkurangan antara 40% berat dan 50% berat disebabkan oleh nisbah serbuk yang tinggi. Unsur campuran telah dicirikan dengan menggunakan XRD.

ABSTRACT

Singgora roof tiles are traditional roof sheet tiles that were widely used in Kelantan and Pattani, Thailand. Singgora roofs can easily defect due to their low strength. The aim of this study was to investigate the physical and mechanical properties of Singgora title with mixed Singgora defected powder. This research examines the development and manufacturing process of the Singgora roof tiles by fabricating a bar sample. In this research, raw clay and Singgora powder were collected and crushed using a mortar, then their particle sizes were sieved to 250 µm. Both elements are mixed together at composition and labeled as 10 wt%, 20 wt%, 30 wt%, 40 wt%, and 50 wt%. The sample was fired at 900 °C for 6 hours. Sample tests were carried out by measuring the shrinkage percentage, density, porosity, and bending. The sample showed a reduction in shrinkage of 7.30% at 10 wt%, whereas the reduction was 4.80% at 50 wt%. The bending strength increased due to the defective Singgora powder acting as a binder, which prevented damage from spreading through the pores. A significant increase in bending strength of 3.8 MPa was seen at 30 wt%. However, the strength decreases between 40 wt% and 50 wt% due to the high powder ratio. The mixed elements were characterized by using XRD.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOL

%	Percentage
Wt%	Weight percentage
°C	Celsius
°	Degree
A.u.	Arbitrary Unit
Cm	centimetre
Mm	millimetre
M_d	Mass of dired air sample
M_w	Mass immersed sample in Air
M_s	Mass of immersed sample in water
L_o	Length initial of sample
L_i	length of sample after drying/firing

LIST OF ABBREVIATION

XRD	X-ray diffraction
POP	Plaster of Paris

CHAPTER 1

1 INTRODUCTION

1.1 Background Study

Originally crafted in the Pattani region of Southeast Asia, Singgora roof tiles are well-known for the unusual fish scale or seashell shape that characterizes their appearance. Clay is often used in the production of these tiles, which is followed by firing to improve the tiles' hardness and make them more waterproof.

Singgora roof tiles made from ceramic material have the brittleness had as a flaws for a variety of reasons depending on the circumstances. Warping, cracking, and firing irregularities are all examples of common faults. Warping may occur when there is not enough time for the material to dry or when there is not sufficient control over the firing temperature (Scherrer, et al., 2017).Cracks may be caused by a number of different factors, including sudden variations in temperature, inadequate clay moisture content, and uneven drying. During the firing process, temperature changes may lead to a variety of difficulties, including uneven coloration and faults in the glaze. These are just two examples of the types of issues that might arise.

Recent years have seen a shift in focus within the ceramics sector toward more ecologically friendly practices and recycling initiatives. The idea to remake the Singgora roof tiles waste are of great assistance to the company. Tiles that was damaged or rejected need to be reused or recycled and turned back into clay so that it can be used in the production of new tiles or other ceramic products. Remake activities have the potential to save expenses connected with production on several fronts, including the environment, finances, and resources.

There's attempt of remake of the ceramic industry, especially of a journal about reported in an Overview of Wastes Recycling in Fired Clay Brick written by Aeslina Abdul Kadir, 2010. The various waste materials used on fired clay brick Fly ash is a fine powder that results from the burning of coal in power plants. Bricks made from this may be stronger and less likely to shrink than those made just from clay, because to the inclusion of siliceous and aluminous elements. The experimental data work investigated the effect of four different treatments of fly ash on mechanical properties. Results showed that bricks manufactured with -40 m fly ash and fired at 950°C achieved better results in compressive strength and bending strength than other bricks.

Singgora roof tiles have a unique look due to their forms, clays, high temperatures, and treatments on the outside. Singgora roof tiles are made to handle normal weather conditions and work well in normal temperatures. However, if they are exposed to temperatures that are too high, they could break or get damaged. The exact temperature at which something breaks can depend on how the clay was made and how it was fired when it was made. At very high temperatures, clay can start to vitrify, which means it turns into glass and loses its shape. It is important to make sure that the temperature at which Singgora tiles are fired is in the right range for proper verification and strength development. Extreme heat, like that from large fires or industrial processes, can be too much for these tiles to handle and could cause them to break.

The causes of defects, recycling options, and identifying characteristics of Singgora roof tiles is essential for businesses to sustainably expand and maintain their product. Craftsmen can increase the durability and environmental sustainability of Singgora roof tiles while still maintaining their cultural heritage and aesthetic value. This can be done by repairing faults, implementing recycling techniques, and identifying the tiles' unique traits.

1.2 Problem Statements

The defect in Singgora roof tiles manufacturing could be identified by analysing what went wrong with Singgora roof tiles during manufacturing and how they may be fixed to make the process more reliable and long-lasting. Common reasons for failure include using an unreliable clay combination, firing at the wrong temperature, applying the glaze poorly, not giving the piece enough time to cure, or mishandling it (Bennett & Pinion, 2015). When Singgora roof tiles break during manufacturing, it may cost businesses a lot of money and threaten the long-term viability of the business. Tiles that are damaged or useless must be thrown away, which may add to pollution and increase manufacturing costs. To avoid that, Singgora roof tiles need to be recycled. In order to increase the durability and quality of Singgora roof tiles, it is crucial to determine what goes wrong during manufacture and fix it. The quality of the recycled Singgora roof tiles will rise a worry its quality can give the same as non-defected Singgora roof tiles be determined by lab testing and learning the characteristics that make whatever it’s good to use for building construction.

1.2.1 Objective

I. To fabricate the recycle roof tiles by varying the wt% of recycle clay.

II. To characterize the recycle roof tiles by its shrinkage, density, porosity, phase formation, and strength.

1.3 Scope of Study

The study's goals are to understand better on how to recycle Singgora roof tiles with defects, what factors contribute to failures in the manufacturing of Singgora roof tiles, and how to avoid the defects. The quality and performance of Singgora roof tiles will be evaluated via laboratory studies, with an emphasis on clay mixing, molding, drying, and firing stages of production (Pongdet, 2017). The percentage of fire shrinkage of Singgora roof tiles, as well as their density, porosity, strength, and measurement of clay samples, X-Ray diffraction analysis (XRD) and compared to the firing shrinkage of both new and recycled tiles. This research may lead to more sustainable and less expensive approaches to produce Singgora roof tiles. The identification and correction of defects in production may boost product quality, cut down on waste, and increase sustainability. Singgora roof tiles that have been recycled would be of the same quality as their non-remake versions.

1.4 Significance of Study

This study has the potential to inform new methods of creating Singgora roof tiles that are both environmentally friendly and cost-effective. Manufacturers could enhance product consistency and quality, minimize waste, and achieve sustainability benefits by recognizing and resolving the reasons for production failures. There shouldn't be any obvious difference in quality between these remake Singgora roof tiles and the original, unbroken tiles.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Ceramic

The term "ceramic" refers to a wide group of inorganic, non-metallic materials that are produced by synthesis at high temperatures. Clay, silica, alumina, and several other minerals are some of the many potential components that might go into the creation of ceramics. After the components have been mixed together, the next step is to mold or cast them into the desired form, which is then followed by a high-temperature fire or sintering process. The word ceramic comes from the Ancient Greek word κεραμικός (keramikós), meaning "of or for pottery (Lidddel & Scott, 2001) The earliest known mention of the root ceram- is the Mycenaean Greek ke-ra-me-we, workers of ceramic (palaeolexicon, 2011). The word ceramic can be used as an adjective to describe a material, product or process, or it may be used as a noun, either singular, or more commonly, as plural noun ceramics. From everyday goods like pottery and tiles to cutting-edge ones like electrical components, aircraft gear, dental implants, and high-performance engineering materials, ceramics have been put to use in a wide variety of ways over the course of thousands of years.

There's a huge selection of ceramics, such as advances ceramic and traditional ceramic and they all have their own special properties and chemical make-up. Some examples include earthenware, stoneware, porcelain, refractories, technological ceramics, and bio ceramics.

2.2 Advanced Ceramic

Advanced ceramic is an evolved version of traditional ceramic. Advanced ceramics represent an "advancement" over traditional definitions. The "advanced" definition of the material is required. This definition has been supplied by Mason, Versailles Project on Advanced Materials and Standards, 2011, which described an advanced ceramic as "an inorganic, non-metallic (ceramic) material." Through the application of a modern materials science approach, new materials or combinations of existing materials have been designed that exhibit surprising variations on the properties traditionally ascribed to ceramics. This has resulted in ceramic products that are as tough and electrically conductive as some metals (Ayode Otitoju, et al., 2020).

Advances in advanced ceramic processing continue at a rapid pace, constituting a revolution in the kind of materials and properties obtained. Engineers and scientists have succeeded in creating ceramic materials with superior mechanical strength, hardness, and wear resistance compared to traditional ceramics. Materials such as silicon carbide and alumina-toughened zirconia exhibit exceptional properties that make them highly desirable for applications in cutting tools, automotive components, and high-temperature environments.

The advancement of technology has been the driving force behind the development of ceramics technology because natural materials have proven inadequate to keep up with the ever-increasing demands placed on product capabilities and functions. Synthesizing new materials to enhance or alter the qualities of naturally existing materials was a common practice among ancient people, and fire was a common tool for this purpose. The development of the furnace sparked seismic shifts in the fields of metalworking, glassmaking, and ceramics (Liang & Dutta, 2001)

2.3 Traditional Ceramic

Traditional ceramics are those made from more common raw resources like clay minerals and quartz sand. China dinnerware, clay building materials including bricks and tiles, abrasives and refractory linings, and Portland cement are all created from these elements via industrial methods. Mined and processed raw materials, moulded into the appropriate form using processes like moulding, throwing, or casting, dried to eliminate moisture, and burned in kilns at particular temperatures: these are the stages required to produce conventional ceramics. Traditional ceramics have been utilized by cultures all over the globe to make anything from everyday objects to sacred relics and works of art. The preservation of cultural traditions and skilled workmanship has been ensured through the transmission of traditional ceramic skills from one generation to the next.

The research of Folasayo Enoch Olalere, 2012 in journal The Act of Mass Production in Kelantan Traditional Pottery, Malaysia make a theory about on the evolution of the cultures that made or acquired ceramic artifacts have benefited greatly from this field of research. Originally from the Hindu and Buddhist traditions, the traditional pottery of Kelantan state in Malaysia was impacted by the arrival of Islam in the 10th century and European colonial power such as the Portuguese, Dutch, and British. Traditional Malay society has always valued the ceramic arts alongside the development of practical products.

Traditional pottery from Kelantan is well-known for its practical use and its inherent connection to local talent. The study from that researcher explores and evaluates the evolution of Malay ceramics right up to contemporary Kelantanese ceramics, as well as the methods and procedures employed for industrial-scale manufacturing in Kelantanese traditional ceramics.

Islam, Hindu, Chinese, British, Buddhist, art all have their roots in Malaysia. However, local potters were unaffected by the increasing number of foreign influences, especially those coming from China about 1100 A.D. The Malay creative process was quite basic; they used basic tools and burned their ceramics at regular temperatures without any kind of control. Due to a lack of knowledge and competence in high fire procedures and quality materials like porcelain, bone china, and stoneware, the cottage industry of pottery continues to thrive in modern Malaysia (Ewins, 2017).

2.4 Clay

Clays material was widely use in ceramic industry. This material was cheap and easy to be obtained naturally almost everywhere around the worlds. Clay minerals like kaolinite ($A1_2Si_2O_5\,[OH]_{4)}$ are secondary geologic deposits created by water, dissolved carbon dioxide, and organic acids weathering igneous rocks while Muscovite $KAl_2(Si_3Al)O_{10}(OH)_2$ is an aluminum phyllosilicate mineral with a clear to translucent sheen. It is the lightest-colored mica mineral, typically colorless, white, or silver. It is found in igneous, metamorphic, and sedimentary rocks, with its main presence in granitic rocks. It develops through regional metamorphism of clay-rich rocks, transforming clay minerals into mica grains. Muscovite is a widely distributed mineral and is used as an electrical and thermal insulator in various industries, including rubber, wallpaper, plastics, paints, ceramics, paper industries, plasters, and roof coverings. (Mason, 2016). Clay minerals are the principal source of alum inosilicates and feature plate-shaped particles on the micrometer scale due to their layered crystal structures. The rheology of a combination containing these particles in water is significantly altered, allowing for a wide variety of processing techniques, including slip casting and plastic shaping. Clay minerals are regarded as formers since they facilitate the shaping of the blended materials. The process of clay extraction is the technique of obtaining clay from underground or surface deposits. It is extracted from sedimentary or igneous rock formations with the use of mechanical or human effort. The first step in preparing clay is to eliminate all sources of moisture and contaminants. Blending clay is the method of merging many clay sources into one with a uniform composition and higher quality. Clay modelling is the art of moulding clay into different shapes.

The last step in creating a clay item is drying it so that any moisture is gone. Firing is the process of exposing the dry clay piece to high temperatures in order to turn it into a hardened ceramic. The last step in creating a pottery is decoration and finishing, which includes giving the object colour, texture, and any other finishing touches the artist deems necessary.

2.5 Singgora Roof Tiles

The Singgora roof is a classic Malay architectural style. Originally called Singgora, Pattani is a city in southern Thailand. This city became well-known throughout all of Southeast Asia for producing the distinctive Singgora roof tiles. Traditional Malay homes often have the Singgora roof because of its weather resilience, longevity, and aesthetic appeal. Singgora, a roof made of clay on foot, comes from the Malay name Singgora, which means "Lion City," and was physically Singgora, taken from the appearance of fish scales. It is well known in East Coast states and Thailand, as stated in the article Preservation of Malay Singgora Roof (Harun, 2013).

Singgora roof tiles are made from clay and require the use of both legs during the shaping process. They are popular in the eastern states of Kelantan and Terengganu, but their popularity has since waned due to the widespread availability and low cost of more contemporary roofing materials. They are good for the environment since they are created from natural clay and can be recycled once they have fulfilled their function (Abdullah, et al., 2021).

The tiles are distinctive due to their rounded shape, interlocking design, and elaborate surface patterns, which provide aesthetic appeal and shed light on the region's artistic and cultural heritage. Singgora roof tiles are widely used in Southeast Asian architecture and must be carefully preserved to ensure the preservation of the region's unique architectural style. Singgora roofs are common on traditional Malay dwellings for their durability, endurance, and aesthetic appeal. The slope of the roof prevents water from pooling and seeping into the structure. Singgora roof tiles are often used in Southeast Asian architecture because of its distinctive design and aesthetic.

2.6 Remake

Materials that can be recycled are those that have been transformed into something new via the use of a remake mechanism. Remaking is the process of extracting usable elements from waste and reprocessing them so that they can be used again in production. Paper, cardboard, plastic, metal, and glass containers are examples of common objects that may be remaked. When individuals and corporations take steps to minimize waste and increase recycling rates, they provide opportunities for considerable cost savings in the areas of resources, energy, and landfill garbage. It may also be possible to cut down on the amount of waste sent to landfills (Yuan, Robert, Mohajerani, Tran, & Pramanik, 2022).

Remake is an essential component of environmentally responsible waste management techniques and makes a contribution to the concept of a circular economy. This can also be applied in the ceramic industry when the material, such as Singgora roof tiles, can be remake, which can reduce labour costs so the industry can make a good new Singgora roof title.

A study was carried out by Subashi De Silva and Mallwattha (2018) as part of their recycling research. Investigations on the viability of fabricating roof tiles using ceramic sludge rather than clay are part of the larger effort to recycle clay roofs. In a production environment, tile samples were made with different levels of sludge. The qualities of resilience, longevity, and water drainage were examined. One useful feature of roof tiles, according to the study, is that their bulk density drops as the concentration of sludge rises. The maximum transverse breaking strength, which is a 22.9% increase over ordinary tiles, was achieved at 20% sludge. A maximum of 20% clay replacement is allowed to meet the water absorption and penetration standards. The efflorescence and sulfuric acid attacks did not damage the specimens. The research showed that the tiles containing 20% sludge decreased interior temperatures by 2.8 degrees Celsius, making them a more pleasant option than regular roof tiles. The runoff from a roof with 25% sludge incorporation exhibited a total solid content of 120.2 mg/l, a pH of 7.36, and a BOD5 of 5 mg/l. The conditions were ideal for rainwater collection.

Standard limitations of run-off characteristics were met while tiles had improved structural, durability, and thermal features above traditional tiles. At the industrial factory, workers threw raw materials together by hand, then pressed the clay mixture into cuboidal plates using an electrical machine, and finally fired the tiles. Tiles were trimmed while still wet so they could be molded into the desired form. After 12 hours of natural drying with smoke moving through the flues and a rising fire temperature from bottom to top, the tiles were removed from the kiln and allowed to cool to room temperature (TARHAN, TARHAN, & AYDIN, 2021).

CHAPTER 3

3 MATERIALS AND METHODS

3.1 Materials

The main materials used in this research were defect Singgora roof tiles that were turned into powder, and clay obtained from the Singgora industry area of Bachok Kelantan. Other than that, there was be mould for the Singgora sample that was prepared by using plaster of Paris.

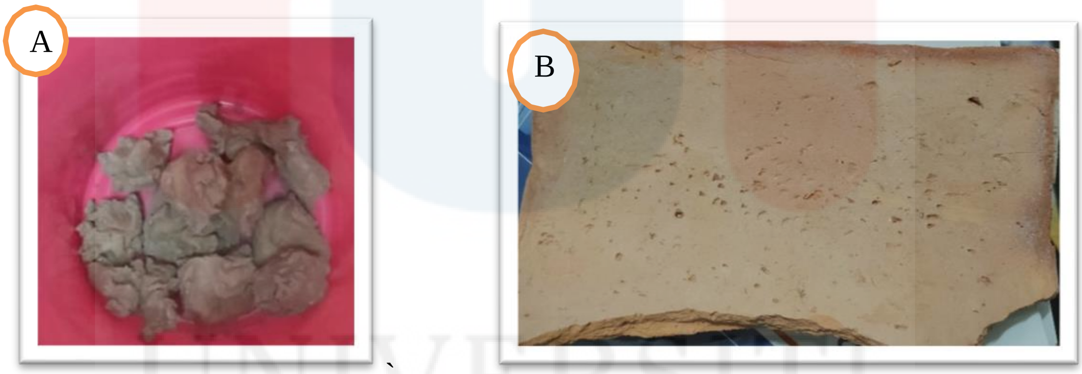

Figure 3.1: The picture of (A) raw clay and (B) defect Singgora.

3.2 Methods

The first thing that has to be done in order to make Singgora roof tiles is to choose high-quality clay that can be shaped without much difficulty. Because it is brought to the appropriate consistency by mixing it with water, it may simply and rapidly shape this clay. Singgora tiles are easily differentiated from other types of tiles due to its distinctive form, which is achieved via the manufacturing process by using Plaster of Paris moulds (POP). The mould that was utilized to make each tile was created to appropriately Singgora roof tiles.

After they have been shaped, the tiles undergo a process known as air-drying in the open air, which may take anywhere between just a couple of days to several weeks, according to the weather. This vital phase is necessary for getting the right hardness and sturdiness of the clay used in the tiles in order to ensure long-lasting use. After being allowed to cure, the ceramic tiles are very carefully put into kilns, where they were put to extremely high temperatures while being carefully supervised. Once going through the process of fire, the clay transforms into a ceramic substance that is able to withstand the extreme climatic conditions that are common in Malaysia.

Figure 3.2: The defect Singgora tiles were crushed.

3.2.1 Raw Material preparation

The defect Singgora roof title was ground into powder and dried to manufacture a new one. The damaged roof tiles were being crushed into powder together with raw Singgora clay, called “grog” (Lesley, 2019).

In order to acquire the powder, the collected raw Singgora clay must be dried using sunlight directly. Once the raw clay had fully dried, it was crushed into a fine powder using a mortar. Subsequently, the powder was sieved using a 250-micron sieve to remove any undesired particles.

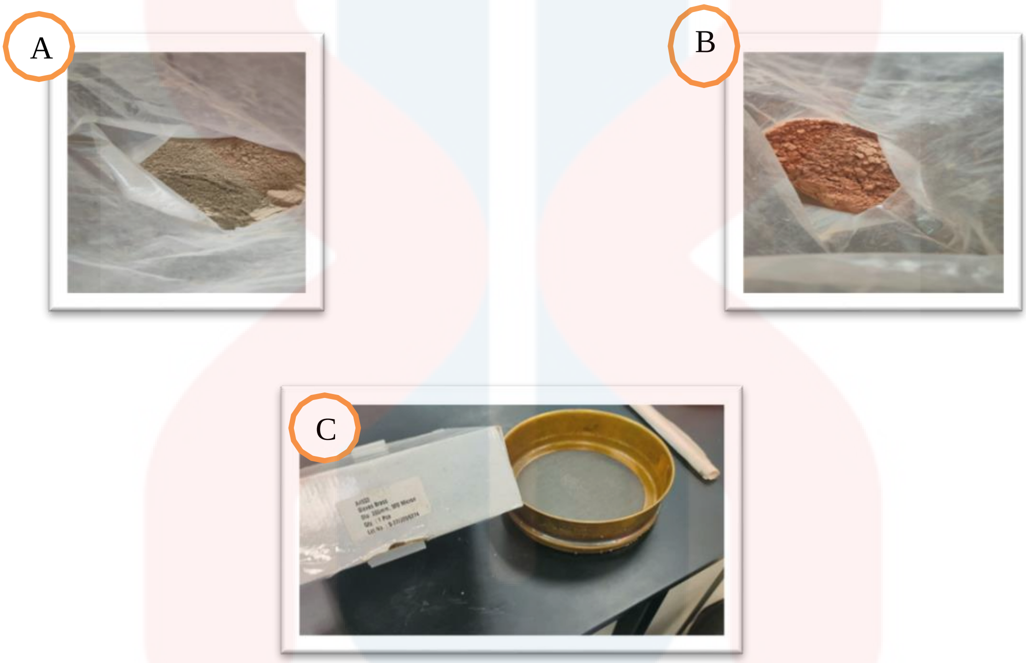

Figure 3.3: Picture of (A) raw clay powder, (B) Defective Singgora powder and (C) 250 micron sieved powder

Table 3.1: Ratio defected roof clay powder mix with raw Singgora clay.

Defected roof clay powder	**Raw Singgora clay**	**Wt%**
10 grams	90 grams	10 %
20 gram	80 grams	20 %
30 gram	70 grams	30 %
40 gram	60 grams	40 %
50 gram	50 grams	50 %

3.2.2 Clay casting process

The process of Ceramic creation involves moulding, selecting a clay body, mixing with water, applying a release agent, pouring and casting, draining excess clay, and shaping the sample into bar shapes. Careful handling is necessary as clay is easily breakable.

Plaster of Paris or Pop is going to be used as a mould; aspects to consider are the desired Singgora pop mould's design and dimensions, mould material preparation, release, and demoulding, mould preparation and polishing, and casting. The mould started with POP powder mixing with water with half of weight POP ratio 2:1. Finally, pour the plaster of Paris mixture into the mould and allow it to cure for the desired amount of time The sample clone was 17cm in length, 3.0 cm in width, and 1.5 cm in thickness. The POP mould needed to be fully dried before it was used.

Figure 3.4: the picture of POP mould

Once the mold is prepared, the next step is to create the slip. The slip is a liquid mixture of clay and water, and achieving the right consistency is essential for a successful casting. The slip must flow smoothly and evenly into the mold while allowing the clay particles to settle uniformly during the casting process. Achieving uniform thickness and quality in the cast item is contingent upon maintaining consistency in the slip.

The combination of clay that is put into plaster of Paris (pop) reveals bubbles on the surface that need to pop out using a sharp stick to minimize the porosity on the sample surface, as in picture (C). The sample fabriacted into a bar form instead of producing the original singgora roof sheet. In industry, singgora roof sheets are created using wooden mould. However, this study employs plaster of Paris (pop) mould.

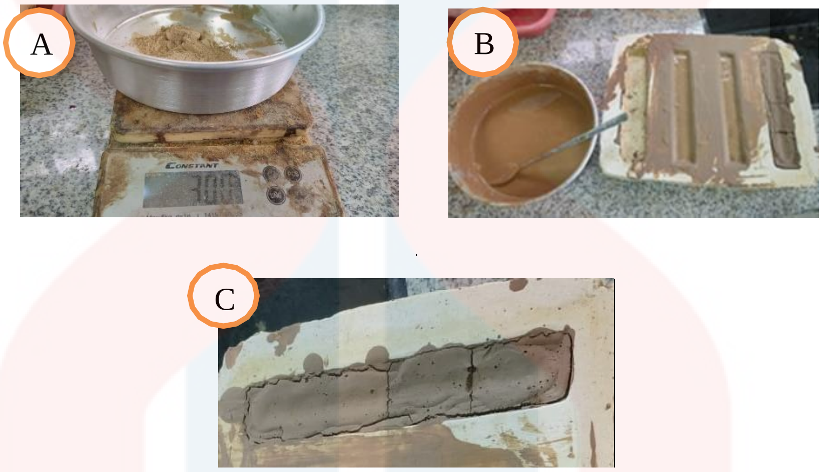

Figure 3.5: the image (A) weigh powder, (B) mixes powder into pop, and (C) shows sample bar bubbles on surface.

3.2.3 Firing preparation

The sample was dried under sunlight for several days, and any contaminant was removed to prevent damage to the final product. The sample was dried and then fired in a furnace at 900 °C for 6 hours. The firing preparation was held at the Singgora Roof Industry to make the final product. This traditional method employs a mixture of clay and water to enhance plasticity. The plasticity of clay is influenced by the morphology of plate-like clay mineral particles, which slide over each other with water acting as a lubricant (Andrade, al-Quresh, & Hotza, 2011).

Commencing the slip casting process involves crafting a plaster mold, commonly made of plaster of Paris, utilizing a metal-shaped bar as the desired object's model. This bar serves as the foundation for the mold and is integral to the slip casting's success, as the plaster mold dictates the final shape of the bar.

After being dried out under sunlight, the sample needs to be carefully taken out because the clay is very fragile because during drying is due to water loss and stresses. The dried sample will be put into electric furnace and fired tat 900°C for 6 hours, same as mentioned by Abdullah, 2014 in assessment on production quality of traditional Singgora tiles in Malaysia. Theas some resctrition using eletcric furnace where the rate of heating and cooling cannot be set After 6 hours, the furance will start to cooling off and the rate is unknonw.

The Figure 3.6 shows that there was a colour changes before and after being fired. The sample colour was changed from grey to reddish colour same like Singgora original roof. The reddish colour in ceramic mean indidcated fired, it goes through both physical and chemical transformations. One of these changes involves iron oxide, which may either undergo reduction or oxidation processes depending on the environment within the kiln. Iron exhibits a reddish or orange colour in the presence of an oxidizing environment (Monteiro & Fontes Vieira, 2004)

Figure 3.6: Picture (A) before, picture (B) after fired in furnace.

3.3 Sample Characterization.

The remake Singgora roof tiles were characterized before and after the firing process by examining their physical properties and drying shrinkage of the sample. The characterization was done by RR (Remake clay) using the ratios shown in Table 3.1.

3.3.1 Percentage of drying shrinkage.

The shrinkage process was related to the composition of water present in clay. A higher composition in clay gave a rapid rate of shrinkage. The percentage of linear shrinkage of the sample could be calculated by using this:

$$\text{Percentage if shrinkage of sample } = \frac{L0-L1}{L0} \times 100\%$$

Where

L_0= length initial of sample

L_1= length of sample after drying or firing.

3.3.2 Density and Porosity of Clay Sample

It was discovered that the density of a ceramic product is connected to its level of porosity. The fact that the ceramic product had the lowest density meant that it had the maximum porosity. In addition to that, the density provides information on the compatibility of the ceramic product. This examination was being carried out in accordance with the ASTM standard C373-88 (2006). Standard Test Method for the Water Absorption, Bulk

Density, and Apparent Porosity of Fired White Ware Products After that, the sample was going to be submerged in water, and the air bubble was going to be eliminated. A desiccator is going to be used to ensure that all of the air bubbles have been eliminated. Using Archimedes' principle as a guide, we determined the weight of the sample by measuring its density using a density kit:

The bulk density was calculated by using this equation,

$$\text{Bulk density, p} = \frac{M_d}{M_w - M_s} \text{ x rho}$$

The percentages of porosity also calculated by using this equation

$$\text{Porosity, p} = \frac{M_w - M_d}{M_w - M_s} \text{ x } 100\%$$

Where

M_d = mass of dried air sample

M_W = mass of immersed sample in air

M_S = mass of immersed sample in water

rho Water = density of water, 0.9982 kg/cm3

Figure 3.7: Density kit

3.3.3 Strength and Measurement of Clay Sample

The procedure known as modulus of rupture (MOR) is a method to test the strength of a sample using a 2-point bending machine and the ASTM C1161-02C Standard Test Method for Flexural Strength of Advanced Ceramic at Ambient Temperature. The mould's specifications should be bigger than the standard that was used for the test.

3.3.4 XRD Analysis

XRD is a non-destructive instrument that can identify and analyse all types of substances, such as fluids, powders, and crystals. The crystallographic structure of Singgora tiles, their composition, the presence of phase transformations or defects, the relationship between crystal structure and material properties, and the association between specific crystalline phases and the tiles' aesthetic or functional characteristics are among the most important pieces of information. The properties and function of materials depend on the 3D atomic structure of crystalline solids.

The X-ray diffraction technique relied on Bragg's law, with the sample being prepared into a powder form. XRD analysis was performed using Bruker's X-Ray diffraction and Scattering instrument in step scan mode, typically commencing from 19° (2θ). Subsequently, the diffract-EVA software was employed to analyse the XRD pattern. These procedural details are crucial for comprehending the construction process of Singgora roof tiles.

CHAPTER 4

4 RESULT AND DICUSSION

4.1 Introduction

Based on the experiment, the results were discussed in this chapter. Certain aspects of the results were described in the table, figures, and graph. The study showed that the materials were characterized their properties, such as the density and porosity, modulus of rupture (bending test), and phase identification (XRD).

4.2 Sample Characterization

The sample preparation included combining damaged Singgora roof tiles with raw clay, as detailed in Table 1. A total of 20 samples were created using various ratios, with five samples per ratio to ensure thorough preparation. It was acknowledged that not all samples might yield excellent results. The clay and Singgora powder were sieved and individually weighed before being mixed. The mixing process adhered to the specified water-to-weight ratio.

4.3 Phase Identifications

Figure 4.1 depicts the XRD pattern of the phase-identified sample ratio, revealing the mineral composition for the sample mixed with defect Singgora powder. The discernible minerals include quartz, muscovite, and kaolinite. Notably, the multiple peaks of quartz in each sample indicate a change in chemical composition due to firing in an electric furnace. Quartz is identified as SiO_2, and its highest intensity peak occurs at 26–27° degrees. However, the peak intensities across all samples lower intensities, likely attributed to the relatively short firing time of 6 hours at 900 °C.

Kaolinite's presence in the pattern is subdued as it decomposes at 300 °C (Yan, et al., 2017). The minor peak observed for the sample 10 wt% represents the only discernible indication in the pattern. Muscovite, despite decomposing at 800 °C, exhibits small intensity peaks in each sample. The amorphous phase introduces variations among the different ratios.

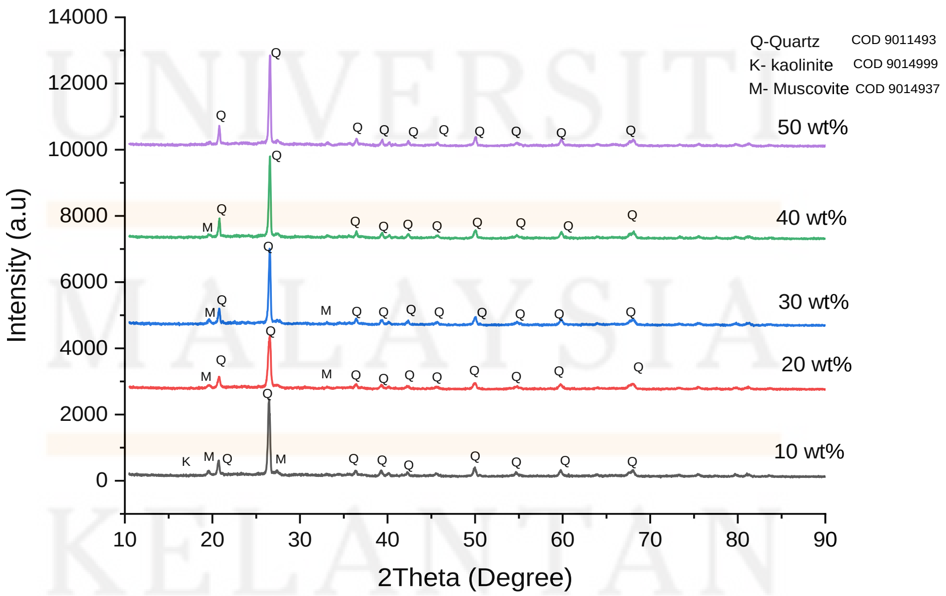

Figure 4.1: XRD pattern graph

4.4 Shrinkage

The clay was shrink during the drying process because the water inside the clay has dried and won't maintain its original measurement. Clay undergoes shrinkage when it dries and is fired, resulting from the loss of water from its layers. Uneven drying rates create internal tensions in clay, leading to fractures or deformations. To prevent this, it's essential to maintain consistent thickness, facilitate gradual drying, and minimize drying speed. Measurements of the sample bar were taken during drying, and the shrinkage of the sample can be calculated using the formula in equation at 3.3.1.

As the graph in Figure 4.2 showed, the sample ratio of 10 wt% lost about 7.30% of its original size, while 20 wt% lost 7.22% and 30 wt% lost 7.10%. There was about a 10% difference in value between them. For 40 wt%, the graph goes down to showing a loss of about 6.20% and goes lower for 50 wt%, losing about 4.80%. The graph showed descending order; the higher the amount of mixing raw clay with Singgora powder (grog), the less shrinkage is due to chemical and physical changes, such as drying out residual moisture, evaporating, which is rich in organic carbons, producing gases during furnace fires, necessitating ventilation and dehydration to break the chemical bond between clay and water, and releasing water molecules (Lesley, 2021)

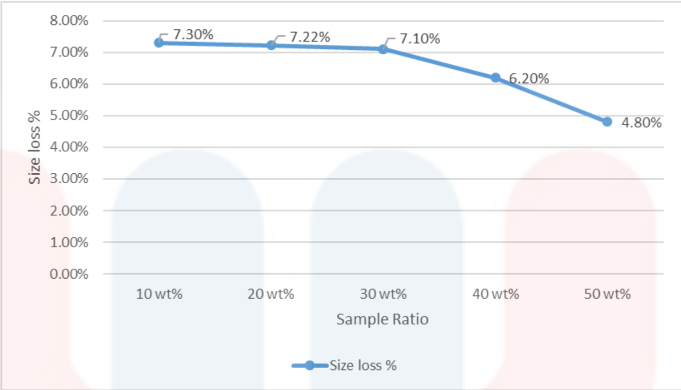

Figure 4.2: shrinkage of sample with increasing of grog.

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4.5 Density and Porosity test

Porosity and density are interrelated. High-porosity materials exhibit lower density due to increased empty space, whereas low-porosity materials demonstrate higher density due to less void space. The sample was tested using a machine, as shown in the Figure 3.7 The data provided needs to be calculated using the method outlined in section 3.3.2 to obtain the density and porosity result.

The graph shows in Figure 4.3 that the density of a material starts at 2.23 g/cm^3 for sample 10 wt% and decreases to 2.13 g/cm^3 for sample 20 wt%'. It then increases to 2.24 g/cm^3 for sample 30 wt%, 2.28 g/cm^3 for sample 40 wt%, and 2.32 g/cm^3 for sample 50 wt%. The porosity percentage initiates at 23% for the 10 wt% sample, then decreases to 22% with the 20 wt% sample. It slightly decreases to 20% for the 30 wt% sample, followed by a further decrease to 19.8% with the 40 wt% sample. Finally, it decreased to the lowest point at 18.5% for the 50 wt% sample.

The graph demonstrates an inverse relationship between density and porosity, with increased density resulting in decreased porosity. This trend is common in materials; as porous materials generally have a lower density due to more void space. The sharp decrease in density from sample 10 wt% to 20 wt% correlates with increased porosity, indicating that sample 20 wt% is more porous and less dense. This is because improperly preparing the sample of 20 wt% causes a lot of moisture reduction inside the sample, especially when firing.

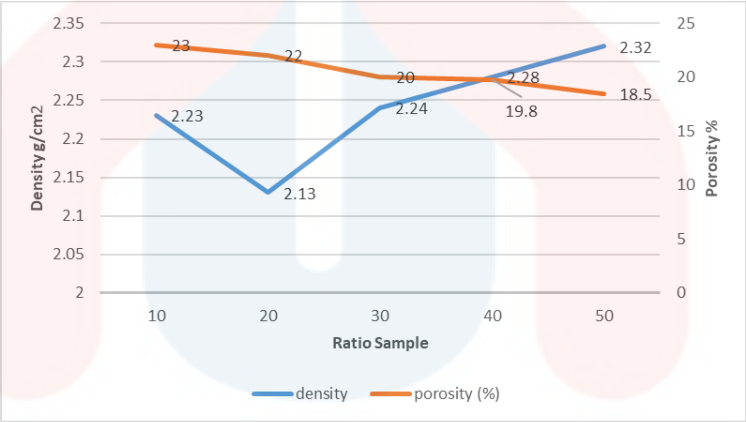

Figure 4.3: Graph density and porosity of different composition of grog.

4.6 Modulus of Rupture Test (Bending)

The Modulus of Rupture is the material's maximum bending stress before yielding, also known as its tensile strength. It measures the member's strength against the tensile stress acting on it. Concrete's modulus of rupture is a crucial design parameter, indicating its strength against transverse load and its tensile strength in the tension zone. It is a measure of the material's resilience and ability to withstand bending. The bar chart depicts the flexural strength of clay ceramics across various composition ratios. The trend exhibits a fluctuating reaction in flexural strength when the percentage of a certain material or treatment in the ceramic blend is modified. For the sample with 10 wt% defect Singgora, the bending strength was at 3.32 MPa. This finding indicates that the ceramic composition at this particular level has been finely tuned to enhance its ability to resist bending. This is likely achieved by adding the grog Singgora powder to raw clay and mixing it. However, once the defect Singgora powder was added for 20 wt%, there is an obvious decrease in bending strength which is decrease to 2 MPa. The decrease may be attributed to many factors, including the change in the ratio may have disrupted the equilibrium between clay and other constituents, negatively impacting the ceramic composition.

A higher porosity at this ratio may have led to a ceramic structure that is less dense and thus less strong. This may be attributed to increased air or water content in the mixture, the combustion of organic substances, or insufficient compaction. Additionally, there might be an increased occurrence of microstructural imperfections such as micro cracks or vacancies, which act as points of stress concentration and diminish the strength of the material. Upon reaching a ratio of 30 wt%, a notable surge in bending strength was noticed which is 3.8 MPa. This signifies the optimal composition or treatment for achieving the highest level of resistance to bending.

This peak may be attributed to the optimal composition of non-clay substances, such as feldspar or silica, in terms of their percentage. These materials have the potential to create glassy phases that strongly bind the clay particles together when heated, resulting in decreased porosity and increased strength. After reaching the ideal point, which occurs at ratios of 40 wt% and 50 wt%, there is a noticeable decline in strength. The strength measurements at these ratios are 2.52 MPa and 2.31 MPa, respectively. The drop means that the ceramic composition isn't as good at withstanding bending pressures. This could be because too many additional clay defected powder can cause flaws or weaken the ceramic's. The bending strength of the clay ceramic is greatly influenced by the particular composition or treatment used at each ratio. The optimal bending strength is attained when the materials are balanced in a 30 wt% ratio, resulting in the most effective contribution to strength. When the ratio is below 30 wt%, the combination may not have enough reinforcing components; however, a larger ratio like 40-50 wt% may result in brittleness or other types of structural compromise. The graph clearly demonstrates the crucial role that the balance of components plays in determining the strength and performance of clay ceramics when tested with bending stress.

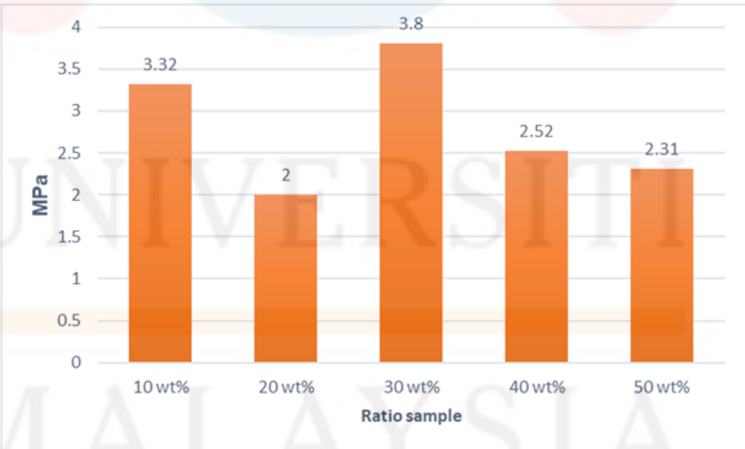

Figure 4.4: graph modulus of rupture different composition of grog (wt%).

CHAPTER 5

5 CONCLUSION AND RECOMMEDATION

5.1 Conclusion

In conclusion, the research for this final year's project on recycled Singgora roofs helped me understand and explore more about ceramic. The experimental investigation fabricated the recycled roof tiles by varying the wt% of raw clay with defected roof tiles. The traditional method employed focused on optimizing clay plasticity through careful manipulation of clay-water ratios. Characterize the recycled roof tiles by their shrinkage, density, porosity, phase formation, and strength.

The study used POP molds to create clay samples, which were dried before firing at 900°C for 6 hours in an electric furnace. The clay samples showed significant physical and chemical changes, with iron oxide contributing to the reddish color. The bar clay had fabricated by ratio 10 wt% 20 wt% 30 wt% 40 wt% 50 wt%.

Characterization analysis using the graph trend of the sample bar with increasing clay and grog powder ratios. The ratio of 50 wt% showed good results for less shrinkage at 4.80%. However, in the bending test, strength is 2.31 MPa, which isn't high compared to a ratio of 30 wt%, which showed excellent results at 3.8 MPa, shrinkage 7.22%, density 2.28 g/cm^3, and porosity 19.8%.

The XRD pattern showed quartz, muscovite, and kaolinite minerals, with quartz exhibiting high and low intensity peaks. Variations in the ratios were introduced by the amorphous phase.

5.2 Recommendation

Several suggestions have been found via this study which is to improve the quality of Singgora roof tiles. In order to enhance the final product, it is important that there is careful preparation of the samples, thus preventing poor results. The samples must undergo a meticulous drying procedure without any disruption from weather conditions such as rain. To do this, we should begin by putting the samples expose to sunlight but with protection such as Greenhouse. The Greenhouses provide a controlled environment where temperature and humidity levels can be adjusted to facilitate the drying process of clay. This controlled environment helps to prevent external factors such as rain, wind, or extreme temperatures from impacting the drying process.

Besides that, the sample should be to fire in higher temperature and longer duration, same as done by industry. By doing so, the proper grain will be developed and the silica element will be solidified to increase the strength of that Singgora roof.

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