FEASIBILITY STUDY ON THE FABRICATION OF ECO-FRIENDLY CONSTRUCTION MATERIAL FROM GLOVE FORMER WASTE

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Civil Engineering (Environmental) with Honours

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"FEASIBILITY STUDY ON THE FABRICATION OF ECO-FRIENDLY CONSTRUCTION MATERIAL FROM GLOVE FORMER WASTE"** was prepared by **TEH CHOO CHEAN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering (Environmental) with Honours at Universiti Tunku Abdul Rahman.

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Date : 23 April 2024

Specially dedicated to

my beloved mother and father.

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ABSTRACT

Rising global urbanization spurs demand for housing and infrastructure, driving up the need for construction like cement sand bricks. However, cement sand bricks are not highly environmentally friendly primarily due to a key component of these bricks which is cement. The manufacturing of cement involves the release of significant amounts of carbon dioxide into the atmosphere, contributing to greenhouse gas emissions and climate change. It is estimated that the cement industry accounts for 8% of the world's carbon dioxide emissions. Next, the glove manufacturing industry generates glove former waste (GFW) which previously acted as ceramic mould in shaping and creating gloves. Vast amounts of GFW are being thrown into landfills since there is no way to recycle them. They can cause environmental problems such as groundwater pollution and soil pollution. GFW can be classified as a suitable pozzolana material since it has more than 70 % SiO_2, Al_2O_3, and Fe_2O_3 based on its chemical composition. This research paper discusses the utilization of GFW as a substitute for cement in CSB production, aiming to mitigate environmental pollution in cement manufacturing and GFW management sectors. GFW was incorporated into cement sand brick as cement replacement with different replacement levels of 0%, 10 %, 15 %, 20 %, and 25 % respectively. The engineering properties and durability properties of all CSB specimens were assessed after 28 days of curing. According to the strength development of compressive strength, the GFW's pozzolanic effect intensifies over time, particularly in later stages which promotes late strength development. The GFW-25 specimen exhibits the most optimal cement replacement percentage, satisfying standard requirements for compressive strength, flexural strength, bulk density, and water absorption rate. Besides, the fabrication of the GFW-25 specimen produces less carbon dioxide by 24.24 % and costs 19.85 % less compared to the conventional cement sand brick. This approach effectively creates a closed-loop system of circular economy by repurposing GFW to produce sustainable bricks, maximizing their value while simultaneously reducing the consumption of limited natural resources, such as cement. In addition, this research study is in line with SDGs 9, 11 and 13.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

°C	Degree Celsius
kg	Kilogram
kg/m^3	*Kilogram per cubic meter*
kV	Kilovolt
%	Percentage
cm	*Centimetre*
µm	Micrometre
mm	Millimetre
m	Metre
°	Degree
MPa	MegaPascal
MPa/s	MegaPascal per second
RM	Ringgit Malaysia
CSB	Cement sand brick
CSEBs	Compressed stabilized earth blocks
GFW	Glove former waste
OPC	Ordinary Portland Cement
PCC	Portland Composite Cement
SCMs	Supplementary cementitious materials
SEM	Scanning Electron Microscopy
C_3S	Tricalcium Silicate
C_2S	Dicalcium Silicate
C_3A	Tricalcium Aluminate
C_4AF	Tetracalcium Aluminoferrite
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide

CH	Calcium hydroxide
C-S-H	Calcium-silicate hydrates
C-A-H	Calcium-aluminate hydrates
C-S-A-H	Calcium-silicate-aluminate hydrates
MgO	Magnesium oxide
$MgCO_3$	Magnesium carbonate
HCL	Hydrochloric acid
NaOH	Sodium hydroxide
CO_2	Carbon dioxide
CO	Carbon monoxide
SO_x	Sulphur oxides
SO_2	Sulphur dioxide
NO_x	Nitrogen oxides
SiO_2	Silicon dioxide
Al_2O_3	Aluminium oxide
K_2O	Potassium oxide
Fe_2O_3	Ferric oxide
P_2O_5	Phosphorus pentoxide
TiO_2	Titanium dioxide
Cl	Chlorine
Cr_2O_3	Chromic oxide
ZrO_2	Zirconium dioxide
MnO	Manganese monoxide
Rb_2O	Rubidium oxide
BaO	Barium oxide
Eu_2O_3	Europium(III) oxide
ZnO	Zinc oxide
CuO	Copper(II) oxide
NiO	Nickel(II) oxide
VOC_s	Volatile organic compounds
SDGs	Sustainable Development Goals
BC	Before century
kWh	Kilowatt hours
ASTM	American Society for Testing and Materials

BS EN	British Standard European Norm
XRF	X-ray fluorescence

CHAPTER 1

INTRODUCTION

1.1 Research Background

Brick is a fundamental building material used in the construction sector. Bricks are mainly used in construction to build load-bearing and non-load-bearing walls. Besides, they are also employed in the construction of buildings, bridges, fences, pavements, and others. Currently, there are two types of bricks available in the market: fired bricks and non-fired bricks. First, clay brick is a good example of a fired brick. Due to their strength, adaptability, and aesthetic appeal, clay bricks have been used for thousands of years and it is still a popular construction material nowadays. Generally, clay brick is composed mainly of alumina and silica (Kumari and Kumar, 2019). The production of clay bricks consists of four major steps which are the preparation of the clay, moulding, drying of the materials and lastly firing of the clay bricks. Through firing, the bricks were able to develop better strength and durability.

However, there are two major drawbacks making clay brick an unsustainable construction material to be employed. As the demand for brick has risen, concerns regarding the overuse and depletion of clay resources have emerged (Lingling et al., 2004). The overexploitation of clay resources has turned into an issue for the environment as it can result in soil degradation and other detrimental environmental impacts (Ncube et al., 2021). Apart from that, the process of manufacturing clay brick is energy-intensive, especially during the process of the firing of the clay bricks which requires temperatures up to around 1000 °C. Atmospheric pollutants such as

CO_2, CO, and SO_x are released during the process of firing (Nyambo, 2017). Of all atmospheric releases, CO_2 emissions made up the largest mass percentage (Ncube et al., 2021). Therefore, the manufacturing of clay bricks releases a significant amount of greenhouse gases into the atmosphere which negatively affects our environment leading to serious environmental issues such as global warming and climate change.

Next, the focus will be placed on another type of brick which is non-fired brick. Non-fired bricks are bricks made of natural soils and stabilizers that are compressed and cured without the need for kiln firing to gain strength. Cement sand brick (CSB) is a good example of non-fired brick. In terms of strength and durability, CSBs are strong and durable. It can withstand higher compressive strength and therefore is suitable to be used in the construction of high-rise buildings, load-bearing walls, non-load-bearing walls, retaining walls, etc. Generally, CSBs are composed of three main materials which are cement, sand, and water. The process of making CSB is relatively simpler if compared to that of conventional clay bricks. The process involves four major steps which are material preparation, mixing, moulding, and curing. Cement acts as a binder which sets and hardens after reacting with water to hold the sand particles together. This process is known as the hydration process in which cement reacts with water to form calcium silicate hydrates gel. In contrast to clay bricks, the manufacturing of CSB is less energy intensive as the firing process is not required to be carried out for the bricks to gain strength.

Nonetheless, the production of CSB involves the use of cement as a stabilizer. Limestone, chalk, and clay are the three most often utilized raw materials in the manufacture of cement. In fact, the process of manufacturing cement generates a significant amount of greenhouse gases which are detrimental to the environment. The burning of fossil fuels for heating and the calcining of the limestone in the raw mix are the two main sources of carbon dioxide emissions in the production of cement (Worrell et al., 2001). It is estimated that the cement industry accounts for 8% of the world’s carbon dioxide emissions (Tracy and Novak, 2023). The huge amount of carbon dioxide generated by the cement industry will lead to serious environmental problems such as global warming and climate change. To reduce the use of cement in CSB production, the idea of incorporating waste as a cement substitute in CSB production has emerged.

In this research, glove former waste (GFW) is incorporated into CSB as a cement substitute. Glove former waste originates from glove former. Glove former plays an important role in the production of gloves as it acts as a mould in shaping and creating gloves made from materials such as latex, vinyl, or nitrile. In the glove manufacturing sector, glove former is usually made of ceramic as they provide the advantages of high thermal shock resistance, chemical resistance, and high specific surface area for the casting. However, wear and tear on the surface of the former will occur as time passes by and this will directly affect the moulding process. So, manufacturers are consistently replacing old formers with new formers after a certain period thereby generating GFW. The disposal of old formers generates a significant amount of GFW which does not degrade easily. Since there is no way to recycle these wastes, vast amounts of them are being thrown into landfills and this is not a sustainable solution. Next, ceramic glaze which is applied on the surface of the glove former possesses the potential to pollute the environment. Heavy metals can be released through leaching from the glaze which will lead to environmental problems such as groundwater pollution, river pollution, and disturbance of aquatic ecosystems.

In this research, GFW is utilized as a resource to moderately substitute Portland cement used for the fabrication of CSB. Through this method, it aids in diminishing the reliance on cement in CSB manufacturing while at the same time maximizing the value of GFW as a resource. On the other hand, it also acts as a sustainable solution to alleviate the environmental problems caused by both cement production and GFW disposal.

1.2 Problem Statements

The production of CSB heavily relies on cement as a stabilizer. However, the manufacturing of cement is highly energy-consuming and not environmentally friendly. The core of cement manufacturing process is clinker production which requires temperatures up to about 1400 °C to 1500 °C with the combustion of fossil fuel as a source of energy. The burning of fossil fuels for heating and the calcining of the limestone in the raw mix are the two main sources of carbon dioxide emissions in the production of cement (Worrell et al, 2001). The combustion of the fuel accounts for around half of the CO_2 emissions, while the conversion of the raw material accounts for the other half (Worrell et al, 2001). Based on a cement factory with cutting-edge machinery and technology, it is estimated that 0.65-0.92 kg of CO_2 is produced for every kg of cement produced (Hoenig, Hoppe and Emberger, 2007). Cement production releases a significant amount of greenhouse gases which contribute to serious environmental problems such as global warming and climate change. Besides, several air pollutants, including particulate matter, sulphur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs) can be released during the manufacture of cement. These contaminants can harm human health and the quality of the air, causing respiratory issues and smog formation.

Malaysia has been the world's leading manufacturer of rubber gloves for more than 20 years (Hutchinson and Bhattacharya, 2020). The outbreak of COVID-19 in 2020 resulted in substantial growth in this industry. During gloves production, a lot of waste has been generated and one of them is GFW which is made of ceramic. So, a lot of ceramic waste is produced during the disposal of old ceramic glove formers. Large amounts of these wastes are being disposed of in landfills because there is no method to recycle them. As a result, if no other sustainable solutions are provided soon, a growing number of landfills will need to be built to handle the rising volume of GFW. The construction of landfills will bring detrimental negative impacts on the local ecosystem which will also lead to the loss of biodiversity. Apart from that, the glaze which is applied on the surface of the glove former is bad for the environment as it contains heavy metals such as lead, barium, lithium, calcium, and sodium. Heavy metals can be released through leaching from the glaze resulting in groundwater pollution and the contamination of water bodies nearby. The aquatic ecosystems may be disturbed by heavy metal contamination, which will result in a loss of biodiversity.

1.3 Aims and Objectives

This study seeks to examine the impact of glove former waste (GFW) on replacing cement in the production of cement sand bricks (CSB). Hence, the optimum cement replacement percentage by using GFW in producing eco-friendly CSB is determined. Below are the aims of this study:

i) To investigate the feasibility of utilizing glove former waste to partially replace cement in producing eco-friendly CSB.
ii) To assess the engineering and durability characteristics of the fabricated eco-friendly CSB.
iii) To evaluate the optimal cement replacement percentage by using glove former waste in producing eco-friendly CSB.

1.4 Outline of Study

In this study, the focus will be placed on investigating the feasibility of utilizing glove former wastes (GFW) to partially substitute cement in producing eco-friendly cement sand brick (CSB). The CSBs are fabricated with 0, 10, 15, 20, 25 % of GFW as cement replacement. The 0 % serves as a control for other specimens. The cement-to-sand ratio used for the fabrication of CSB is 1 : 3.4 while the water-cement ratio is fixed at 0.5 for all the specimens. The CSB is made with a steel mould with the length of 210 mm, height of 90 mm, and width of 90 mm. The specimen is compacted manually with the help of a 20 tons hydraulic shop press. All the specimens are allowed to be cured for 7, 14, and 28 days respectively. Subsequently, several tests will be conducted to assess the structural and longevity attributes of the CSBs. In terms of engineering properties, laboratory tests such as compressive strength test, flexural strength test, and scanning electron microscopy test will be conducted. On the other hand, laboratory tests such as water absorption test, porosity test and density test will be carried out too to determine the durability properties of the CSB.

1.5 Overall Thesis Framework

This research study is divided into five different chapters which are introduction, literature review, research methodology, results & discussion, and conclusion as shown in **Table 1.1**.

Table1.1: Research Thesis Framework

Chapter	Title of Chapter	Scope of Chapter
1	Introduction	• Introduction of clay bricks and their drawbacks on the environment. • Introduction of cement sand bricks and their drawbacks on the environment. • Introduction of glove former wastes and their drawbacks on the environment. • Introduction of glove former waste as partial cement replacement in CSB. • Aims and objectives of this research.
2	Literature Review	• Properties of cement and their impacts on the environment. • Properties of glove former waste and their impacts on the environment. • General background of clay bricks. • Advantages and disadvantages of clay bricks. • General background of cement sand bricks. • Advantages and disadvantages of cement sand bricks. • Relevant past research on CSB fabrication with different types of wastes.

3	Methodology	• Broad overview of the methodology used in the research. • Details procedures of material preparation. • Formulation of the CSB manufacturing blend. • Details procedures on moulding, demoulding and curing of the specimen. • Tests to be conducted. Steps to conduct the laboratory tests.
4	Results and Discussion	• Discuss the characteristics of GFW. • Present and interpret laboratory test results. • Analyze the structural characteristics and long-term resilience of the manufactured CSB. • Explore the feasibility of substituting cement in CSB. • Cost analysis of the production of CSB with cement replacement. • Estimation of carbon emission to produce CSB with cement replacement.
5	Conclusion and Recommendation	• A general synopsis of the research work. • The recommendation included suggestions for future improvements to CSB.

CHAPTER 2

LITERATURE REVIEW

2.1 Cement

The need for shelter has always been an essential aspect of human survival. It functions primarily to protect humans from elements such as extreme weather conditions, wild animals, and natural disasters. Hence, it is a safe and secure environment where occupants can rest and feel safe. With the advancement of human civilization, shelters have changed over time. The oldest kind of shelter was probably basic huts built of branches, leaves, and other items found in nature. During the Stone Age, humans started using stone as a building material for their homes. As human civilization progressed, they started constructing homes out of mud, clay, and other natural materials. During the medieval period, brick and stone were frequently used in the construction of shelters. By utilizing bricks, the construction became stronger and more durable. In the modern era, concrete is considered one of the most essential materials in construction. It is widely used because of its strength, versatility, and durability. Hence, most of the buildings nowadays are made of concrete.

In 2022, the estimated share of Malaysia's GDP that the construction industry would account for is 3.4 % (Statista Research Department, 2023). The construction industry emerges as one of the industries driving the economy of Malaysia. However, the construction industries have significant adverse impacts on the environment. As a major sector, construction industries generate a lot of greenhouse gases which will lead to another problem which is global warming. The construction industry accounts for 39 % of global energy-related carbon emissions, the production of building materials and construction make up about 11 % and the remaining 28 % comes from operational emissions (Global Alliance for Buildings and Construction, 2019). One of the main factors contributing to carbon emissions in the construction industry is cement production.

Presently, cement stands as a crucial construction material in the contemporary building sector. It is extensively used as a binding material because it hardens after contact with water. When cement is mixed with water, it creates a paste that binds aggregates such as sand and gravel together to form a solid, sturdy, long-lasting material known as concrete. The most common type of cement used worldwide is Ordinary Portland Cement (OPC), which is ideal for all conventional concrete buildings. In 2022, a total of 4.1 billion tonnes of cement would have been produced globally (Garside, 2023). China is the country that accounts for more than half of all cement produced worldwide with an estimated value of 2.1 billion metric tons in 2022 (Garside, 2023). It has become the second most utilized material in the world after water.

2.1.1 Properties of Cement

Portland cement is primarily composed of four main compounds. The four primary compounds include Tricalcium Silicate (C_3S), Dicalcium Silicate (C_2S), Tricalcium Aluminate (C_3A) and Tetracalcium Aluminoferrite (C_4AF). Each of the minerals performs a very distinct role in the hydration process that turns dry cement into solidified cement paste. Most of Portland cement's binding power and strength come from the calcium silicates, which make up about 70-80 % of Portland cement (Eglinton, 1987, p.7). First, C_3S undergoes hydration quickly in the early stage which is about the first 28 days, and it contributes to the early strength of the cement. On the other hand, C_2S hydrates slowly and it takes time more than 28 days for hydration to actively take place. Therefore, it contributes to strength development in the later stages. A gel of calcium silicate hydrates is formed after the hydration process of both silicates which is the main binding agent in hardened cement paste

(Eglinton, 1987, p.7). Next, C_3A is highly reactive, and it releases a significant amount of heat during the early hydration period. C_3A contributes to the initial setting time of the cement. However, C_3A will cause the concrete to set immediately which will affect the workability of the concrete. Hence, calcium sulphate such as gypsum or anhydrite is added to the clinker to control C_3A from reacting rapidly to minimize setting problems. It is especially vulnerable to sulphate attack (Eglinton, 1987, p.9). Lastly, C_4AF is the end product produced when iron and aluminum are used to lower the clinkering temperature during the manufacturing of cement. It does not significantly increase the cement's strength but is primarily responsible for the color effects that turn cement grey.

2.1.2 Process of Cement Production

The manufacturing of cement is highly energy-consuming. The production of cement can be separated into three major steps (Worrell et al., 2001). The first step is the preparation of the raw materials, then the raw materials will be sent for the process of calcination in the kiln as the second step. Lastly, the end product which is cement clinker will be sent for grinding. The simplified process of cement production is shown in **Figure 2.1**.

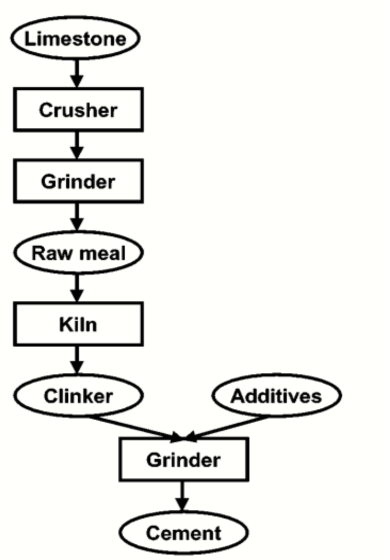

Figure 2.1: Simplified Process of Cement Production.

Limestone, chalk, and clay are the three most often utilized raw materials in the manufacture of cement. Most of the materials are extracted from quarries. Then, the raw materials are crushed into smaller pieces by machines such as a gyratory crusher, a roller, or a hammer mill and mixed proportionally to ensure the consistency and quality of the cement (Worrell et al., 2001). After crushing, the mixture is fed into ball or rolling mills where it is ground into powder form which is known as raw meal.

Subsequently, coming to the core of the cement manufacturing process which is clinker production. The raw meal is fed into the rotary kilns which is an inclined rotating cylindrical tube with a diameter up to 6 m. The tube is mounted at a 3 to 4° horizontal angle and rotates 1 to 4 times each minute (Worrell et al, 2001). The kiln is heated up to a temperature of about 1400 to 1500 degrees Celsius with the combustion of fossil fuels. The raw meal will react differently according to the temperature change. During calcination, limestone and magnesium carbonate start to break down into $CaCO_3$, MgO, and CO_2 as the temperature rises to about 550 °C and will complete at 960 °C (Mintus, Hamel, and Krumm, 2006). Then, one of the components of clinker, C_2S, is generated between 900 °C and 1200 °C while other components such as C_3S, C_3A, and C_4AF are formed between the temperature of 1200 °C to 1280 °C (Engin and Ari, 2004). Finally, solid clinker is melted down to make a well-mixed, nodular clinker at a temperature greater than 1280 °C (Mintus, Hamel, and Krumm, 2006). Clinker that has reached a temperature of 1450 °C is then cooled to 100 °C over a cooler stage using outside air before being moved to the final unit for grinding.

Lastly, the clinker is ground along with some additives such as gypsum and fly ash in ball mills, roller mills, or roller presses. The grinders will turn the clinkers into powder form which is known as cement.

2.1.3 Drawbacks of Cement Production

As aforementioned, cement production is one of the main factors contributing to carbon emissions in the construction industry. The burning of fossil fuels for heating and the calcining of the limestone in the raw mix are the two main sources of carbon dioxide emissions in the production of cement (Worrell et al, 2001). **Figure 2.2** illustrates schematically the cement manufacturing process and related CO_2 emissions at various stages. The combustion of the fuel accounts for around half of the CO_2 emissions, while the conversion of the raw material accounts for the other half (Worrell et al, 2001). Specifically, it can be said that 40 % of total emissions are caused by the burning of fossil fuels in the kiln, while the remaining 10 % are due to the transportation of raw materials and the use of energy by electrical motors. The remainder, which accounts for the majority of the emissions (almost 50 %), is released during the process of $CaCO_3$ and $MgCO_3$ decomposition (Mahasenan, Smith, and Humphreys, 2007).

Depending on the type of fuels utilized, it is estimated that 0.9 to 1.0 tonnes of CO_2 are produced for every tonne of clinker (Metz et al., 2005, p.442). Based on a cement factory with cutting-edge machinery and technology, 0.65-0.92 kg of CO_2 is produced for every kg of cement produced (Hoenig, Hoppe, and Emberger, 2007).

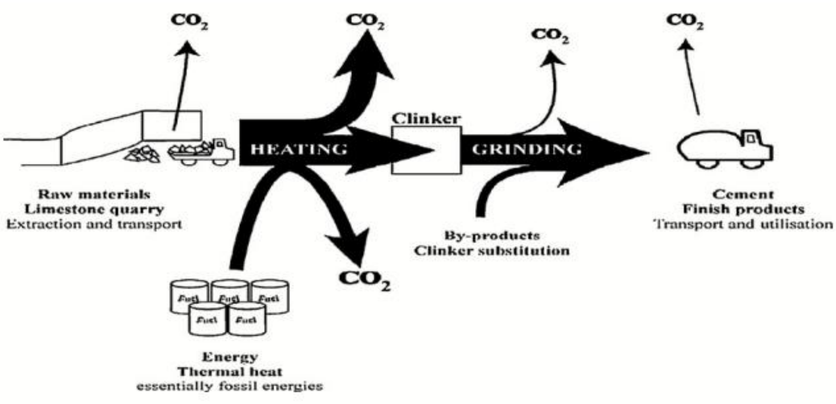

Figure 2.2: Simplified Cement Fabrication Process with a Specific Interest in CO_2 Emissions (Ali, Saidur and Hossain, 2011).

2.2 Glove Former Waste

For more than 20 years, Malaysia has been the world's top producer of rubber gloves (Hutchinson and Bhattacharya, 2020). Malaysia maintains its competitiveness and ability to attract business throughout the world thanks to its ongoing technical innovation. The robotics and automation employed in Malaysia manufacturing plants are a wonder to behold and continue to be a major competitive advantage. In 2020, the outbreak of the COVID-19 pandemic caused a substantial rise in the demand for rubber gloves worldwide, particularly for medical gloves but also for non-medical ones.

Different parties, which include medical, healthcare, and civilians have shown a strong demand for gloves and masks in fighting the COVID-19 pandemic. In 2020, Malaysia exported rubber gloves worth USD 8.4 billion, more than twice as much as in 2019 (Nguyen, 2021). The production of rubber gloves surged significantly in 2020 due to the COVID-19 pandemic. According to **Figure 2.3**, a total of 102.59 billion pairs of rubber gloves were produced in 2020 and the number continue to rise to 136.8 billion in 2021. The United States, China, and Germany are the top three countries to which Malaysian rubber gloves are exported.

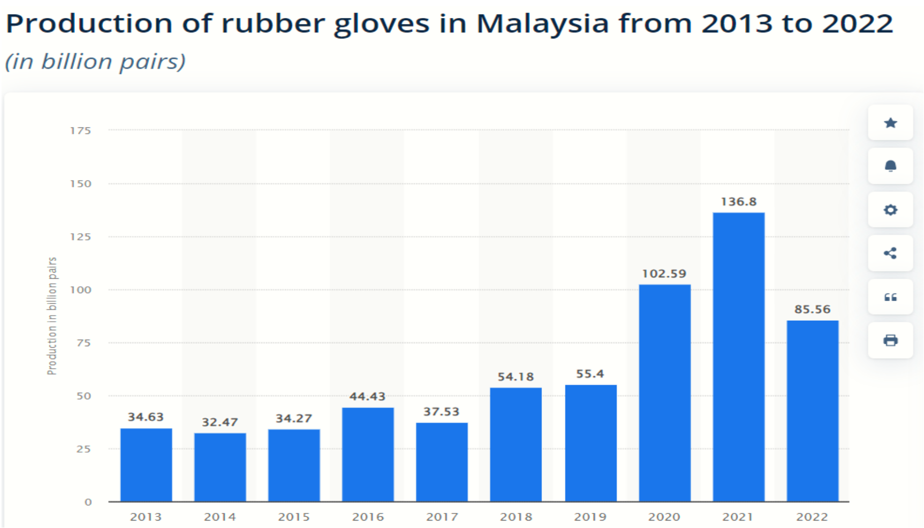

Figure 2.3: Production of Rubber Gloves in Malaysia (Statista Research Department, 2023).

2.2.1 Process of Glove Production

The process of manufacturing rubber gloves normally involves seven steps. They include raw material testing, compounding, dipping, leaching, vulcanizing, stripping and tumbling, quality control, and packaging. For raw material testing, the raw materials such as latex, nitrile, or vinyl are evaluated and analyzed in the laboratory where they go through a variety of comprehensive and thorough quality checks such as chemical qualities testing before entering the compounding process (Jirasukprasert et al., 2014).

The second step will be compounding. Chemical substances are prepared and blended for dispersion by using the ball mill technique. The laboratory-approved dispersion is then combined with latex according to its specific formulation. Subsequently, hand-shaped dipping formers made of ceramic are used to create the glove's form during the process. Dust and pollutants are removed from the formers by cleaning them with diluted HCL acid, NaOH, and water (Jirasukprasert et al., 2014). Before coating the former with latex, the former will first go through the coagulant tank filled with calcium nitrate and then dried. This aids in the attachment of the latex to the molds during the process of dipping formers into the compound latex tanks.

Next, the coated formers will be sent for the process of leaching and vulcanizing. The process of leaching is carried out by dipping the formers into treated hot water at a temperature of 80-90 °C. This is to ensure that latex protein is maintained at a relatively low level and to get rid of non-rubber particles, chemical residue, and extractable water-soluble components (Jirasukprasert et al., 2014). This is because latex protein might cause allergic reactions in some individuals. After leaching, the gloves are then subjected to a vulcanization process. This process involves the utilization of sulfur and other ingredients heated up to improve the strength and durability of the gloves (Jirasukprasert et al., 2014). Subsequently, once the glove material has cured, the gloves are removed from the former. Then, the quality control test is carried out by random sampling with methods such as airtight inspection, watertight test, and visual inspection (Jirasukprasert et al., 2014). Only high-quality gloves are permitted to move on to the next stage; defective gloves are discarded. In the last stage, the gloves are then packed in a dust-free environment and prepared for distribution to the market.

As aforementioned, the production of gloves involves the using of glove former. Glove dipping former plays an important role in the production of gloves as it acts as a mold in shaping and creating gloves made from materials such as latex, vinyl, or nitrile. In this research, the glove former wastes used were supplied by Kitaran Recovery Sdn. Bhd. It is a company that provides services for scheduled waste recovery and is located at Tungzen Industrial Park, Perak Darul Ridzuan, Malaysia. In the glove manufacturing sector, ceramic dipping formers are commonly utilized. Ceramic glove dipping formers provide the advantages of high thermal shock resistance, chemical resistance and high specific surface area for the casting (Tharasana et al., 2020).

2.2.2 Properties of Glove Former Waste

According to information provided by Kitaran Recovery Sdn. Bhd., the glove former wastes they provide are composed of several different compounds. They include ceramic clay, calcined alumina, gypsum, dolomite, potash feldspar, silica, and various colour pigments. Each compound serves its specific functions in the manufacturing process. As mentioned earlier, ceramic clay serves as the main raw material for creating ceramic glove former. It serves as the foundational component that offers plasticity and workability, enabling the former to be shaped into the desired shape (Fang and Chen, 2020). Besides, ceramics also offer several beneficial properties such as high resistance to corrosion and chemical attack, high melting point, high elastic modulus, and low thermal expansion (The American Ceramic Society, n.d.).

Next, alumina is an essential ingredient in making ceramic glove dipping former. It imparts hardness, refractoriness and increases Young’s modulus, and provides resistance against both acidic and alkaline attacks to the ceramic (Richards, 1991). Because of the presence of alumina, the former is more resilient and able to retain its shape during the glove production process. Subsequently, gypsum is used in a small amount as a binder due to its properties of quick setting and hardening (Lushnikova and Dvorkin, 2016). Consequently, dolomite and potash feldspar both act as fluxing agents in ceramics. It aids in lowering the firing temperature required to sinter the ceramic material. Subsequently, fine silica particles are frequently utilized as a material for packing purposes, and they also function as sintering aids in the production of ceramic glove formers (Fernandes et al., 2014).

2.2.3 Drawbacks of Glove Former Waste

Commonly, ceramic glove formers are built to last for a long period to reduce the production cost of needing to be replaced frequently. However, wear and tear on the surface of the former will occur as time passes by and this will directly affect the molding process. Hence, the manufacturer will have to replace the old formers with new formers after a certain duration based on the conditions of the glove formers. The disposal of old ceramic glove formers generates a large amount of ceramic waste. Since there is no way to recycle these ceramic wastes, vast amounts of these wastes are being thrown into landfills.

The quantity of ceramic waste is on the rise, prompting various entities to seek a sustainable resolution for ceramic disposal. Even though ceramic is made from natural substances, they cannot be easily degraded. The estimated duration for the complete degradation of ceramic is more than a millennium. That means more and more landfills are required to be constructed to cope with the increasing amount of ceramic waste if there are still no other sustainable solutions being introduced. The construction of landfills will bring detrimental negative impacts on the local ecosystem. This is because the establishment of landfills often involves land clearing. The natural habitats of local species are removed during land clearing which will lead to a loss of biodiversity. Species that depend on these ecosystems for survival, reproduction, and shelter may face population declines due to the decrease in natural resources. In addition, this will indirectly affect the population of local endangered species that rely on specific environments for survival.

Next, ceramic glove former also possesses the potential to pollute the groundwater and water bodies nearby due to the introduction of glaze on the surface of ceramic glove former. Glazed and unglazed ceramic products differ mainly in their surface properties as glazed ceramics have a shiny, reflective glass-like surface. Glaze is applied to the surface of ceramic products as a protective layer to increase its overall strength, durability, and resistance to abrasion. Glaze is a mixture of silica and a certain amount of fluxes. Heavy metals such as lead, barium, lithium, calcium, and sodium are used as fluxes to lower the melting point of silica (Davis, n.d.). However, heavy metals can be released through leaching from the glaze (Aderemi et al., 2017). Leachability is influenced by several variables, including the composition of the glaze, the firing conditions, the pH, the temperature, and the length of time the food is in contact with it (Belgaied, 2003).

In terms of pH, heavy metals can escape from the glaze under acidic or alkaline conditions. Therefore, it will result in groundwater contamination as the escaped heavy metals seep into the ground meeting the water table. The groundwater moves very slowly which means the heavy metals might remain in the ground water for a long period making it almost impossible to remove the contaminants. Besides, the heavy metals will pollute water bodies nearby through the runoff of contaminated soils. Heavy metal pollution can disturb the aquatic ecosystem which will lead to a loss of biodiversity. The heavy metals tend to accumulate in organisms as time passes which is known as bioaccumulation. Bioaccumulation of toxic heavy metals in aquatic living things has a significant impact on the rate of organisms' ability to survive and reproduce (Garai et al., 2021).

In short, dumping ceramic glove former wastes into landfills is not a sustainable way since it requires a huge amount of land due to its long lifespan. The construction of landfills will bring detrimental impacts on the local ecosystem due to land clearing eventually harming the environment. Besides, it poses negative impacts on the environment as it contains heavy metal within ceramic glazes which is toxic. The heavy metals might leach from the glaze then enter the soil and eventually pollute the groundwater and water bodies nearby.

The main objective of this research is to investigate the feasibility of using glove former waste to partially replace cement in the production of CSBs. The idea of incorporating glove former waste into CSBs to partially replace cement complies with the concept of the circular economy. A circular economy aims to decrease the usage of raw materials and reuses “waste” as a resource to create new goods and materials with value. In this system, products and resources are aimed to stay in the economy for as long as possible at their best value to avoid wastage of resources. The goal of the circular economy is to establish a closed-loop system in which resources, materials, and goods are recycled, repaired, repurposed, and reused to fully maximize their values and reduce their negative impacts on the environment. The idea of incorporating glove former wastes into the production of cement-sand bricks can be considered a sustainable solution for the disposal of glove former waste. Through this method, the negative impacts of glove former wastes on the environment can be resolved easily. This is because landfilling is by far the only method to deal with the glove former waste. Besides that, the glove former waste can re-enter the economy again in other forms maximizing its value as a resource.

On the other hand, the carbon footprint of producing cement-sand brick can be reduced through the partial replacement of cement with glove former wastes. As aforementioned, the production of cement generates a significant amount of greenhouse gases which are detrimental to the environment. Currently, the construction industry is moving towards sustainable construction because people slowly discovered the negative impacts of cement on the environment. Hence, research on suitable materials to replace cement has become a hot topic in the construction industry. So, this research aims to investigate the feasibility of glove former waste to be used to partially replace cement in the production of cement-sand brick. This type of brick can be considered eco-friendly brick which aligns with specific Sustainable Development Goals (SDGs) such as SDG 9 which focuses on industry innovation and infrastructure, SDG 11 which pursues sustainable cities and communities and SDG 13 which is related to climate action. The research on eco-friendly brick reflects innovation in the construction industry and, on the other hand, promotes sustainable developments and climate action which complies with SDG 9, SDG 11 and SDG 13.

2.3 Conventional Fired Clay Bricks

From 9000 to 8000 BC, the earliest traces of brick-masonry buildings were discovered in the Mesopotamian region that is now Israel (Fernandes, 2019). Clay brick was the best and most resilient building material invented by humans. Therefore, it served as a fundamental component of construction in the Mesopotamian, Egyptian, and Roman eras (Fernandes, 2019). Due to their strength, adaptability, and aesthetic appeal, clay bricks have been used for thousands of years and it is still a popular construction material nowadays. In our world today, clay bricks can still be seen in buildings, bridges, culverts, chimneys, pavements, brick flooring, etc. Generally, clay brick is composed mainly of alumina and silica which is then followed by a small amount of lime, oxide of iron, and magnesia (Kumari and Kumar, 2019). The presence of alumina imparts plasticity to the clay while silica helps to avoid fracture, shrinkage, and warping of raw bricks, lime also aids in avoiding shrinkage of bricks, and oxide of iron provides a red appearance to the bricks (Kumari and Kumar, 2019).

The production of fired clay bricks consists of four major steps which are the preparation of the clay, moulding, drying of the materials, and firing of the clay bricks (Yüksek, Öztaş and Tahtalı, 2020). First, the process starts with the preparation of raw clay through extraction from the ground. The raw material selection was crucial as it significantly affects how well and how long a brick performs (Vitruvius and Morgan, 1960). Then, the raw clay is gathered and stored in an open space for a few days or even weeks for decomposition. The raw clay is mixed and turned frequently to remove as many dissolved salts as possible to produce a more consistent material (Límon and Alvarez de Buergo, 1997). The raw material will then undergo the process of crushing to the desired grain size and water will be added. To enable molding, the resulting mixing must possess a certain degree of plasticity.

Subsequently, the mix will be placed into wood molds which are bottomless but normally a layer of sand is placed on the ground first to prevent the brick from sticking to the base during the drying process. Next, the slightly hardened clays are detached from the wood molds and located in an open well-protected area for further drying to acquire its final shape. The drying process may take 7 days or longer depending on the particular climatic conditions (Fernandes, 2019). Although drying is accelerated in hotter climates, bricks should be shielded from direct sunshine since they are susceptible to warping and cracking (Alvarez de Buergo and Limon, 1994).

Lastly, the clay bricks will be placed in a kiln with temperatures of approximately 1000 °C for firing. The bricks were able to develop significantly better mechanical and chemical resistance after firing for several days. During this stage, different complex chemical reactions take place as the temperature increases. First, the removal of hygroscopic water happens at 100 °C and subsequently, the organic stuff within the clay undergoes oxidation between the temperature of 350 and 650 °C. When the temperature reaches 650°C, silica and alumina begin to dissociate. Then, between 850 and 950 °C, the carbonate structure breaks down then produces calcite and dolomite. Then the temperature continues to rise until nearly 1000 °C where the process of sintering and vitrification occurs (Alvarez de Buergo and Limon, 1994).

2.3.1 Properties of Conventional Fired Clay Bricks

Conventional clay bricks have several significant properties that make them suited for use in a variety of construction applications. Clay bricks offer great thermal insulation properties. The clay bricks absorb heat from the surroundings during the daytime and only release the heat at nighttime (Kamal, 2021). They help to regulate indoor temperatures by minimizing heat transmissions. Therefore, the occupants can feel warm in winter and cooler in summer thanks to the insulation properties of clay bricks. Besides, the reason why clay brick is widely used in construction is due to its strength and durability. Clay bricks can last for a significant amount of time with the requirement that it is properly manufactured with good materials. They have the strength to endure compressive stresses and can bear the weight of structures over time.

Subsequently, clay bricks possess the ability to fire resistance. Due to their density, there isn't much room left for combustion to start and spread therefore making them highly resistant to intense and well-developed fire (Kamal, 2021). They are thus a secure option for situations where fire safety is crucial, like firewalls and fireplaces. Next, clay bricks require relatively low maintenance after construction. This is highly related to its durability properties and if properly installed, they can last for many years without severe defects. Generally, the cost for the maintenance of clay brick is very low or negligible if compared to block construction which requires maintenance regularly (Kamal, 2021).

2.3.2 Drawbacks of Conventional Fired Clay Bricks

Clay is the main natural resource that is required in making conventional clay bricks. As the demand for brick has risen, concerns regarding the overuse and depletion of clay resources have emerged (Lingling et al., 2004). It is undeniable that most of the world's clay reserves are becoming depleted due to overexploitation (Sahu and Kota, 2017). The overexploitation of clay resources has turned into an issue for the environment as it can result in soil degradation and other detrimental environmental impacts (Ncube et al., 2021). The extraction of clay commonly requires the excavation of topsoil and vegetation of large areas of land. This will disturb the natural habitat and ecosystem which the local animals and plants rely on for survival. In addition, it will also cause the loss of biodiversity and endanger local flora and fauna which depends on the ecosystem. The Chinese government has banned the use of burnt clay bricks in construction to preserve agricultural land while materials such as fly ash are encouraged to be used (Lingling et al., 2004).

Besides that, the process of manufacturing clay brick is energy-intensive, especially during the process of the firing of clay bricks which requires temperatures up to around 1000 °C. Coals and fossil fuels are commonly used as a source of energy for combustion in the firing process. The burning of coal used in the current brick manufacturing process releases atmospheric pollutants such as CO_2, CO, and SO_x (Nyambo, 2017). Of all atmospheric releases, CO_2 emissions made up the largest mass percentage (Ncube et al., 2021). A typical clay brick emits 0.41 kg of CO_2 and has an embodied energy of about 2.0 kWH (Venkatarama Reddy and Jagadish, 2003). So, the manufacturing of conventional clay bricks releases a significant amount of greenhouse gases into the atmosphere which negatively affects our environment leading to serious environmental issues such as global warming and climate change.

2.4 Non-fired Bricks

The conventional clay brick is categorized as fired brick since kiln firing is required to be carried out during the manufacturing process for the brick to gain strength. As aforementioned, the production of conventional clay bricks causes serious environmental problems such as soil depletion due to extensive clay extraction and the high emission of greenhouse gases due to the kiln firing process. Thus, another type of bricks which is known as non-fired bricks was introduced as another option for the industry players. Non-fired bricks are bricks made of natural soils and stabilizers that are compressed and cured without the need for kiln firing to gain strength. A variety of unfired bricks are accessible in the marketplace such as compressed stabilized earth blocks (CSEBs) and cement sand bricks (CSBs). Stabilizers play an important role in the production of non-fired bricks as they serve as a binding material to hold the soil mixture together. Cement is frequently employed as a stabilizer because it is readily available and gives these blocks the requisite strength and durability attributes for compliance with the building codes (Sekhar and Nayak, 2018).

The process of producing non-fired bricks is relatively simpler if compared to that of fired bricks. The process usually involves soil selection, mixing with stabilizer, compaction, and curing. Soil selection is important as suitable soil is needed to ensure proper compaction of the bricks. Then, a stabilizer such as cement is added to the soil mixture as a binding agent to hold the soil particles together. Subsequently, the soil mixture is placed inside a dedicated brick mold and then compacted with machines such as hydraulic presses to a desired density. Lastly, the compacted bricks will undergo the process of curing to gain strength over some time.

2.4.1 Cement Sand Bricks

Cement sand brick is categorized as non-fired brick as the firing process is not involved in the process of producing the brick. Generally, cement sand bricks are composed of three main materials which are cement, sand, and water. In cement sand bricks, Portland cement acts as a binder which sets and hardens after reacting with water to hold the sand particles together. Sand is then utilized as a filler, and when mixed with cement, it increases the strength of the bricks. The process of making cement sand bricks is relatively simpler if compared to that of conventional clay bricks. The process involves four major steps which are material preparation, mixing, moulding, and curing.

During material preparation, the sand used will be sieved to remove those gravels and organic matter that is not suitable for brick making. Then, the water used for the hydration of cement must be clean without contaminants such as acids, oils, and organic matter (Kamal, 2021). Next, water is added to the mixture of sand and cement for proper mixing. A homogeneous mix is vital as it will affect the strength of the bricks eventually. Subsequently, the mix will be placed into fabricated molds layer by layer and the mixture in the molds is compacted with compression equipment. Lastly, the compacted bricks are removed from the molds and left to cure for a specific period. The curing duration can vary, ranging from 7, 14, to 28 days, depending on specific condition requirements.

2.4.2 Advantages of Cement Sand Bricks

In terms of strength and durability, cement sand bricks are strong and durable. It can withstand higher compressive strength and therefore is suitable to be used in the construction of high-rise buildings, load-bearing walls, non-load-bearing walls, retaining walls, etc. It is unaffected by damp, bugs, or mould and only gets stronger with time (Kamal, 2021). Next, cement sand brick has the properties of low water absorptivity. This is particularly beneficial when construction is taking place in a moist and muddy environment. With this property, the performance of the bricks will not be affected easily in contrast to clay bricks which get damaged easily when exposed to moisture (Sarah, 2021). Besides, cement sand bricks consume less mortar during bricklaying thanks to their flat and even surfaces. In terms of price, cement sand bricks are cheaper compared to conventional clay bricks. This is because the process of manufacturing cement bricks is straight forward and simple. It is not as energy-intensive as the production of conventional clay bricks. In Malaysia, conventional clay bricks normally cost roughly RM 1.20 per piece, whereas cement bricks cost about RM 0.30 per piece (Sarah, 2021). Hence, cement sand brick is a more affordable option if the construction budget is a problem.

2.4.3 Disadvantages of Cement Sand Bricks

The production of cement sand bricks involves the use of cement as a stabilizer. In fact, the process of manufacturing cement generates a significant amount of greenhouse gases which are detrimental to the environment. The cement industry accounts for 8 % of the world’s carbon dioxide emissions (Tracy and Novak, 2023). The two primary sources of carbon dioxide emissions in the manufacture of cement are the burning of fossil fuels for heating and the calcining of the limestone in the raw mixture (Worrell et al, 2001). The burning of fossil fuels in the kiln is specifically responsible for 40 % of overall emissions with the remaining 10 % coming from the transportation of raw materials. The remaining 50 % is contributed by the decomposition of $CaCO_3$ and $MgCO_3$ during calcination (Mahasenan, Smith, and Humphreys, 2007). The huge amount of carbon dioxide generated by the cement industry will lead to serious environmental problems such as global warming. Global warming will indirectly cause other environmental issues such as climate change, sea level rise, biodiversity loss, extreme weather events, and a lot more.

Besides that, the production of cement sand brick consumes a lot of sand which in the other way leads to overexploitation of sand. Sand is the most widely used solid material on Earth and 50 billion metric tons of sand are consumed annually (Newcomb, 2022). The type of sand used in concrete production and cement bricks originates from river sand. Extraction of river sand from the riverbed frequently disrupts the nearby aquatic ecosystem, resulting in biodiversity depletion within the river.

2.5 Relevant Past Research

Numerous researchers have explored the substitution of cement with various waste materials in the fabrication of cement sand bricks. These materials include silica fume, fly ash, palm oil fuel ash, and ground granulated blast furnace slag, among others. However, to date, there has been no investigation into the utilization of GFW as a cement substitute in CSB production. **Table 2.1** outlines past research efforts focused on integrating different waste materials into CSB fabrication processes, aiming to bolster strength and decrease cement usage.

Table 2.1: Overview of Past Relevant Research on CSB Fabrication.

Title	Type of material used for cement replacement	Percentage replacement of cement (%)	Optimum percentage for substitution (%)	Compressive strength of optimum on day 28 (MPa)	References
Influence of Ground Granulated Blast Furnace Slag (GGBS) as Cement Replacement on the Properties of Sand Cement Brick	Ground Granulated Blast Furnace Slag (GGBS)	0, 10, 20, 30, 40, 50, 60	20	49.00	(Mat Dom et al., 2022)

Properties of Cement Brick with Partial Replacement of Sand and Cement with Oil Palm Empty Fruit Bunches and Silica Fume	Silica Fume (SF)	0, 10, 15, 20, 25	10	12.40	(Ling et al., 2019)
Properties of cement bricks containing sago fine waste (SFW) with different water-cement ratio	Sago Fine Waste (SFW)	0, 2, 4, 6, 8, 10	2	24.29	(Norhayatis et al., 2023)

Experimental study on utilization of fly ash in cement brick	Fly Ash	0, 10, 20, 30, 40	30	26.01	(Bharatkumar, Pitroda and Raval, 2019)
Recycling of high volumes of cement kiln dust in bricks industry.	Cement Kiln Dust (CKD)	0, 30, 50	50	Approximately 32.00	(El-Attar, Sadek and Salah, 2017)
Utilization of Baggase Waste Based Materials as Improvement for Thermal Insulation of Cement Brick	1) Sugarcane bagasse 2) Banana bagasse	0, 2, 4, 6, 8, 10	1) 4 2) 4	1) 17.23 2) 15.59	(Aminudin et al., 2017)

The effects of partial replacement of cement in cement mortar and brick by Microwave Incinerated Rice Husk Ash (MIRHA)	Microwave Incinerated Rice Husk Ash (MIRHA)	0, 5, 10, 15, 20, 25	20	20.24	(Wan et al., 2011)
Compressive Strength Behaviours of Lagoon-Water Cured Cement-Aluminium Dross Concrete	Aluminum dross (AlDr)	0, 5, 10, 15, 20, 25	10	14.59	(Afolabi et al., 2021)

Palm Oil Fuel Ash and Mussel Shell Powder as Supplementary Cementitious Materials in Non-Load Concrete Brick.	Palm Oil Fuel Ash (POFA) & Mussel Shell Powder (MSP)	20 + 2, 4, 6, 8, 10	20 + 4	5.5	(Zahid et al., 2021)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will focus on outlining the procedures for conducting the study. The fabrication of cement sand bricks involves four main steps: material preparation, mixing, moulding & demoulding, and curing as depicted in **Figure 3.1**. Each step will be extensively discussed. The study will involve fabricating cement sand bricks with varying percentages (0 %, 10 %, 15 %, 20 %, and 25 %) of coarse and fine glove former waste (GFW) as cement replacement. Laboratory tests, conducted according to international standards such as ASTM and BS EN, will assess how the engineering and durability properties of the bricks change as GFW replaces cement.

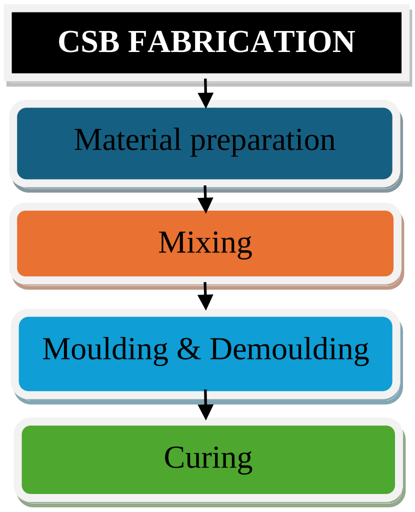

Figure 3.1: Four Major Steps of CSB fabrication.

3.2 Materials Preparation

In this study, the materials required for the fabrication of CSB are cement, sand, glove former waste, and water. The materials are prepared based on specific requirements to ensure that the results obtained are accurate and reliable. Precautionary steps are taken to ensure that the materials are not affected by external environmental factors such as temperature changes, humidity, and exposure to rain and sunlight.

3.2.1 Cement

Cement plays an important role in the fabrication of CSB as it acts as a binder that holds the aggregates together. Cement undergoes a chemical process called hydration when combined with water, producing calcium-silicate hydrates (C-S-H) gel that binds aggregates like sand together to produce strong and durable building materials. The cement used in this study is YTL Castle Portland Composite Cement (PCC) as shown in **Figure 3.2**. It is suitable for various applications such as brickmaking, bricklaying, concreting, plastering, etc. The major difference between PCC and Ordinary Portland Cement (OPC) is that supplementary cementitious materials (SCMs) are added to the clinker in PCC. The PCC used in this study is manufactured by grinding cement clinkers with high-quality limestone as SCMs to reduce the amount of the clinker needed thereby reducing the carbon footprint of the cement, making it an eco-friendly product. The PCC used is certified to MS EN 197-1 : 2014, Portland Limestone Cement, CEM II / B-L 32.5N. The cement used in this study is stored in an air-tight container to protect it from moisture. This is because the cement may harden and form lumps or clumps if exposed to moisture from the environment for a long time. Any cement that has lumps should not be used in construction since it will not produce a homogeneous mix. According to ASTM C 192/C 192M – 02, the cement used shall pass through a sieve that is 850 μm or finer to remove the lumps.

Figure 3.2: YTL Castle Portland Composite Cement.

3.2.2 Sand

To form CSB, sand is used as aggregates to mix with cement and water. They aid in distributing and transferring loads throughout the CSB, to increase their ability to withstand cracking and structural failure. In this study, only fine sand is used for the fabrication of CSB. So, the sand will first go through the process of sieving, and only sand with particle size smaller than 1.7 mm will be used. Then, the fine sand as shown in **Figure 3.3** will be stored inside a container to prevent direct exposure to moisture in the atmosphere.

Figure 3.3: Sand.

3.2.3 Glove Former Waste

Glove former waste used in this research was provided by Kitaran Recovery Sdn Bhd as shown in **Figure 3.4**. The glove former waste will undergo the process of sieving to obtain GFW with two different sizes. The coarse GFW particles are sized between 0.30 mm and 1.70 mm while the fine GFW particles have sizes smaller than 0.30 mm. The GFW will then be stored within a zip bag separately to prevent direct exposure to the moisture in the environment.

Figure 3.4: Glove Former Waste.

3.3 Mix Design

Based on previous relevant research and multiple tests, the cement-to-sand ratio used for the fabrication of CSB in this research is 1: 3.4 while the water-cement ratio is fixed at 0.50 for all the specimens. In this research, the CSB will be fabricated with 0 %, 10 %, 15 %, 20 %, and 25 % of glove former waste as cement replacement. The 0 % served as a control for other samples.

Based on ASTM C192/C 192M – 02 which stated the standard procedure for concrete mixing, the first step is to dry mix the cement with the sand without adding water until they are completely blended. Then, water is slowly added to the mass and the mixture is mixed until the concrete is homogeneous in appearance and with desired consistency. During the mixing process, an electric concrete mixer is used to help ensure a uniform mix.

Table 3.1: Mix design ratio of fabrication of CSB with GFW as cement replacement.

Specimen ID	Materials	
	Cement (%)	GFW (%)
GFW-0 (Control)	100	0
GFW-10	90	10
GFW-15	85	15
GFW-20	80	20
GFW-25	75	25

Notes:

GFW-0: Control CSB without GFW

GFW-10: CSB with 10 % GFW as cement substitute

GFW-15: CSB with 15 % GFW as cement substitute

GFW-20: CSB with 20 % GFW as cement substitute

GFW-25: CSB with 25 % GFW as cement substitute

Table 3.2: Weight of Composite for each 210 mm x 90 mm x 90 mm specimen.

Specimen ID	Weight of Material Per Specimen (g)			
	Sand	Water	Cement	GFW
GFW-0 (Control)	2244.00	330.00	660.00	0.00
GFW-10	2244.00	330.00	594.00	66.00
GFW-15	2244.00	330.00	561.00	99.00
GFW-20	2244.00	330.00	528.00	132.00
GFW-25	2244.00	330.00	495.00	165.00

Figure 3.5: Mixing.

3.4 Moulding & Demoulding

The steel mould used in this research study has a length of 210 mm, height of 90 mm, and width of 90 mm. Place the concrete mixture into the steel mould layer by layer, a total of 3 times, until the mould is filled. Each layer will be manually compacted with the help of a mini hoe to remove excessive voids. A 20 tons hydraulic shop press is used in this study to compact the concrete mixture. The concrete mix is compacted with a force of 3.5 metric tons. With proper compaction, the air voids within the mixture are reduced thereby increasing the density of the specimen. After compaction, the steel mould will be disassembled and the newly fabricated CSB will then be placed on a piece of plywood. During the demoulding process, great care must be taken at every step to prevent damaging the brick specimens, as they are still very fragile at this stage.

Figure 3.6: CSB Steel Mould.

Figure 3.7: Compaction of CSB with Hydraulic Shop Press.

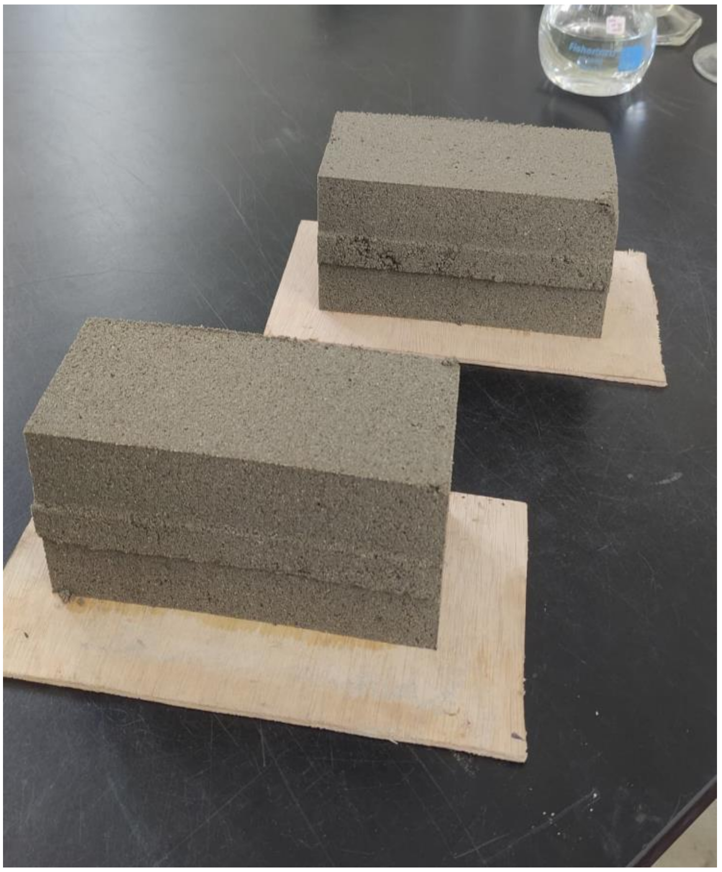

Figure 3.8: Demoulding.

3.5 Curing Process

After demoulding, the samples are left to air-dry for 24 hours to first set and harden. After gaining initial strength, the samples are placed into the poly tank for water curing for 7, 14, and 28 days respectively. Each of the specimens is labeled accordingly with the date and its specimen ID.

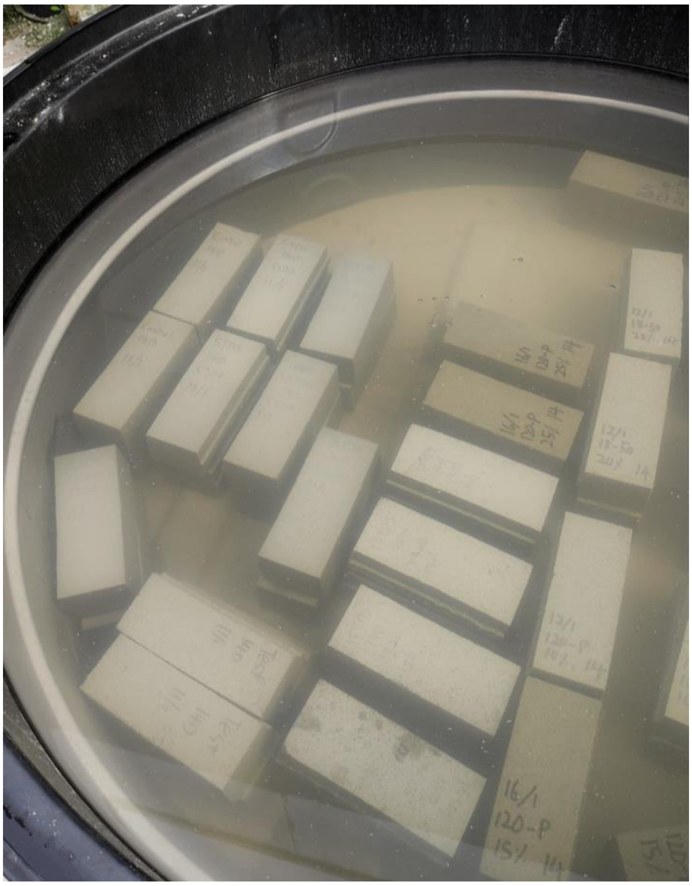

Figure 3.9: Curing of CSB.

3.6 Laboratory Tests

Subsequently, various tests will be carried out to assess the engineering and durability properties of the fabricated CSB with GFW as a partial cement substitution. In terms of engineering properties, laboratory tests such as compressive strength test, flexural strength test, and scanning electron microscopy test will be conducted. On the other hand, laboratory tests such as water absorption test, porosity test, and density are to be conducted too to determine the durability properties of the CSB.

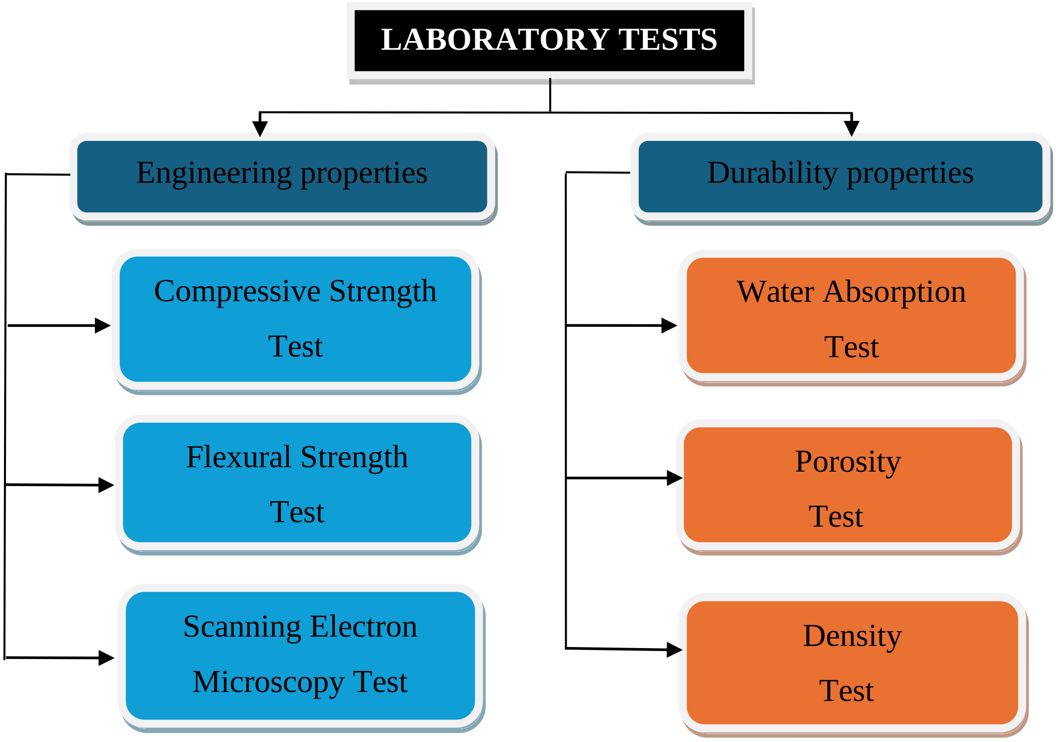

Figure 3.10: Laboratory Test for Evaluation on the Engineering and Durability Properties of CSB.

3.6.1 Compressive Strength Test

The main objective of conducting a compressive strength test is to examine the maximum axial or compressive load the CSB can take before it fails. Besides that, the load-bearing capacity of CSB specimens with different percentages of cement replacement under different curing days will be measured too. The compressive strength tests are carried out following the standards provided by BS EN 12390-3:2009. Before testing, it is necessary to calculate the cross-sectional area of the specimen on which the compressive force acts. Then, make sure that the bearing surface of the testing machine is clean. Auxiliary platens such as plywood are placed between the CSB specimen and the platens of the testing machine to ensure uniform transfer of the load from the machine. The specimen is placed in a position where the load is applied perpendicularly to the surface of the brick. A constant rate of loading in the range of 0.2 MPa/s to 1.0 MPa/s is applied to the specimen until it fails. Compressive strength of the CSB can be computed with Equation 3.1.

$$f_c = \frac{F}{A_c} \tag{3.1}$$

where,

f_c = compressive strength, in N/mm^2

F = maximum load at failure, in N

A_c= cross-sectional area of the specimen on which the compressive force acts, in mm^2

Figure 3.11: Compressive Strength Test.

3.6.2 Flexural Strength Test

Flexural strength tests are conducted on bricks to ascertain the maximum amount of bending stress that a brick can withstand before failing. It is a crucial characteristic to take into account, especially when using bricks in applications where they might be subjected to bending forces. A T-Machine Universal Testing Machine is used to conduct the flexural strength test. The test is conducted according to the standards provided by BS EN 12390-5:2009. Before the test, each specimen's center and a 40 mm offset from the end of both sides were marked. Then, place the CSB specimen on the machine with the specimen's longitudinal axis accurately centered and at a right angle to the longitudinal axes of the upper and lower rollers. Then the specimen is subjected to forces from three different points until it fails. The maximum bending stress that the specimen can take before failing will be recorded. Flexural strength of the CSB can be computed with Equation 3.2.

$$f_v = \frac{FxL}{bxh^2} \quad (3.2)$$

where,

f_v = flexural strength, in N/mm^2

F = maximum load applied on the specimen, in N

L = distance between supports, in mm

b = width of the specimen, in mm

h = height of the specimen, in mm

Figure 3.12: Flexural Strength Test.

3.6.3 Microstructure Analysis

For microstructure analysis, Scanning Electron Microscopy (SEM) is utilized to analyze the microstructure of the cement bricks after 28 days of curing. It is a specific kind of electron microscope that scans a sample's surface with a concentrated beam of electrons to create photographs of the object (McMullan, 1995). Through this method, the effect of glove former waste as supplementary cementitious materials on the microstructure of the CSB can be observed. The test is conducted according to the standards provided by ASTM C1723-16. The CSB specimen will first be crushed into smaller pieces and those with dimensions not exceeding 1 cm* 1 cm coming from the innermost cores of the specimen will be collected. The microscope is set with a 15kV of SEM accelerating voltage with multiple different magnifications like 500, 1000, 2000, and 5000x to examine the CSB specimen's insight structure. This analysis aids in comprehending the porosity, interfacial interactions, and particle arrangement inside the CSB specimen.

Figure 3.13: FESEM machine.

3.6.4 Water Absorption Test

This basic test aims to evaluate the water absorption capacity of bricks and other building materials. Bricks that absorb less water are often stronger and more resilient. The water absorption test is conducted aligned with the standards provided by ASTM C642-06. The CSB specimens are dried in an oven at a temperature of 100 to 110 °C for at least 24 hours. Then, the specimen is removed from the oven, allowed to cool to a temperature of 20 to 25 °C in dry air, and then recorded down its mass. Immerse the sample in water at about 21 °C for at least 48 hours as shown in **Figure 3.14** to ensure the specimen is saturated. Subsequently, the surface moisture of the specimen is removed with a towel and then its mass is recorded. The percentage of water absorption of the specimens can be calculated with Equation 3.3 shown below.

$$Absorption\ after\ immersion, \% = \frac{(B - A)}{A}\ x\ 100 \qquad (3.3)$$

where,

B = mass of surface-dry specimen in air after immersion, g

A = mass of oven-dried sample in air, g

Figure 3.14: Water Absorption Test.

3.6.5 Porosity Test

The porosity test is conducted on bricks to examine their porosity level, which refers to the volume of voids or open spaces within the materials. This test provides valuable information about a material's ability to absorb and retain liquid. The strength and durability of CSB samples are highly affected by the level of porosity the specimen possesses. The specimen's level of porosity has a detrimental effect on

CSB durability to a greater extent. The test is conducted according to RILEM Recommendations. The specimen is placed into the oven for drying at a temperature of 105 °C for 24 hours. After cooling, the dry weight of the specimen is measured. Subsequently, the CSB is located in a desiccator and filled with water to 1 cm above the sample as shown in **Figure 3.15**. After sealing the desiccator with high vacuum grease, the vacuum pump is allowed to run for 15 minutes and then stop for the next 2 hours. Then, the vacuum pump is switched on again for another 10 minutes. After 24 hours, the mass of CSB in water and at saturation are recorded. The level of porosity of the specimen can be calculated with Equation 3.4 shown below.

$$Porosity = \frac{M_a - M_d}{M_a - M_w} \; x\, 100 \qquad (3.4)$$

where,

M_a = Mass of saturated specimen, g

M_d = Mass of oven dried specimen, g

M_w = Mass of specimen in water, g

Figure 3.15: Porosity Test.

3.6.6 Bulk Density Test

The bulk density test aims to examine the bulk density CSB. According to ASTM C90, bricks can be classified into lightweight (<1680 kg/m3), medium weight (1680-2000 kg/m3), and (>2000kg/m3) in terms of their density. The test is conducted according to standards provided by ASTM C140/C140M-20. The CSB samples underwent a drying process in an oven for a duration of 24 hours, with the temperature set within the range of 100 to 115 °C. Following the drying procedure, the specimens were cooled to room temperature before being weighed for their dry weight. Then, the brick samples were submerged in water for 24 hours. After 24 hours, the CSBs were taken off the water and dry with a cloth to remove any excess surface water on the specimen. Subsequently, the weight of the saturated specimens was measured with buoyancy balance. The bulk density of the specimen can be calculated with Equation 3.5 shown below.

$$D = \frac{W_d}{W_s - W_i} x\, 1000 \qquad (3.5)$$

where,

D = Bulk density, kg/m^3

W_d = oven-dry weight of specimen, kg

W_s = saturated weight of specimen, kg

W_i = immersed weight of specimen, kg

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The experimental results of the mechanical properties and durability properties of the fabricated cement sand brick will be analyzed and discussed comprehensively. In terms of engineering properties, experimental tests such as compressive strength test, flexural strength test, and microstructure analysis were conducted. In terms of durability properties, experimental tests such as water absorption rate, porosity, and bulk density test were carried out. The results obtained will be used to study the feasibility of incorporating Glove Former Waste (GFW) as cement replacement in fabricating Cement Sand Brick (CSB). In this study, the CSBs were fabricated using GFW with different particle sizes respectively. The coarse GFW particles were sized between 0.30 mm and 1.70 mm while the fine GFW particles had sizes smaller than 0.30 mm. GFW was incorporated into CSB as cement replacement with different particle sizes and replacement levels of 0 %, 10 %, 15 %, 20 %, and 25 % respectively.

4.2 Characteristics of Glove Former Waste

The as-received Glove Former Waste (GFW) from Kitaran Recovery Sdn Bhd was in dry form with negligible moisture content. **Figure 4.1** shows the GFW after undergoing the sieving process. The coarse GFW had particle sizes ranging between

0.30 mm and 1.70 mm while the fine GFW had particle sizes smaller than 0.30 mm. The GFW has a pH range between 7-8 and it has a specific gravity of 2.66.

Figure 4.1: Coarse GFW and Fine GFW.

Subsequently, the chemical composition of GFW was analyzed by X-ray fluorescence (XRF). The analysis's findings are shown in **Table 4.1**. The result showed that GFW is made up of mainly silica (SiO_2) and alumina (Al_2O_3). Both silica and alumina contributed approximately 93 % of the total material mass. According to ASTM C618, a material can be considered pozzolanic if it meets the requirement of having the summation of SiO_2, Al_2O_3, and Fe_2O_3 more than 70 %. For GFW, the total of SiO_2, Al_2O_3, and Fe_2O_3 was 95.04 % which exceeds the limit of 70 % therefore can be classified as a suitable pozzolana material. Pozzolans are amorphous siliceous or siliceous and aluminous minerals that react with calcium hydroxide (CH) and water to create cementitious hydration products, including calcium silicate hydrates (C-S-H) and calcium aluminate hydrates (C-A-H) which contribute to the strength and durability of concrete (Walker and Pavía, 2010). Besides, other oxides such as MgO, CaO, MnO, CuO, and ZnO were also found in a relatively low percentage within the GFW.

Table 4.1: Characteristics of GFW.

	GFW
Colour	White
pH	7 - 8
Specific gravity	2.66

Table 4.2: Chemical Composition of GFW using XRF.

Chemical composition (%)	GFW
SiO_2	63.750
Al_2O_3	29.892
K_2O	3.171
Fe_2O_3	1.401
CaO	0.469
P_2O_5	0.459
TiO_2	0.292
Cl	0.168
Cr_2O_3	0.155
ZrO_2	0.041
MnO	0.040
Rb_2O	0.037
BaO	0.025
MgO	0.017
Eu_2O_3	0.015
ZnO	0.008
CuO	0.003
NiO	0.003

4.3 Compressive Strength

Table 4.3 and **Table 4.4** show the compressive strength of the CSB specimens with coarse and fine GFW respectively as cement substitutes at different ages.

Table 4.3: Compressive Strength of CSB with Coarse GFW as Cement Substitute.

Specimen ID	Compressive Strength (MPa)		
	7 days	14 days	28 days
GFW-0	13.674	13.930	14.256
GFW-10	10.593	11.187	12.117
GFW-15	10.314	10.548	10.804
GFW-20	8.353	9.454	9.945
GFW-25	6.881	8.266	9.895

Table 4.4: Compressive Strength of CSB with Fine GFW as Cement Substitute.

Specimen ID	Compressive Strength (MPa)		
	7 days	14 days	28 days
GFW-0	13.674	13.930	14.256
GFW-10	10.619	12.534	14.374
GFW-15	7.594	10.140	13.904
GFW-20	7.308	8.526	12.724
GFW-25	6.066	8.113	10.261

In addition, **Figure 4.2** and **Figure 4.3** illustrate the compressive strength of the CSB specimens with coarse and fine GFW respectively as cement substitutes at different ages.

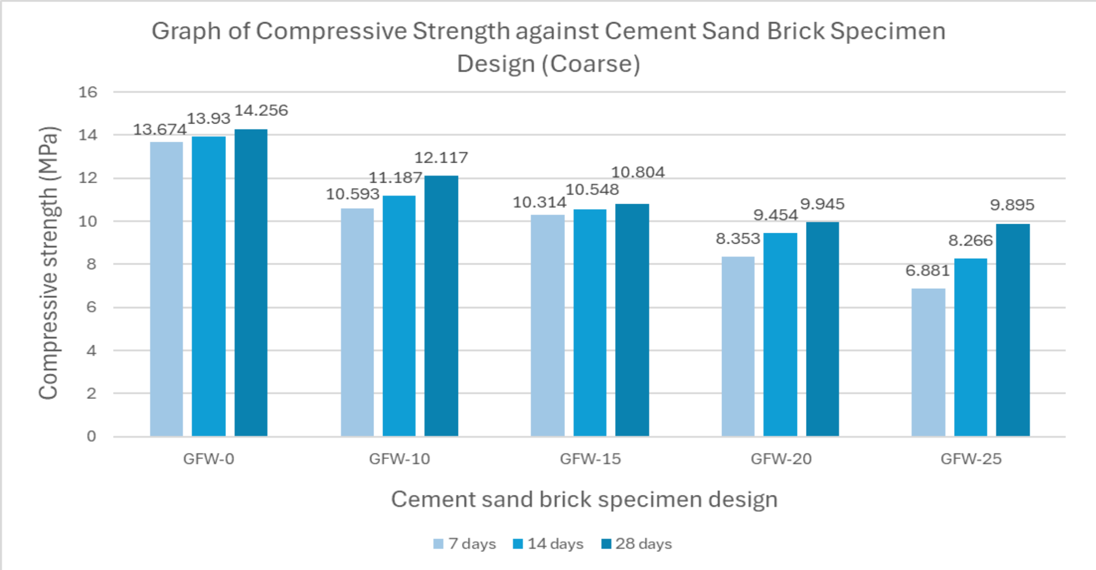

Figure 4.2: Graph showing the Relationship between Compressive Strength and Coarse CSB.

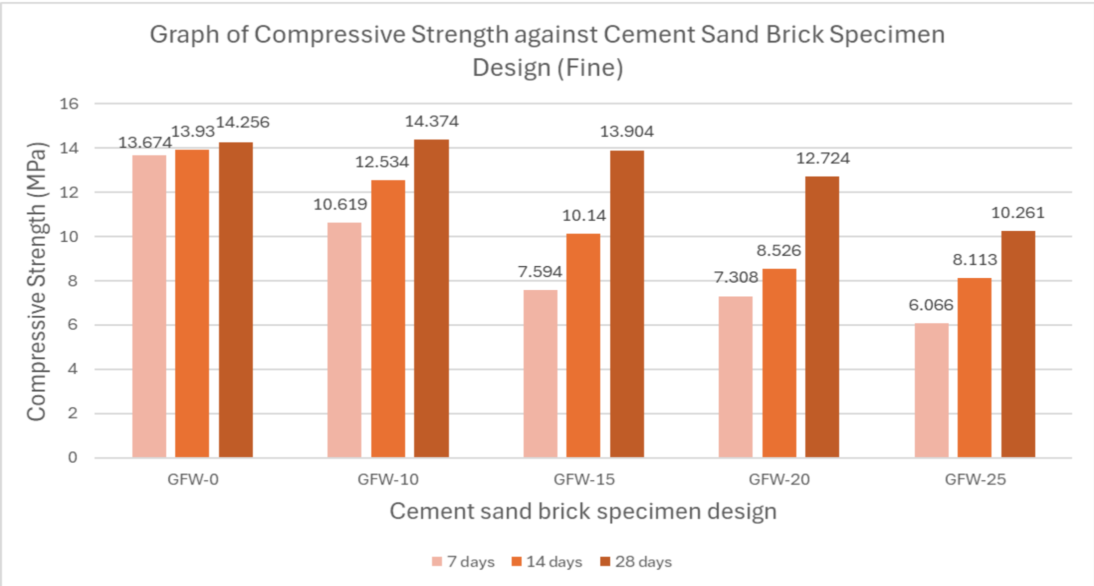

Figure 4.3: Graph showing the Relationship between Compressive Strength and Fine CSB.

Figure 4.4 and Figure 4.5 illustrate how using coarse and fine GFW respectively as a partial cement substitute affects compressive strength development over time.

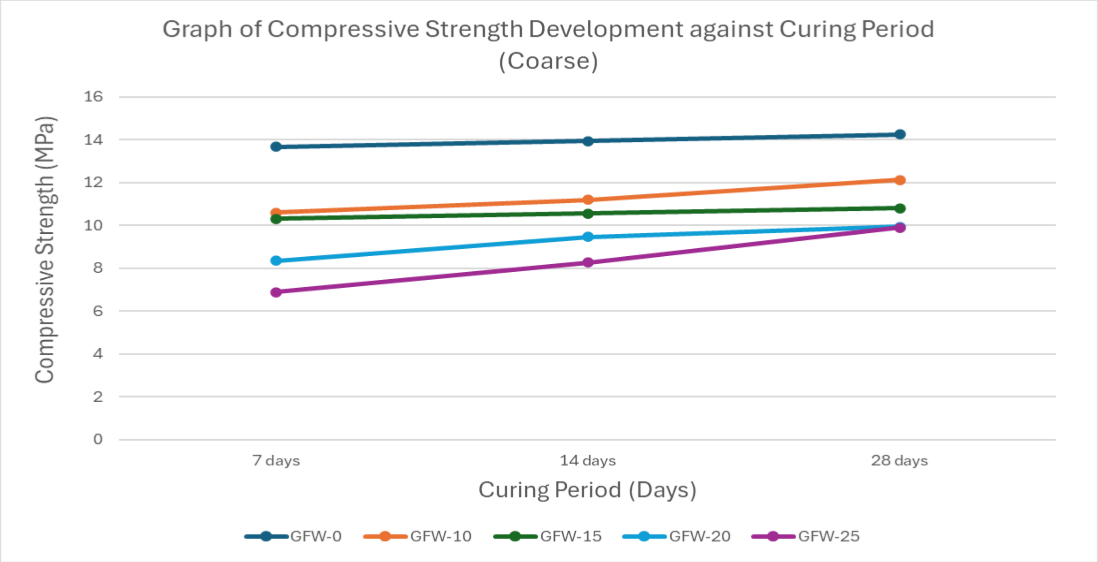

Figure 4.4: Graph of Compressive Strength Development against Curing Period (Coarse).

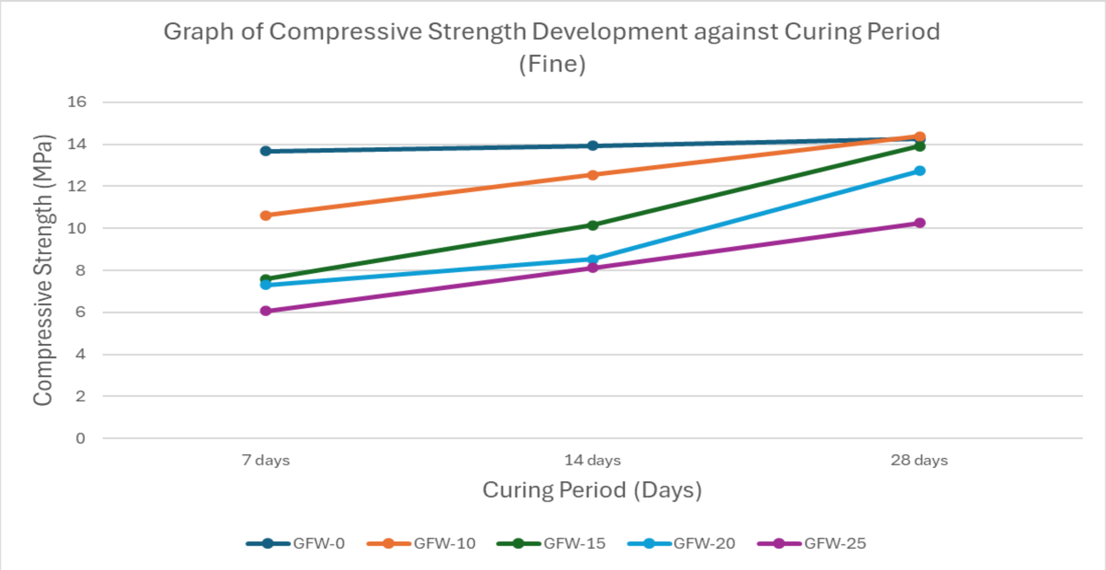

Figure 4.5: Graph of Compressive Strength Development against Curing Period (Fine).

In terms of engineering properties, compressive strength is the most important CSB metric to be examined when it comes to construction buildings. The compressive strength of the CSBs was measured after 7, 14, and 28 days at different percentages of the GFW as cement substitution. The percentages of cement substitution by GFW were 0 %, 10 %, 15 %, 20 %, and 25 % respectively, at a fixed water-cement ratio of 0.50.

Figure 4.2 shows the compressive strength of the CSB specimens with coarse GFW as cement substitution. The coarse GFW had particle sizes ranging between 0.30 mm and 1.70 mm which is considered big if compared to the cement particle size which falls within the range of 0.007 mm and 0.20 mm (Ma, Wu and Zhang, 2011). **Figure 4.4** illustrates that the compressive strength of the CSB specimen increased gradually and steadily from 7 to 28 days for all the CSB specimens. The compressive strength of CSB with 25 % cement substitution increased by 43.80 % from 6.881 MPa to 9.895 MPa after 28 days of curing. However, the compressive strength of the CSB specimens decreased as the percentage of GFW substitution increased. If compared to the controlled specimen, the compressive strength on day 28 decreased by 15.00 %, 24.21 %, 30.24 %, and 30.59 % for GFW-10, GFW-15, GFW-20, and GFW-25 respectively.

The utilization of coarse GFW to replace cement in CSB did not show improvement in compressive strength as shown in **Figure 4.4**. This could be due to the fact that the coarse GFW did not actively react with CaO from cement to form additional cementitious compounds such as C-S-H gel and C-A-H gel as it had a smaller specific surface area due to its larger particle size. Instead, the coarse GFW might function more as a filler material that partially fills empty gaps and apertures between cement, improving the granules' physical density (Tawfik et al., 2020). An additional rationale for explaining the decrease in compressive strength with the increase in GFW percentage was attributed to the phenomenon of dilution. (El-Dieb and Kanaan, 2018). The reduction in cement content as GFW increased reduced the main binding material, CH required for the hydration process to take place resulting in lesser development of calcium-silicate hydrate gel and calcium-aluminate hydrate gel. Hence, the overall compressive strength of the CSB specimens with coarse GFW as cement substitution did not improve.

Next, **Figure 4.3** shows the compressive strength of the CSB specimens with fine GFW as cement substitution. The fine GFW had a particle size smaller than 0.30 mm. Subsequently, **Figure 4.5** demonstrates that the compressive strength of the

CSB specimen increased from 7 to 28 days for all the CSB specimens. It can be noticed from **Figure 4.3** that for all the CSB specimens with cement substitution, the compressive strength grew drastically after 14 days of curing. The compressive strength after 14 days of curing increased by 14.68 %, 37.12 %, 49.24 %, and 26.48 % for GFW-10, GFW-15, GFW-20, and GFW-25 respectively. This phenomenon shows that the fine GFW exhibits the properties of good strength development at later ages of curing compared with early age. Similar observations were reported by Li et al. (2020) that the strength gain was observed at the later age of curing.

Apart from that, the overall compressive strength of the CSB specimens with fine GFW as cement substitution was higher than that of CSB specimens with coarse GFW as cement substitution. In addition, the CSB specimen with 10 % cement replacement at 28 days of age achieved the highest compressive strength with 14.374 MPa greater than the control specimen as shown in **Figure 4.3**. All the scenarios above implied that the fine GFW performed better in terms of pozzolanic reactivity. This could be due to the fact that fine GFW has a larger specific surface area which facilitates the interaction between the pozzolan and cement. The improvement in compressive strength was mainly due to the better pozzolanic reaction (Li et al., 2024). It encouraged the formation of more cementitious hydration products such as C-S-H gel and C-A-H gel when alumina and silica within the GFW react with Calcium hydroxide from cement. As a result, the microstructure densifies at the same time lowering the porosity and voids of the specimen causing the CSB to be stronger (Al-Shugaa et al., 2024).

However, the compressive strength of CSB dropped when the replacement level went beyond 10 %. This could be due to the dilution effect in which the amount of cement required for binding purposes was insufficient as the GFW replacement level increased. It caused excessive silica and alumina available in the specimen, but insufficient calcium hydroxide from the cement for the hydration process to take place (Li et al., 2024).

According to the Malaysian Standard MS 76:1972, CSB intended for use in construction masonry must achieve a minimum compressive strength of 7 MPa. All the CSB specimens fabricated with coarse and fine GFW successfully met the required minimum compressive strength as stated in the standard. The results show that CSB with 10 % cement replacement by the fine GFW provides the optimum results in terms of compressive strength. However, it is feasible to replace cement with GFW up to 25 % for the fabrication of CSB since they all met the required minimum compressive strength of 7 MPa.

4.4 Flexural Strength

Table 4.5 and **Table 4.6** show the flexural strength of the CSB specimens with coarse and fine GFW respectively as cement substitutes at different ages.

Table 4.5: Flexural Strength of CSB with Coarse GFW as Cement Substitute.

Specimen ID	Flexural Strength (MPa)		
	7 days	14 days	28 days
GFW-0	2.107	2.231	2.334
GFW-10	1.603	1.926	2.048
GFW-15	1.585	1.817	2.275
GFW-20	1.302	1.449	2.056
GFW-25	1.288	1.415	1.989

Table 4.6: Flexural Strength of CSB with Fine GFW as Cement Substitute.

Specimen ID	Flexural Strength (MPa)		
	7 days	14 days	28 days
GFW-0	2.107	2.231	2.334
GFW-10	1.424	1.502	1.548
GFW-15	1.485	1.731	1.782
GFW-20	1.427	1.596	1.602
GFW-25	0.920	1.274	1.595

In addition, **Figure 4.6** and **Figure 4.7** illustrate the flexural strength of the CSB specimens with coarse and fine GFW respectively as cement substitute at different ages.

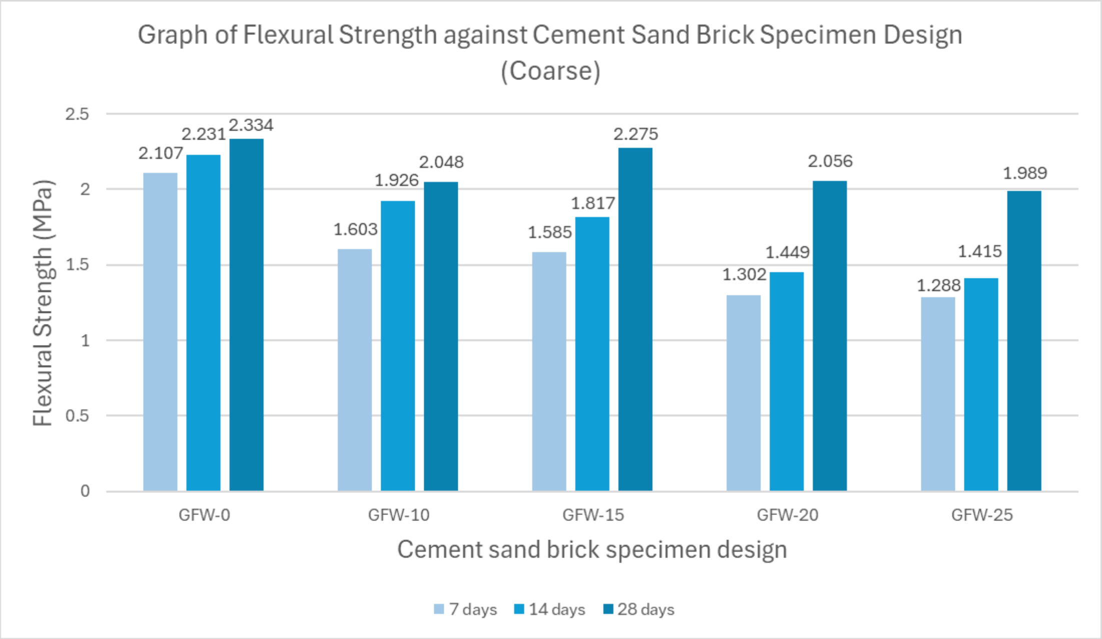

Figure 4.6: Graph showing the Relationship between Flexural Strength and Coarse CSB.

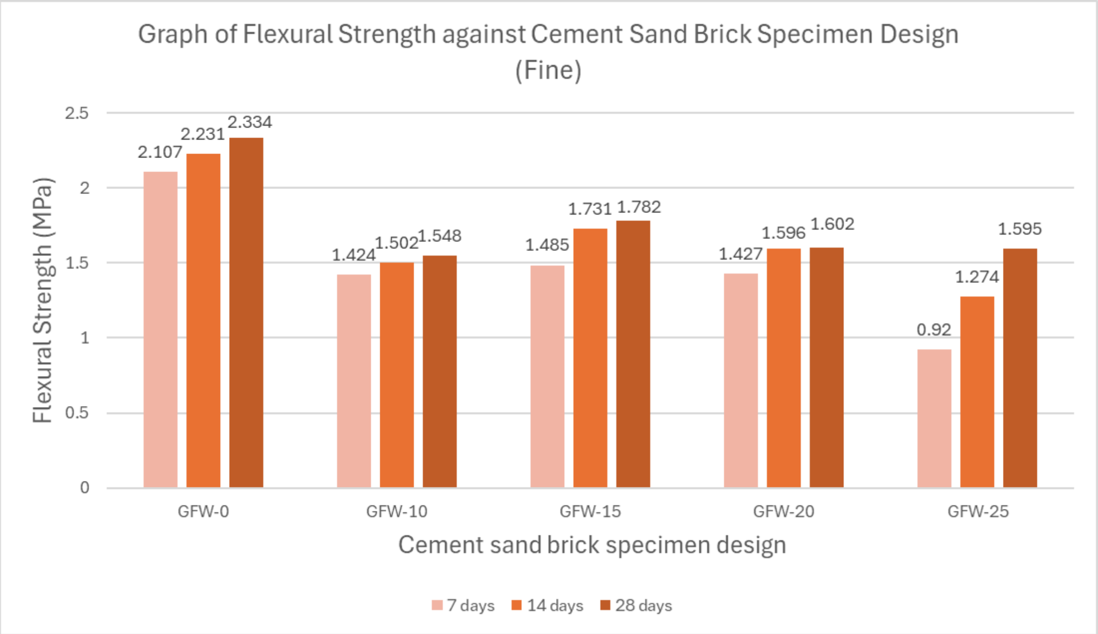

Figure 4.7: Graph showing the Relationship between Flexural Strength and Fine CSB.

Figure 4.8 and Figure 4.9 illustrate how using coarse and fine GFW respectively as a partial cement substitute affects flexural strength development over time.

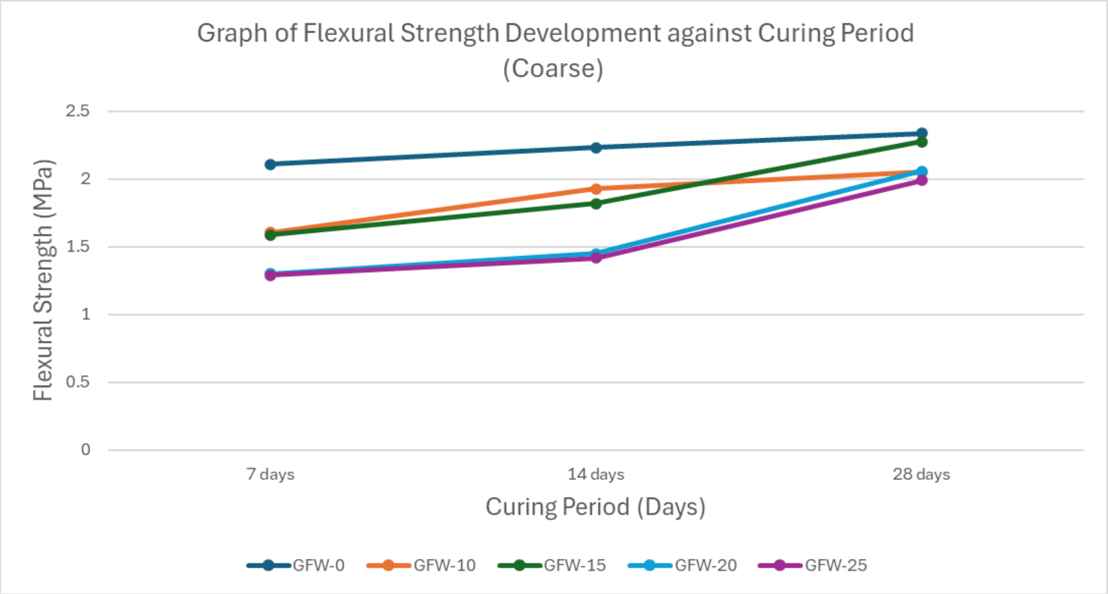

Figure 4.8: Graph of Flexural Strength Development against Curing Period (Coarse).

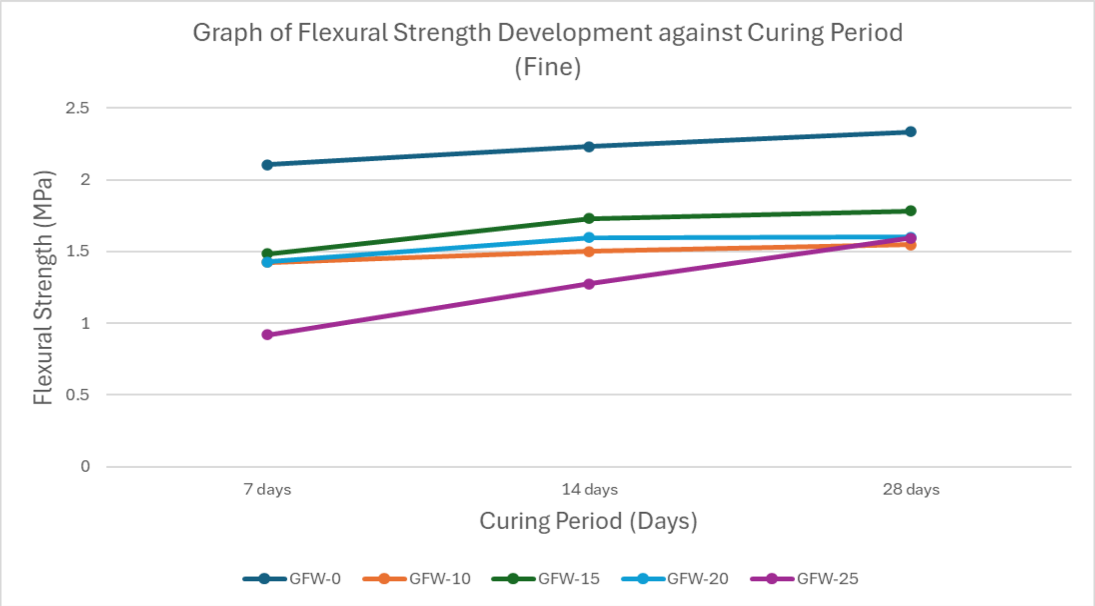

Figure 4.9: Graph of Flexural Strength Development against Curing Period (Fine).

Flexural strength is another vital CSB metric to be assessed in terms of engineering properties. The flexural strength of the CSB specimens was measured after 7, 14, and 28 days at different percentages of the GFW as cement substitution.

Table 4.5 and **Table 4.6** show the flexural strength of the CSB specimens with coarse GFW and fine GFW as cement replacement respectively. By comparing the flexural strength of the CSB specimens incorporating coarse GFW with that of fine GFW, it can be observed that the CSB specimens that utilized coarse GFW as cement replacement did achieve a higher flexural strength overall. This could be due to the fact that the coarse GFW might be functioning more as a filler material which improves the granules' physical density (Tawfik et al., 2020). Incorporating coarse GFW, which is also a hard material into the CSB specimen enhances the overall hardness of the aggregates hence improving the flexural strength of the CSB specimen. A similar observation was reported by Sivakumar et al. (2021) that by incorporating ceramic waste with similar size the flexural strength improved.

Figure 4.6 shows that the CSB specimen with 15 % cement replacement at 28 days of age achieved the highest flexural strength of 2.275 MPa among other CSBs with cement replacement. The strength gain happened after 14 days of curing proving that there was also a pozzolanic reaction between coarse GFW and cement as the properties of good strength development at later ages of GFW had shown in CSB specimens with 15 %, 20 %, and 25 % of cement replacement.

Subsequently, **Table 4.6** presents the results of the flexural strength of the CSB specimens with fine GFW as cement substitution. Then, **Figure 4.7** illustrates that the flexural strength of the CSB specimens increases from 7 to 28 days for all the CSB specimens. It can be noticed that the CSB specimen with 15 % cement substitution at 28 days of age achieved the highest flexural strength of 1.782 MPa among other CSBs with cement substitution. A similar result was observed when the CSB specimen was substituted with coarse GFW.

The elevation in flexural strength can be elucidated by the incorporation of fine GFW into the CSB specimen which induced the pozzolanic reaction between the GFW and cement. This reaction encouraged the formation of more cementitious hydration compounds such as C-S-H gel and C-A-H gel when GFW which is rich in alumina and silica reacts with CH from cement. The development of calcium-silicate hydrates and calcium-aluminate hydrates gels strengthens internal bond between sand by filling up the voids between them to reduce the porosity of the CSB specimens (Al-Shugaa et al., 2024). Hence, the flexural strength of the CSB increased from 7 to 28 days, and besides, there was an improvement in flexural strength when the substitution level went from 10 % to 15 %.

However, the flexural strength dropped when the replacement level went beyond 15 %. This might be attributed to the dilution effect whereby as the GFW replacement level rose, the amount of cement needed for binding purposes became insufficient. Even though there is extra pozzolan, the hydration process is limited due to insufficient cement (Li et al., 2024).

Based on British Standard BS 6073 Part 1:1981, it states that the CSB used as construction masonry must have a minimum flexural strength of 0.65 MPa. All the CSB specimens fabricated with coarse and fine GFW successfully met the required minimum flexural strength as stated in the standard. The results show that CSB with 15 % cement replacement by the coarse GFW provides the optimum results in terms of flexural strength. However, it is possible to substitute cement with GFW up to 25 % in the fabrication of CSB because they all have the requisite minimum flexural strength of 0.65 MPa.

4.5 Bulk Density

The results of the density of the cement sand bricks were examined after 28 days of curing. **Table 4.7** and **Table 4.8** show the results of the experiment.

Table 4.7: Density of Cement Sand Brick with Coarse GFW as Cement Substitution.

Specimen ID	Bulk Density of the CSB on day 28 (kg/m^3)
GFW-0	1822.30
GFW-10	1809.96
GFW-15	1802.98
GFW-20	1795.35
GFW-25	1790.08

Table 4.8: Density of Cement Sand Brick with Fine GFW as Cement Substitution

Specimen ID	Bulk Density of the CSB on day 28 (kg/m^3)
GFW-0	1822.30
GFW-10	1804.88
GFW-15	1795.06
GFW-20	1793.76
GFW-25	1765.99

Figure 4.10 and **Figure 4.11** illustrate the bulk density development trend as the GFW substitution level increases.

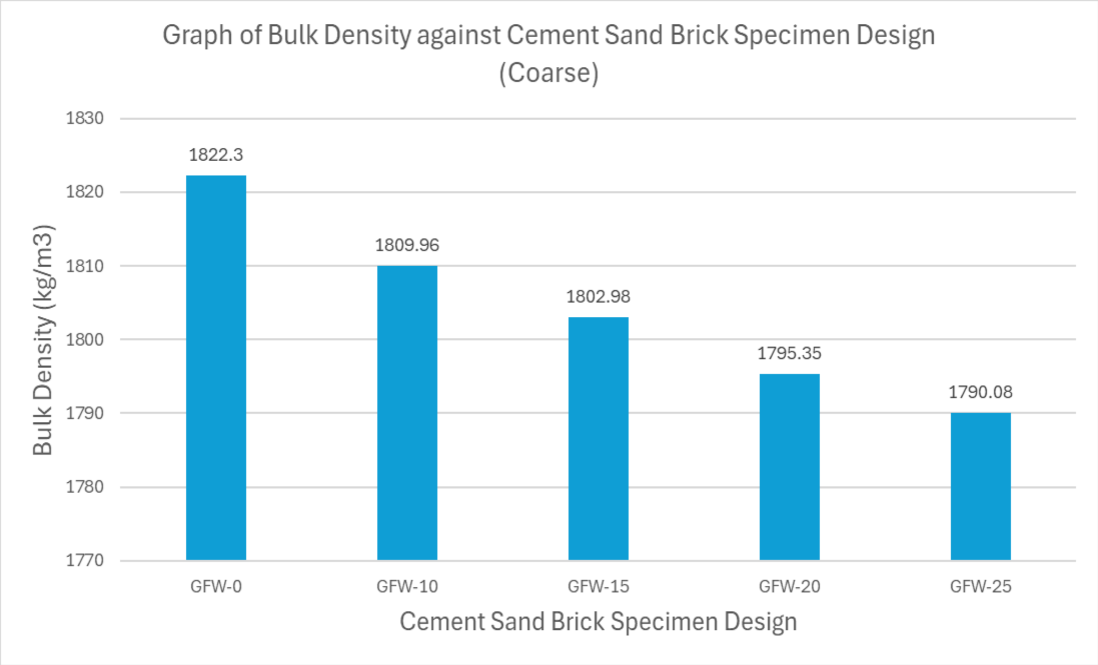

Figure 4.10: Chart showing Bulk Density versus Coarse Cement Sand Brick Design at Day 28.

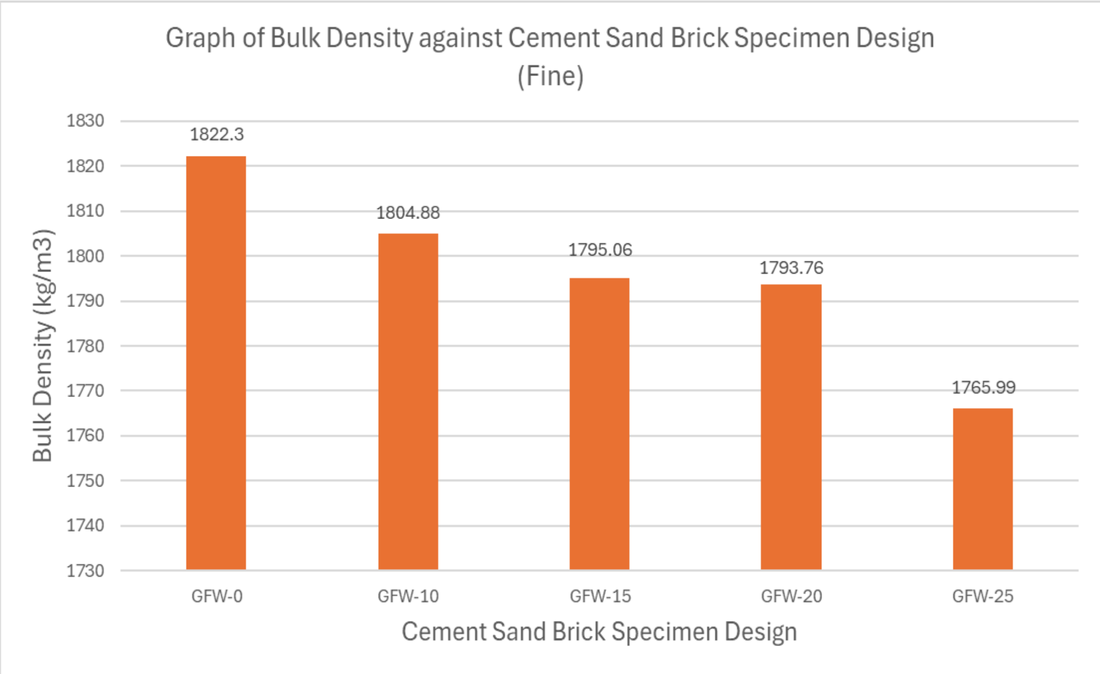

Figure 4.11: Chart showing Bulk Density versus Fine Cement Sand Brick Design at Day 28.

Based on **Figure 4.10**, the bulk density of the CSB specimen dropped steadily as the GFW substitution level increased. A similar trend is observed in **Figure 4.11** as well. The results of the bulk density of the CSB specimen did not differ much between the specimens replaced with coarse GFW and fine GFW. For coarse GFW, the CSB specimen with 10% cement replacement at 28 days of age achieved the highest bulk density of 1809.96 kg/m^3 however the bulk density dropped to 1790.08 kg/m^3 as the GFW replacement level increased to 25 %. For fine GFW, the CSB specimen with 10 % cement replacement at 28 days of age achieved the highest bulk density of 1804.88 kg/m^3 however the bulk density dropped to 1765.99 kg/m^3 as the GFW replacement level increased to 25 %. This was primarily due to the difference in specific gravity between GFW and cement. The cement was substituted by GFW which has a lower specific gravity of 2.66 if compared to cement which has a higher specific gravity. In general, cement has a specific gravity of 3.15 (Ghonaim and Morsy, 2023). GFW has a lower value in specific gravity hence it caused the reduction in bulk density of the CSB specimen as the GFW substitution level increased.

According to Malaysia Standard **MS 76: 1972**, it states that the bulk density of CSB should fall between the range of 1300 kg/m^3 to 2200 kg/m^3. All the CSB specimens fabricated with coarse and fine GFW successfully met the requirements as stated in the standard. As a result, it is possible to substitute cement with GFW up to 25 % in the fabrication of CSB as it has the lowest bulk density which makes it lighter and easier to handle during construction.

4.6 Water Absorption

Table 4.9 and **Table 4.10** show the water absorption rate of the CSB specimens with coarse and fine GFW respectively as cement substitute at different ages.

Table 4.9: Water Absorption Rate of CSB Specimen with Coarse GFW as Cement Substitution.

Specimen ID	Water Absorption Rate (%)		
	7 days	14 days	28 days
GFW-0	10.407	9.685	8.764
GFW-10	10.835	13.338	12.247
GFW-15	10.097	12.226	11.560
GFW-20	14.151	13.557	12.402
GFW-25	14.029	14.094	11.964

Table 4.10: Water Absorption Rate of CSB Specimen with Fine GFW as Cement Substitution.

Specimen ID	Water Absorption Rate (%)		
	7 days	14 days	28 days
GFW-0	10.407	9.685	8.764
GFW-10	14.141	13.337	12.162
GFW-15	12.399	11.398	11.456
GFW-20	11.477	12.078	12.559
GFW-25	14.505	14.018	13.645

In addition, **Figure 4.12** and **Figure 4.13** illustrate the water absorptivity of the cement sand brick with coarse and fine GFW respectively as cement substitute at different ages in graph form.

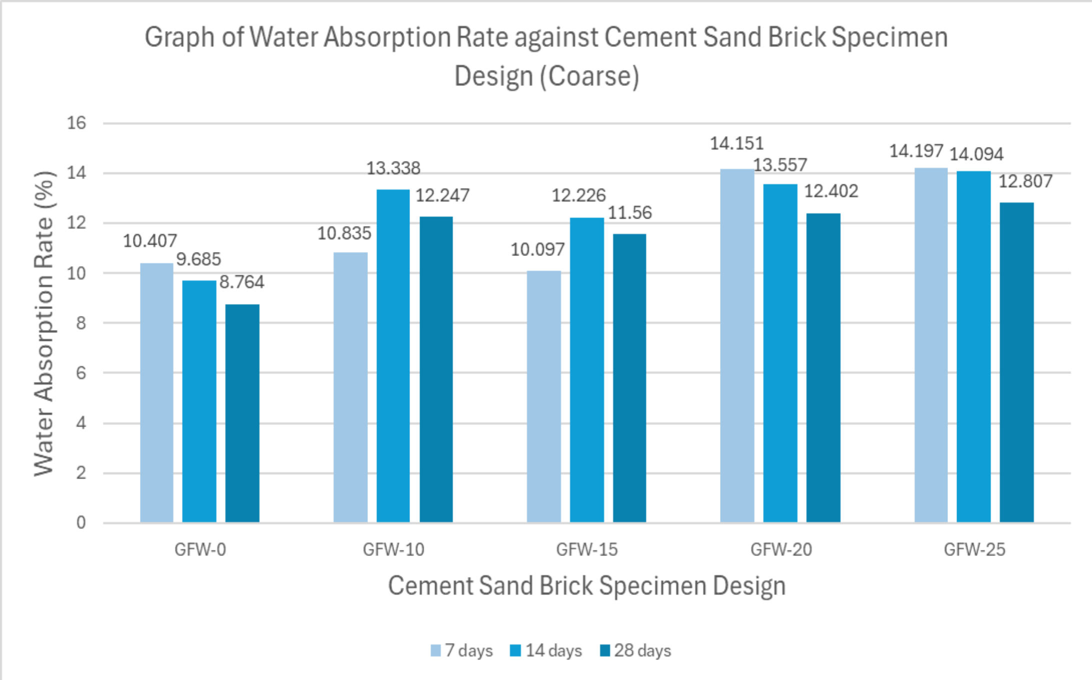

Figure 4.12: Graph Displaying Water Absorption Rate versus Coarse Cement Sand Brick Design.

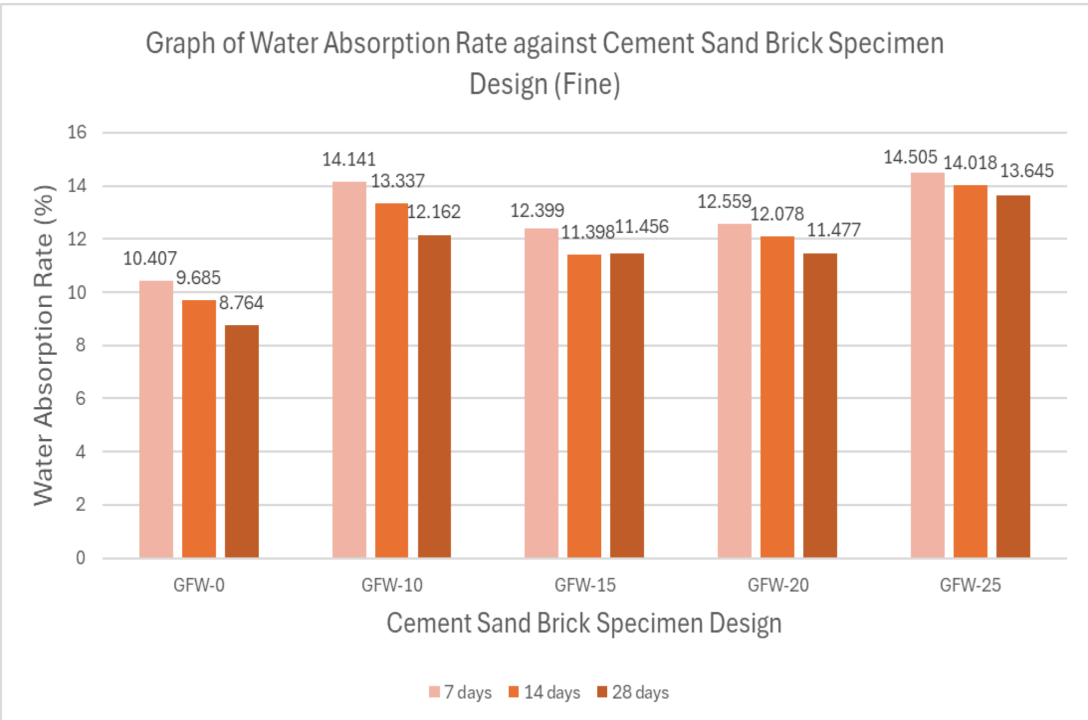

Figure 4.13: Graph Displaying Water Absorption Rate versus Fine Cement Sand Brick Design.

Figure 4.14 and Figure 4.15 illustrate how using coarse and fine GFW respectively as a partial cement substitute affects water absorption rate development over time.

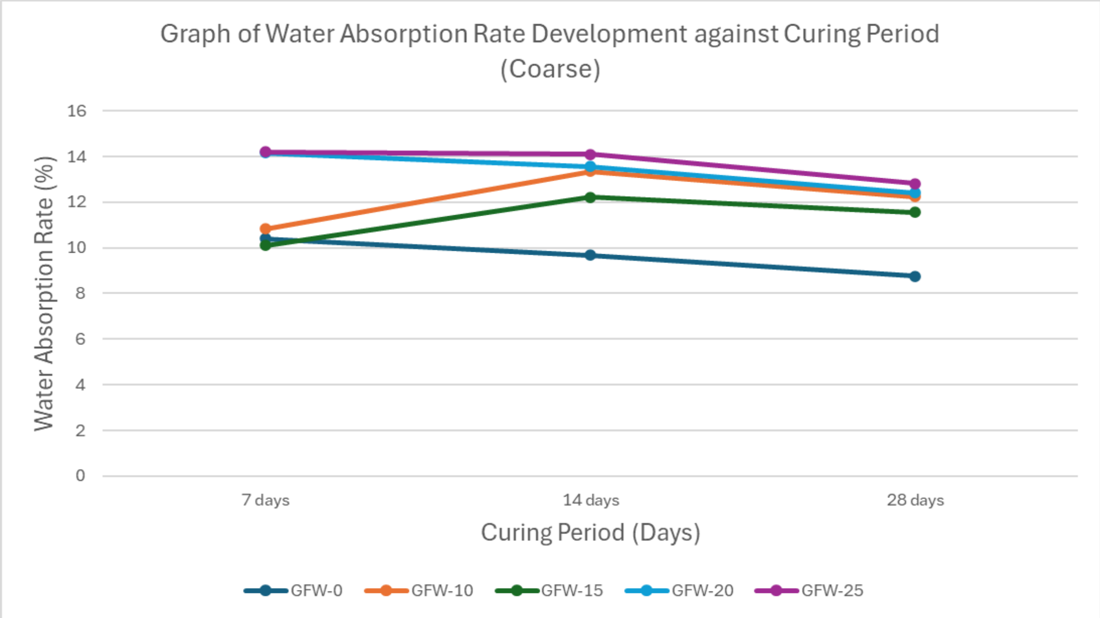

Figure 4.14: Graph of Water Absorption Rate Development against Curing Period (Coarse).

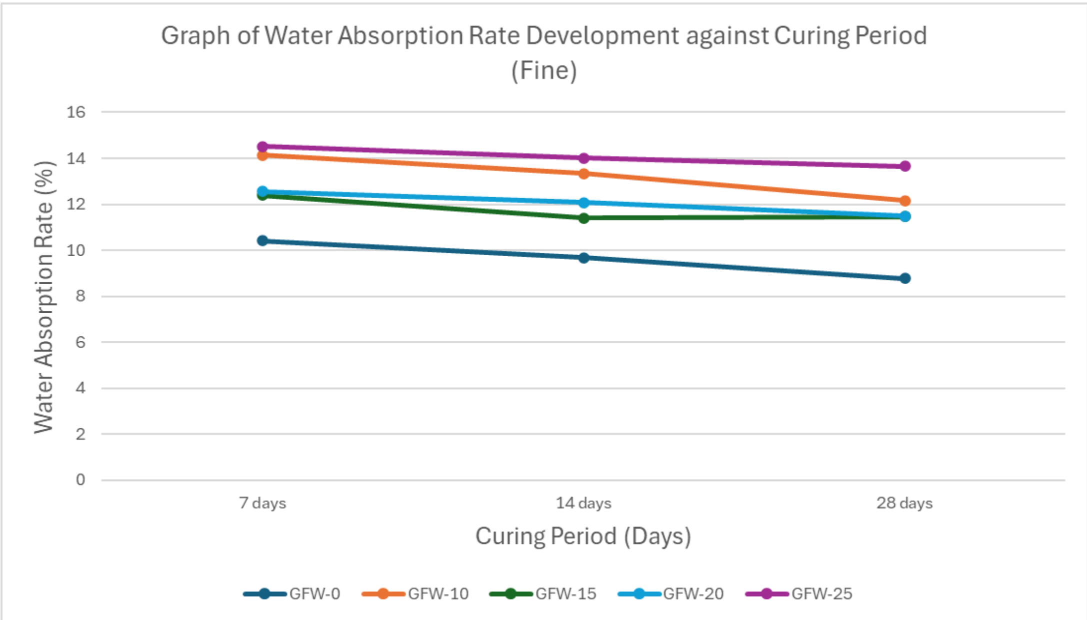

Figure 4.15: Graph of Water Absorption Rate Development against Curing Period (Fine).

Figure 4.12 depicts the water uptake rate of CSB samples integrated with coarse GFW during the 7, 14, and 28-day curing periods. As can be seen from **Figure 4.12**, the water absorption rate of the CSB specimens with 0 %, 20 %, and 25 % of cement replacement decreased gradually from day 7 to day 28 of curing. This correlates well with the result of the compressive strength and flexural strength of the specimen. In other words, the water absorption rate is inversely proportional to both the compressive strength and flexural strength. This is attributed to the pozzolanic reaction in which the GFW which is rich with reactive alumina and silica combines with active ions like Ca^{2+} and OH^{-} in cement to form new calcium-silicate-aluminate hydrates (C-S-A-H) gel (Pelisser, Steiner and Bernardin, 2012). The formation of additional cementitious gel helps to strengthen the bond between aggregates by filling up the pores between them hence reducing the porosity and water absorptivity of the specimen while on the other hand increasing the strength of the bricks.

However, the water uptake rate of the cement sand brick with 10 % and 15 % of cement replacement exhibit a different trend. It can be observed from **Figure 4.12** that the water absorption rate for specimens with 10 % and 15 % cement replacement on day 7 of curing was relatively lower compared with other specimens on day 7 of curing. This could be due to the fact that the coarse GFW might be functioning well within this range of substitution as a filler material which filled up macropores and voids between particles. Hence, the water absorption rate dropped.

Subsequently, **Figure 4.13** presents the results of the water uptake rate of the cement sand brick with fine GFW as cement substitution. It can be observed that the water absorption rate of the CSB specimens decreased gradually from 7 to 28 days for all the CSB specimens. These results highly correlate with the results of the flexural strength of the CSB specimen replaced with fine GFW. As previously mentioned, the water absorption rate is inversely proportional to the strength of the specimen. So, as the water absorption rate of the specimen decreases the strength of the specimen on the other hand increases from day 7 to 28. This indirectly proves that there was a pozzolanic reaction between the GFW and cement. As the water absorption rate decreases from day 7 to 28, it implies that the specimens are getting less porous. This is attributed to the fact that the pozzolanic reaction can produce additional cementitious compounds such as C-S-H gel and C-A-H gel when alumina and silica within the GFW react with CH from cement. As a result, the microstructure densifies at the same time lowering the porosity and voids of the specimen (Al-Shugaa et al., 2024).

According to India Standard **IS-1077:1992**, it specifies a maximum water absorption rate of 20 %. All the CSB specimens fabricated with coarse and fine GFW successfully met the requirement as stated in the standard. The results show that CSB with 15 % cement replacement by the fine GFW provides the optimum results in terms of water absorption rate. However, it is possible to substitute cement with GFW up to 25 % in the fabrication of CSB because they all achieved the requisite maximum water absorption rate of below 20 %.

4.7 Porosity

Table 4.11 and **Table 4.12** show the results of the porosity of the CSB specimens with coarse and fine GFW respectively as cement substitutes at different ages.

Table 4.11: Porosity of CSB Specimen with Coarse GFW as Cement Substitution.

Specimen ID	**Porosity (%)**		
	7 days	14 days	28 days
GFW-0	24.298	22.579	20.657
GFW-10	22.552	25.460	21.725
GFW-15	21.884	24.047	21.586
GFW-20	27.927	25.059	21.794
GFW-25	22.958	22.171	21.874

Table 4.12: Porosity of CSB Specimen with Fine GFW as Cement Substitution.

Specimen ID	Porosity (%)		
	7 days	14 days	28 days
GFW-0	24.298	22.579	20.657
GFW-10	24.894	23.721	22.010
GFW-15	23.262	23.185	21.507
GFW-20	23.864	22.800	21.855
GFW-25	27.652	25.641	25.313

In addition, **Figure 4.16** and **Figure 4.17** illustrate the porosity of the CSB specimens with coarse and fine GFW respectively as cement substitutes at different ages.

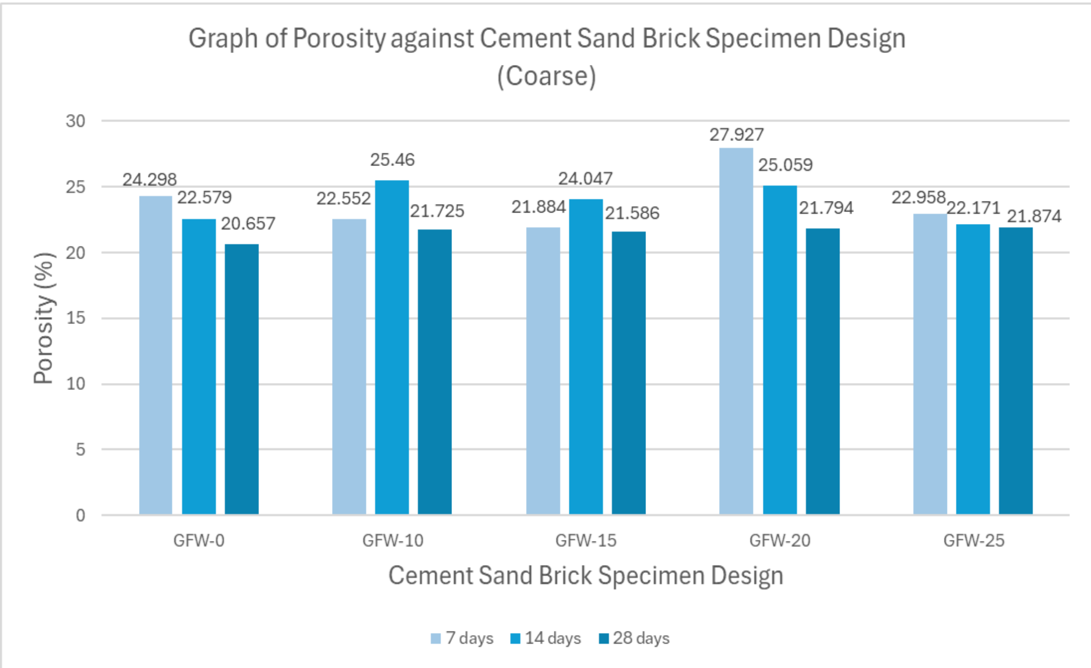

Figure 4.16: Graph Depicting Porosity in relation to the Design of Coarse Cement Sand Brick Specimens.

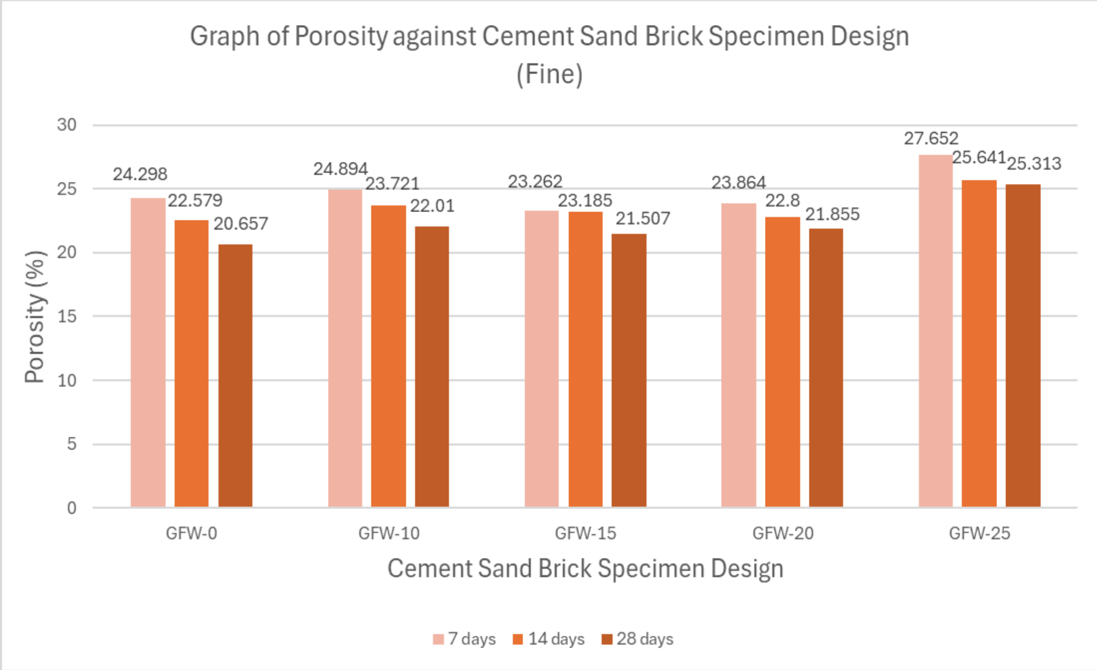

Figure 4.17: Graph Depicting Porosity in relation to the Design of Fine Cement Sand Brick Specimens.

Figure 4.18 and Figure 4.19 illustrate how using coarse and fine GFW respectively as a partial cement substitute affects porosity development over time.

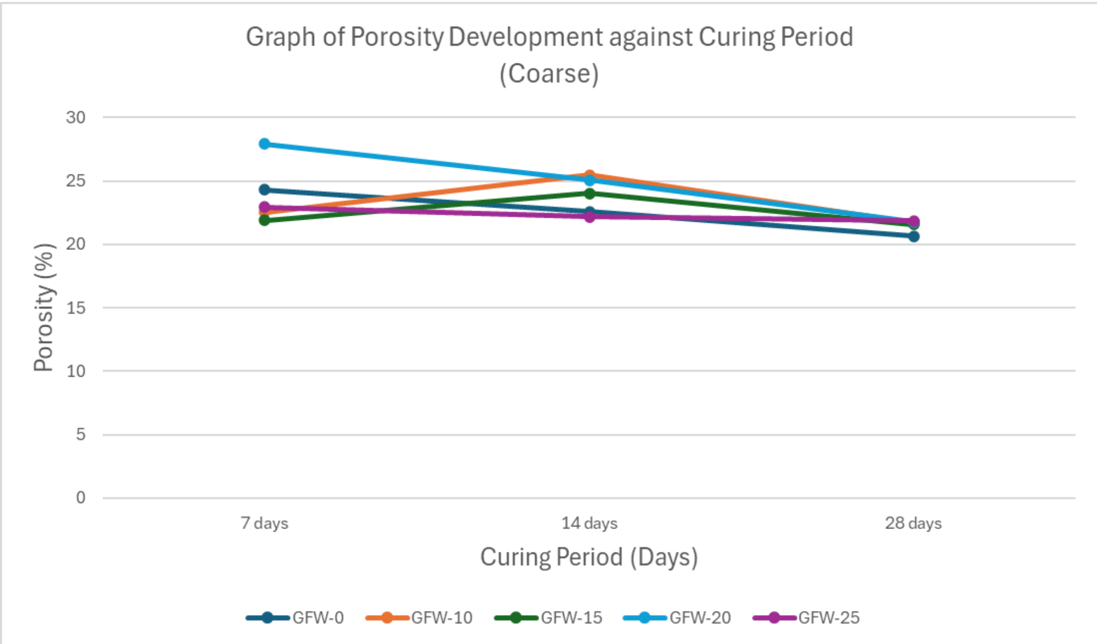

Figure 4.18: Graph of Porosity Development against Curing Period (Coarse).

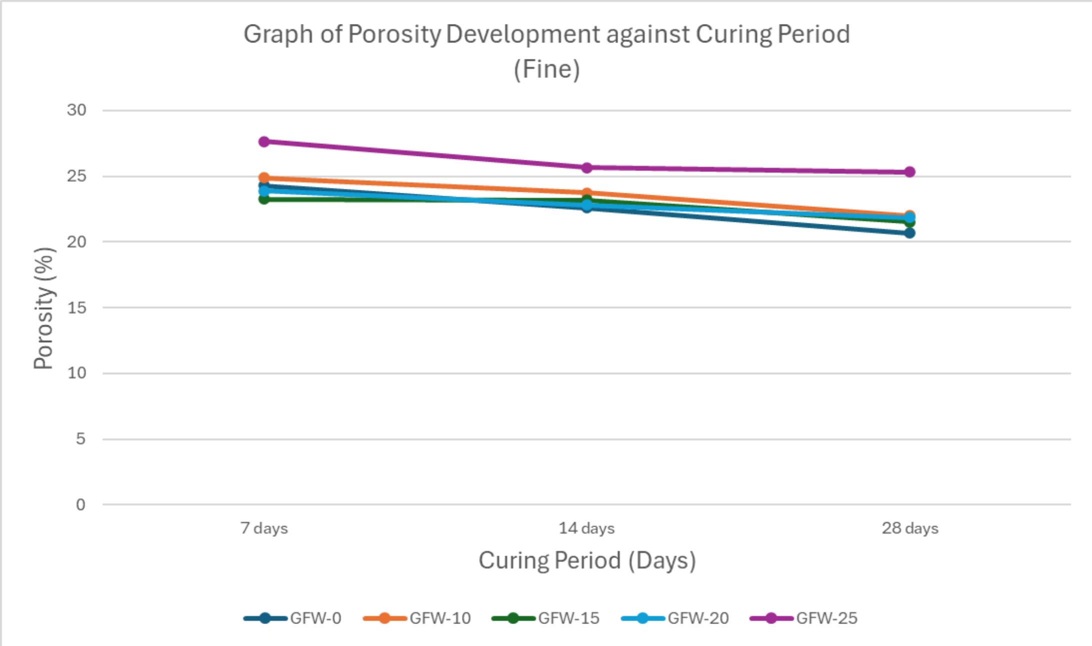

Figure 4.19: Graph of Porosity Development against Curing Period (Fine).

Figure 4.16 illustrates the porosity of CSB specimens incorporated with the coarse GFW at the 7, 14, and 28 days of curing. It can be observed from **Figure 4.16** that the porosity of the CSB specimens with 0 %, 20 %, and 25 % cement replacement decreased gradually from day 7 to day 28 of curing. These results highly aligned with the result of the water absorption test implying that the water absorption rate is directly proportional to the porosity of the specimen. Therefore, a similar trend can be observed between the result of water absorption rate and porosity. The decrease in porosity for specimens with 0 %, 20 %, and 25 % from day 7 to day 28 of curing is attributable to the pozzolanic reaction between the GFW and cement. The GFW which is rich with reactive alumina and silica combines with active ions like Ca^{2+} and OH^{-} in cement to form new calcium-silicate-aluminate hydrates (C-S-A-H) gel (Pelisser, Steiner and Bernardin, 2012). The formation of additional cementitious gel helps to strengthen the bond between aggregates by filling up the pores between them hence reducing the porosity of the specimens.

However, the porosity of the CSB specimens with 10 % and 15 % of cement replacement exhibit a different trend. It can be observed from **Figure 4.16** that the porosity for specimens with 10 % and 15 % cement replacement on day 7 of curing was relatively lower compared with other specimens on day 7 of curing. This could be due to the fact that the coarse GFW might be functioning well within this range of substitution as a filler material which filled up macropores and voids between particles. Hence, the porosity of the specimens dropped.

Next, **Figure 4.17** shows the results of the porosity of the CSB specimens with fine GFW as cement replacement. It can be observed that the porosity of the CSB specimens decreased gradually from 7 to 28 days for all the CSB specimens. These results highly correlate with the results of water absorption of the CSB specimen replaced with fine GFW. As previously mentioned, the water absorption rate is directly proportional to the porosity of the specimen. So, as the water absorption rate of the specimen decreases the porosity of the specimen, on the other hand, decreases too from day 7 to 28. This is attributed to the fact that the pozzolanic reaction can produce additional cementitious compounds such as C-S-H gel and C-A-H gel when alumina and silica within the GFW react with CH from cement. The cementitious gel acts as a binder to strengthen the bond between particles. As a result, the microstructure densifies at the same time lowering the porosity and voids of the specimen (Al-Shugaa et al., 2024).

None of the standards specify a specific minimum porosity value for CSB specimens. Therefore, water absorption rate can be used as a reference for porosity, as there is a strong correlation between these two metrics. The results show that CSB with 15 % cement replacement by the fine GFW provides the optimum results in terms of porosity.

4.8 Microstructure Analysis

To examine the alterations in the microstructure of CSB specimens with different percentages of GFW substitution, Field Emission Scanning Electron Microscopy (FESEM) analysis is performed on specimens following 28 days of curing.

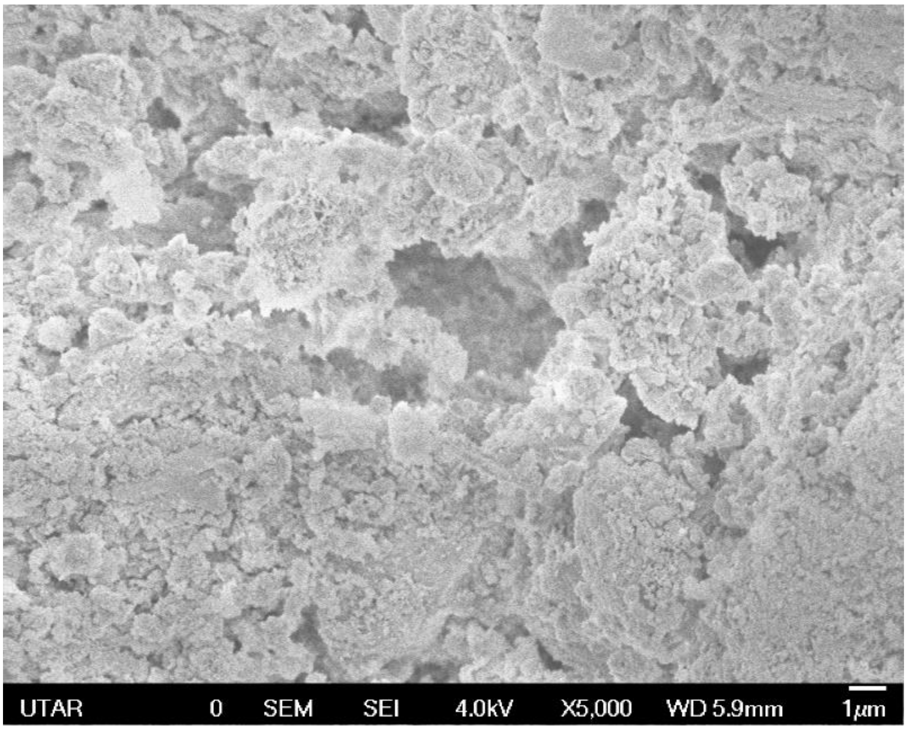

Figure 4.20: Microscopic Composition GFW-10 (Coarse).

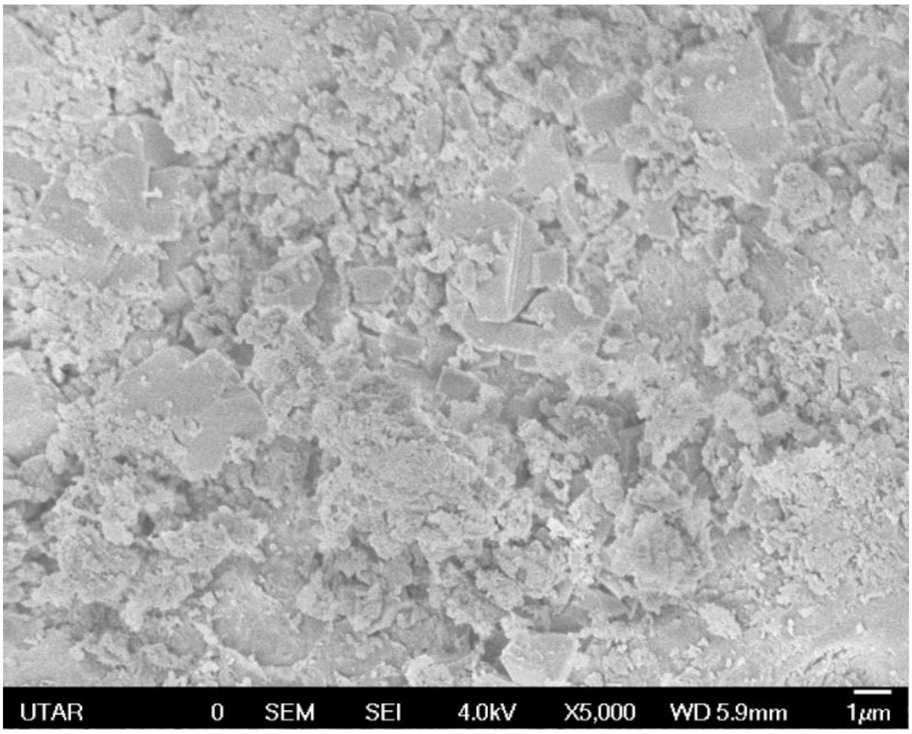

Figure 4.21: Microscopic Composition GFW-10 (Fine).

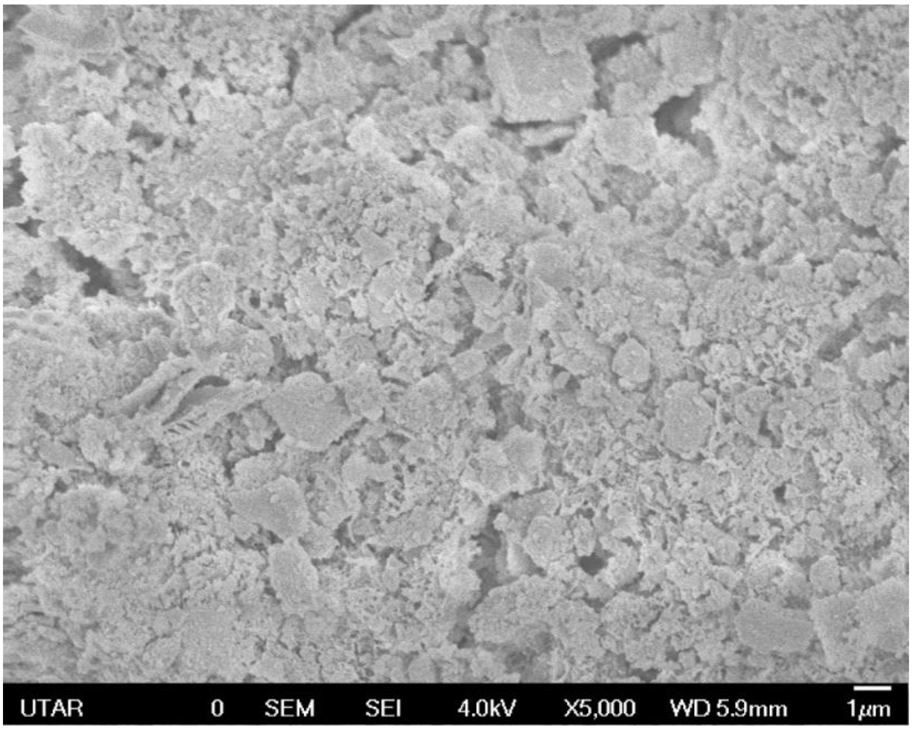

Figure 4.22: Microscopic Composition GFW-15 (Coarse).

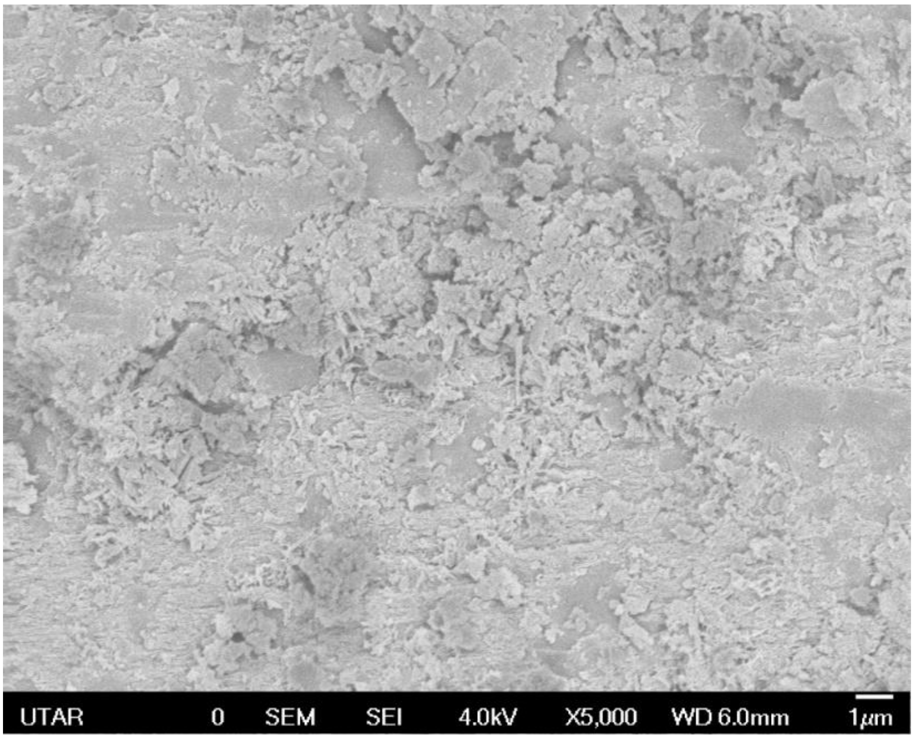

Figure 4.23: Microscopic Composition GFW-15 (Fine).

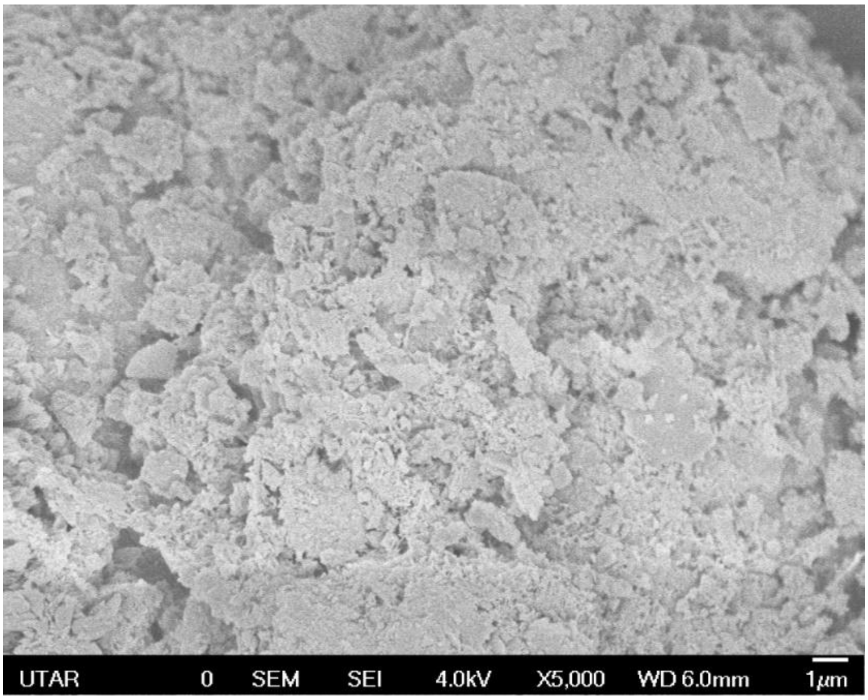

Figure 4.24: Microscopic Composition GFW-20 (Coarse).

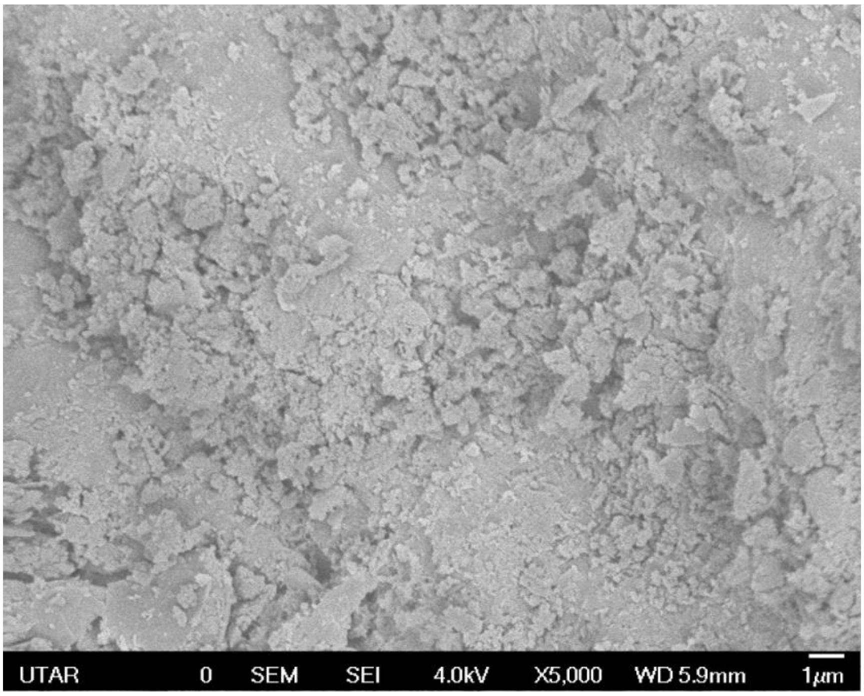

Figure 4.25: Microscopic Composition GFW-20 (Fine).

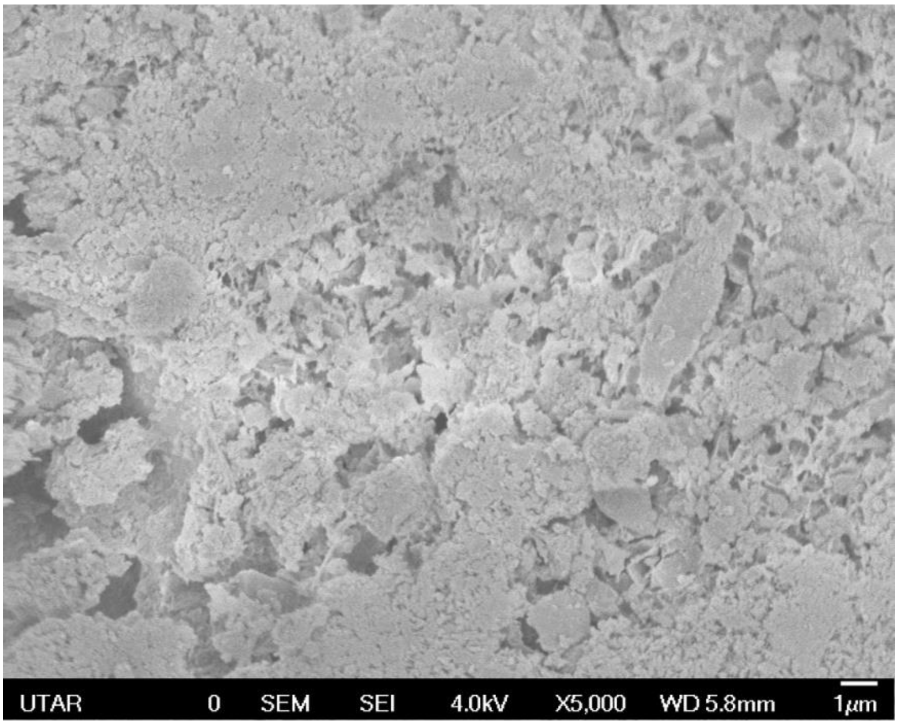

Figure 4.26: Microscopic Composition GFW-25 (Coarse).

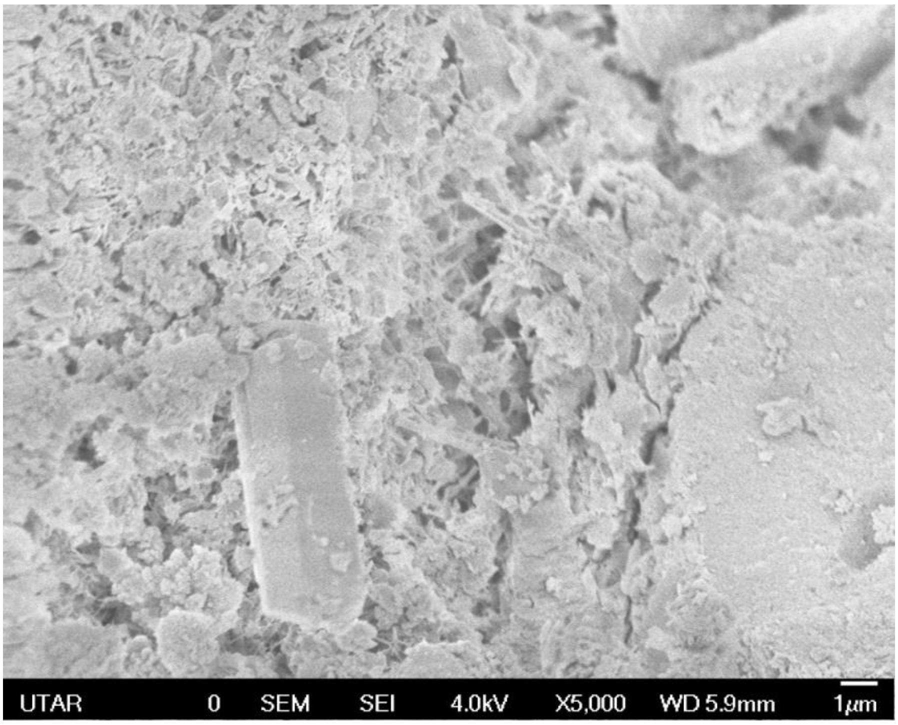

Figure 4.27: Microscopic Composition GFW-25 (Fine).

The microstructure of the CSB specimens was observed under a magnification of 5000 times. The cement sand brick with a curing period of more than 28 days was used to conduct the Field Emission Scanning Electron Microscopy analysis. The changes in the microscopic composition of the cement sand brick with increasing levels of GFW replacement can be observed from **Figure 4.20** to **Figure 4.27**. Based on observation, it can be noticed that the CSB specimen substitute with the fine GFW showed a denser and more compact microstructure compared to the CSB specimen substitute with the coarse GFW. This phenomenon can be spotted by comparing **Figure 4.22** with **Figure 4.23**. The CSB specimen with 15 % of coarse GFW as cement substitute appeared to be more porous and less compact while the CSB specimen with 15 % of fine GFW as cement substitute demonstrates a more homogeneous appearance with minimal pores and cracks. This observation implies that the fine GFW achieved a better performance as a pozzolan. This can be attributed to its higher specific surface area which makes it react more easily with cement to form additional cementitious compounds such as C-S-H gel and C-A-H gel to fill up the pores and voids within the specimen.

As shown by **Figure 4.26** and **Figure 4.27**, cracks and pores became obvious when the cement substitution level reached 25 % for both coarse and fine GFW. This finding implies that the 25 % GFW may not have supplied enough CH to completely support the reaction, which could account for the CSB specimen' lower compressive and flexural strengths. The FESEM research revealed that replacing cement with GFW in CSB specimens had a substantial impact on its microstructure and elemental makeup. This is due to pozzolan reactions, CH consumption, and the creation of more C-S-H gel (Al-Shugaa et al., 2024).

Overall, fine GFW performed better than that of coarse GFW. The maximum amount of GFW that could be added without negatively affecting the characteristics of the microstructure of the CSB specimen was 15 % based on the analysis.

4.9 Comparative Evaluation of Fabricated Cement Sand Brick

According to the results obtained, all the CSB specimens on day 28 with GFW as cement substitution met all required standards for compressive strength, flexural strength, bulk density, and water absorption rate. The GFW-25 specimen can be deemed as an ideal specimen among all the specimens with GFW substitution as it satisfies every need and achieves the maximum amount of cement replacement.

Table 4.13: Contradistinction of CSB Standard Requirements with Actual Experimental Outcomes (Coarse).

Parameters	**Standard Requirements**	**CSB Specimens (Coarse)**				
		GFW-0	GFW-10	GFW-15	GFW-20	GFW-25
Compressive Strength (N/mm^2)	> 7 N/mm^2 (MS 76:1972)	14.256	12.117	10.804	9.945	9.895
Flexural Strength (N/mm^2)	> 0.65 N/mm^2 (BS 6071 Part 1:1981)	2.334	2.048	2.275	2.056	1.989
Bulk Density (kg/m^3)	1300 – 2200 kg/m^3 (MS 76:1972)	1822.30	1809.96	1802.98	1795.35	1790.08
Water Absorption (%)	< 20% (IS-1077:1992)	8.764	12.247	11.560	12.402	11.964

Table 4.14: Contradistinction of CSB Standard Requirements with Actual Experimental Outcomes (Fine).

Parameters	Standard Requirements	CSB Specimens (Fine)				
		GFW-0	GFW-10	GFW-15	GFW-20	GFW-25
Compressive Strength (N/mm^2)	> 7 N/mm^2 (MS 76:1972)	14.256	14.374	13.904	12.724	10.261
Flexural Strength (N/mm^2)	> 0.65 N/mm^2 (BS 6071 Part 1:1981)	2.334	1.548	1.782	1.602	1.595
Bulk Density (kg/m^3)	1300 – 2200 kg/m^3 (MS 76:1972)	1822.30	1804.88	1795.06	1793.76	1765.99
Water Absorption (%)	< 20% (IS-1077:1992)	8.764	12.162	11.456	12.559	13.645

4.10 Cost Analysis

As shown in **Table 4.15**, the total cost of fabricating one GFW-0 specimen is RM 0.413 while on the other hand, the cost of fabricating one GFW-25 specimen is RM 0.331. The cost of fabricating a CSB specimen reduces by 19.85 % if there is a reduction in cement usage by 25 %. Hence, it is relatively cheaper to fabricate GFW-25 which consumes 25 % less cement as cement is the most expensive material among all the other materials. According to the price quoted by Lau Tat Sdn Bhd, which is a hardware shop, the price of cement sand brick costs RM 0.35 per unit. So, producing a single GFW-25 specimen costs 5.43 % less than the selling price of a regular CSB as compared to the market selling price. Therefore, it is more economical and environmentally friendly to utilize GFW-25 specimens as building materials since it has a relatively lower price and lower cement content compared to the conventional CSB.

Table 4.15: Cost Analysis of One Control Unit of GFW-0 vs GFW-25.

		GFW-0		**GFW-25**		**Difference (%)**
Composition	Price per unit	Unit	Total (RM)	Unit	Total (RM)	
Cement	RM 0.500 per kg	0.660 kg	0.330	0.495	0.248	24.85
Sand	RM 0.037 per kg	2.244 kg	0.083	2.244	0.083	0
Water	RM 0.00145 per kg	0.330 kg	0.000479	0.330	0.000479	0
Total Cost			**0.413**		**0.331**	**19.85**

*The price per unit of cement and sand was based on the quotation from Man Tong Hardware Shop.
*The water cost was based on the latest water tariff rate from Lembaga Air Perak (Lembaga Air Perak, 2022).

4.11 Estimation of Carbon Dioxide Emissions

Based on **Table 4.16**, it states that 0.6088 kg of CO_2 will be released to fabricate a single unit of normal CSB specimen. On the other hand, the fabrication of GFW-25 CSB specimen releases only 0.4608 kg of CO_2 which is lower compared to the normal CSB specimen. The total CO_2 emissions by the fabrication of CSB dropped by 24.31 % if there was a reduction in cement usage by 25 %. This makes CSB specimens with 25 % of GFW replacement an eco-friendly building material with a lower carbon footprint.

Table 4.16: Comparison of the Carbon Dioxide Emission of One Control Unit of GFW-0 vs GFW-25.

		GFW-0		**GFW-25**		**Difference (%)**
Materials	CO_2 Emission	Unit (ton)	Total (kg)	Unit (ton)	Total (kg)	
Cement	900 kg/ton of cement	0.000660	0.594	0.000495	0.446	24.92
Sand	6.6 kg/ton of sand	0.002244	0.0148	0.002244	0.0148	0
Total Emission (kg)			**0.6088**		**0.4608**	**24.31**

*The data on CO_2 emissions for each ton of cement production was retrieved from (Fayomi et al., 2019)
*The data on CO_2 emissions for each ton of sand was retrieved from (Zhu et al., 2023)

4.12 Sustainable Development Goals & Circular Economy

According to the results, the fabrication of CSB with GFW incorporated as cement replacement demonstrates a positive result in terms of its engineering properties and durability properties. It successfully met all the standard requirements even though the GFW replacement level reached the highest level of 25 %. Besides, it is a cheaper option compared to conventional cement sand brick making it more economical in construction. In addition, the fabrication of CSB with GFW incorporated emits less carbon dioxide gas compared to the conventional cement sand brick.

Figure 4.28: Sustainable Development Goals that Aligned with Current Research (United Nations, 2015).

Based on the results, this research work aligns with several Sustainable Development Goals (SDGs) outlined by the United Nations. First, the fabrication of eco-friendly CSB contributes to SDG 9: Industry, Innovation, and Infrastructure. Building material innovation is demonstrated by the use of GFW to partially replace cement in the production of bricks, a move that supports the development of sustainable construction materials. It is encouraging more effective and sustainable ways to repurpose waste materials in construction. Next, this research promotes sustainable cities and communities that fall under SDG 11. This research provides an environmentally friendly alternative for construction materials that help to reduce the environmental impact of urban development. Subsequently, the fabrication of CSB with GFW incorporated as cement replacement helps reduce carbon dioxide emissions associated with brick manufacturing. By partially replacing the cement with GFW, it helps to lower the carbon footprint of the construction industry and contributes to efforts to mitigate climate change which aligns with SDG 13: Climate Action.

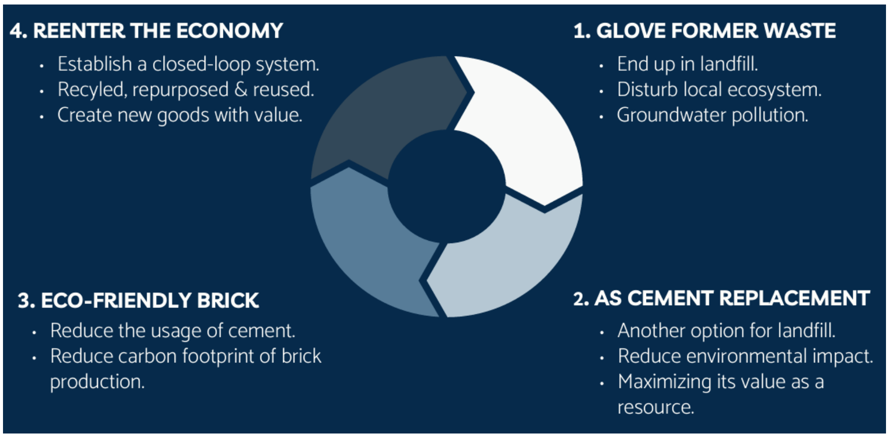

Figure 4.29: Circular Economy of Utilization of GFW in CSB Fabrication.

The approach of incorporating GFW as partial cement replacement complies with the concept of circular economy. This could help to reduce the amount of glove former waste that ended up in landfills which negatively affects our environment. By utilizing glove former waste as cement replacement, it acts as an alternative solution for landfill disposal which could help in reducing the environmental impact of glove former waste. At the same time, it is also maximizing its value as a resource. Subsequently, through this method, the usage of cement in brick production can be reduced thereby reducing the overall carbon footprint of brick manufacturing. This approach successfully establishes a closed-loop system in which glove former waste is recycled, repurposed, and reused to maximize its value by creating new goods which are bricks.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study focused on investigating the feasibility of utilizing glove former waste (GFW) from glove manufacturing companies to partially replace cement in producing eco-friendly cement sand brick (CSB). The chemical characteristics of GFW had been studied too in this research to identify its suitability as pozzolans. Various laboratory tests were conducted to evaluate the engineering and durability properties of the specimens. Based on the experimental results, all the CSB specimens with 10, 15, 20, and 25 % of GFW as cement replacement had met the required standard after 28 days of curing. The results of this study may therefore be summed up as follows:

1. GFW can be classified as a suitable pozzolana material that can be used as an alternative to partially replace cement since it has more than 70 % SiO_2, Al_2O_3, and Fe_2O_3 based on its chemical composition.
2. Fine GFW inhibits the growth of compressive strength particularly in the early stages but promotes good strength development at later stages. This indicates that the GFW's pozzolanic effect intensifies over time, particularly in later stages.
3. Coarse GFW improves the flexural strength of the CSB specimens when the GFW replacement level reaches 15 %.

4. The coarse and fine GFW-25 specimens achieve the optimum cement replacement percentage, meeting the standard requirements for compressive strength, flexural strength, water absorption rate, and bulk density.
5. The fabrication of GFW-25 specimens produces less carbon dioxide and requires less cost compared to the conventional cement sand brick.

5.2 Recommendations

Below are several proposed recommendations for the future fabrication of CSB with GFW as cement replacement:

1. Perform a comprehensive evaluation of the long-term engineering properties, durability, and environmental implications associated with substituting GFW for cement in CSB.
2. Explore the viability of integrating GFW with other supplementary cementitious materials as substitutes for cement in the production of environmentally sustainable CSB, through further research.
3. Replace sand with lightweight aggregates in CSB production to decrease its overall weight.

The aforementioned recommendations stem from insights garnered during the research study. These suggestions could prove beneficial for future research pertaining to this subject.

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