FEASIBILITY STUDY ON THE FABRICATION OF ECO-FRIENDLY CONSTRUCTION MATERIAL FROM DYE INDUSTRY WASTEWATER TREATMENT SLUDGE

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

Faculty of Engineering and Green Technology
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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 DYE INDUSTRY WASTEWATER TREATMENT SLUDGE”** was prepared by **Toh Wei Hong** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Civil Engineering (Environmental) at Universiti Tunku Abdul Rahman.

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Supervisor : Ir. Ts. Dr. Leong Kah Hon

Date : 3 May 2023

Specially dedicated to
my beloved mother and father

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ABSTRACT

The construction industry is rapidly developing in the whole world due to urbanization and population growth. The rising demand for housing infrastructure caused increased construction activity, leading to a high volume of brick manufacture. Fired brick is the most common brick that is used in construction due to low maintenance and high durability. However, the production of fired brick releases many toxic gases and carbon footprints that can cause serious air pollution. Therefore, cement sand brick (CSB) also known as non-fired brick is invented to substitute fired brick as it is more environmentally friendly and easier to manufacture. Although it can decrease the demand for fired brick, development in CSB also leads to a massive amount of cement production. The cement manufacturing sector is a major contributor to greenhouse gas emissions that will lead to climate change and dust pollution. On the other hand, textile dyeing sludge is a hazardous industrial waste produced via textile dyeing wastewater treatment system. It contains various toxic organic compounds that can affect the aquatic environment if it is not managed properly. Thus, textile dyeing sludge (TDS) is chosen for the substitution of cement in the fabrication of CSB in order to minimize the production of cement while also lowering TDS generation. The objectives of this research are to study the feasibility of the fabrication of eco-friendly cement sand bricks with partial replacement of sludge from dye industry wastewater treatment. Besides that, this research aims to analyse the engineering properties and durability characteristics of the CSB to identify the optimum TDS replacement percentage TDS. The substitution percentage of TDS is 5%, 10%, and 15%, at the same time two different particle size ranges of TDS will be tested in this feasibility study. All the specimens in this study were tested in three different curing periods (7, 14, and 28 days), and analysed the engineering properties and durability of the specimens after being replaced with textile dyeing sludge. The tests included compressive strength, microstructure analysis, flexural strength, water absorption, bulk density, and porosity. After the tests, this feasibility study found that the substitution of textile dyeing sludge does not increase the engineering properties and durability characteristics of CSB due to the lower amount of calcium oxide (CaO) content, higher sulphate concentration, and excessive Loss of Ignition (LOI) value that can produce pores and voids to affect its durability. However, the optimum specimen is 15FTDS as it satisfies all the standard requirements. The final test result of the 15FTDS is compressive strength: 8.07 MPa; flexural strength: 1.52%; bulk density: 1784.51kg/m^3; porosity: 23.14%; water absorption: 9.09%. In addition, the substitution of 15 % TDS reduces the total carbon dioxide (CO_2) emissions by 14.64% per unit and 11.86% of production cost compared to conventional CSB which promotes a more sustainable future. In conclusion, the replacement of cement with TDS in the fabrication of CSB is feasible to achieve sustainable new product generation by reducing waste production and resource consumption which is addressed by Sustainable Development Goals (SDGs) (SDG 1, SDG 9, SDG 11, SDG 12, and SDG 13.) and promoting circular economy by utilizing waste material from the dye manufacturing industry.

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LIST OF SYMBOLS / ABBREVIATIONS

%	Percentage
<	Less than
°C	Degree Celsius
μm	Micrometre
g	gram
kg	kilogram
kg/m^3	Kilogram per cubic metre
Kg/ton	Kilogram per ton
kV	Kilovolt
kWh	Kilowatt hours
mg/kg	Milligram per kilogram
mm	Millimetre
mm^2	Millimetre square
MPa	MegaPascal
N	Newton
N/mm^2	Newton per milimetre square
RM	Ringgit Malaysia

$3CaO.Al_2O_3.12H_2O$	Calcium monosulfoaluminate
AAs	Aromatic amines
Al	Aluminium
$Al(OH)_3$	Aluminium hydroxide
Al_2O_3	Alumina
ASTM	American Society for Testing and Materials
Br	Bromine
BS EN	British Standard European Norm
C_3S	Tricalcium silicate

Ca	Calcium
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
$CaO.Al_2O_3.3CaSO_4.32H_2O$	Calcium Sulfoaluminate
$CaZn_2(OH)_6\cdot 2H_2O$	Calcium hydroxyl zincate
Cd	Cadmium
CH_4	Methane
CKD	Cement kiln dust
Cl	Chlorine
Cl_2	Chlorine gas
CO	Carbon monoxide
CO_2	Carbon dioxide
Cr	Chromium
CSB	Cement Sand Brick
CSEB	Compressed stabilized earth brick
C-S-H	Calcium-silicate-hydrate
Cu	Copper
Cuo	Copper (II) oxide
F	Fluorine
Fe	Iron
Fe_2O_3	Iron oxide
Fe_3O_4	Iron (II, III) oxide
FESEM	Field Emission Scanning Electron Microscopy
GGBS	Ground granulated blast furnace slag
GHG	Greenhouse gas
H_2O	Water
H_2SO_4	Sulphuric acid
HCl	Hydrochloric acid
HCN	Hydrogen cyanide
K	Potassium
K_2O	Potassium oxide
LOI	Loss of Ignition
$MgCO_3$	Magnesium carbonate
Mgo	Magnesium oxide

Mn	Manganese
MnO	Manganese (II) oxide
MS	Malaysia Standard
$Na_2SO_4.10H_2O$	Sodium sulphate decahydrate
NaOH	Sodium hydroxide
NH_3	Ammonia
Ni	Nickel
NO	Nitrogen oxide
NO_x	Nitrogen oxides
O_2	Oxygen
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PAHs	Polycyclic aromatic hydrocarbons
PAHs	Polycyclic aromatic hydrocarbons
Pb	Lead
PbO	Lead (II) oxide
POPs	Persistent organic pollutants
S	Sulphur
Sb	Antimony
Sb_2O_3	Antimony oxide
SDGs	Sustainable Development Goals
SEM	Scanning Electron Microscopy
Si	Silicon
SiO_2	Silica dioxide
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
TDS	Textile dyeing sludge
Ti	Titanium
TiO_2	Titanium dioxide
Zn	Zinc
ZnO	Zinc oxide

CHAPTER 1

INTRODUCTION

1.1 Research Background

Bricks have been used by humans for centuries as a construction material. They are architectural features with a rich history. Bricks are commonly employed in masonry structures connected with cement, interlocks, and adhesives. The manufacturing of bricks has been traced back, to times dating around 7000 BC (Murmu & Patel 2018). Brick has played a significant part in the evolution of human civilization as the basic building material of diverse structures. Brick-making techniques have advanced over the centuries and the development of mass-manufacturing methods has simplified the incorporation of bricks in residential building projects. Bricks offer diverse uses in construction including sidewalks, walls, chimneys, fireplaces, and more. They are able to withstand various weather conditions, have low maintenance requirements, and have high durability (Murmu & Patel, 2018).

There are two main types of bricks which are fire bricks and non-fire bricks. Fire bricks are also called refractory bricks. It is commonly used for furnaces, fireboxes, and kilns to resist high temperatures as these bricks are specially built to withstand severe heat conditions. Fire bricks are primarily made of fireclay that has been hardened through kiln firing. During the firing process of brick, several gases are produced such as water vapour (H_2O), carbon dioxide (CO_2), oxygen (O_2), chlorine (Cl_2), sulphur dioxide (SO_2), carbon monoxide (CO), HCN (hydrogen cyanide), ammonia (NH_3), fluorine (F), and NO (nitrogen oxide) (Ukwatta et al., 2018). The release of toxic gases has significant consequences for air quality and environmental impact. Besides that, the burning of fuel in brick firing will also contribute to the depletion of non-renewable energy resources. On the other hand, non-fired brick is a form of brick that does not undergo the traditional firing process. Instead of being fired at high temperatures, these bricks are made through natural drying methods or low-temperature techniques. For example, compressed stabilized earth brick (CSEB) and cement sand brick (CSB) are types of non-fired bricks.

Compressed stabilized earth brick (CSEB) is a construction material made by compressing a mixture of soil such as sand or clay and a stabilizer together under high pressure to form a brick and then allowing it to cure. The stabilizing agent, typically lime or cement can improve the durability and water resistance of the bricks. CSEB is a sustainable and environmentally beneficial replacement for conventional fired bricks as it offers many advantages including low energy consumption, decreased environmental impact, and low production cost. Cement sand brick (CSB) is a construction material made from a mixture of cement, water, and sand. These components are mixed to form bricks and subsequently undergo a curing process to gain hardness and strength. CSB offers high fire resistance which is commonly used for fire-resistant structures. Besides that, they are a cost-effective alternative to conventional building materials and their lightweight simplifies the construction process as well. Additionally, the manufacture of CSB is much easier than fire brick as it does not involve a firing process which helps minimize environmental pollution.

According to Pang and Abdullah (2013), the textile industry is one of the rapidly developing industries and has made an important economic contribution to Malaysia. While the textile industry has improved Malaysia’s economy and provided many job opportunities, it also consumes a significant amount of water which leads to a high amount of effluent and pollutant load. In the dyeing and finishing process of textile fibres, the discharged dye is a major contributor to environmental pollution. Treating this effluent individually via biological, physical, and chemical approaches is often expensive and results in substantial sludge quantities. Textile dyeing sludge (TDS) is a hazardous industrial waste generated through textile dyeing wastewater treatment. TDS contains various toxic organic materials including dyeing agents, additives, surfactants, polycyclic aromatic hydrocarbons (PAHs), persistent organic pollutants (POPs), aromatic amines (AAs), and heavy metals. Every year, the textile dyeing industry in China generates a huge amount of wastewater, reaching around 2.1 billion tonnes, with 21 million tonnes of sludges (Liu et al., 2020).

There are several methods for the disposal of sludges such as composting, incineration, and landfilling. Currently, the incineration method is a widely used treatment method as it not only allows for energy recovery but also reduces the volume of sludge effectively. However, the expense of incineration residue disposal and infrastructure maintenance is high, especially for the textile dyeing sludge as it consists of high heavy metal concentration and is classified as hazardous waste. Therefore, incineration is not suggested for treating this sludge due to poof calorific value and hazardous by-products (Chen et al., 2023). Hence, landfilling is the most traditional and cost-effective method for disposing of hazardous waste. However, it requires a significant amount of land space and has the potential to cause groundwater pollution due to leachate. Design regulations for hazardous waste landfills are enforced to reduce the risk of hazardous waste being released into the environment such as leachate collecting systems and leak detection systems. Thus, recycling the dyeing sludge for brickmaking is one of the solutions to reduce environmental pollution and decrease the usage of land space occupation.

Cement is an important binding material used in brick construction. It is formed by grinding a combination of limestone, clay, and other materials. According to Supriya et al. (2023), between 2000 and 2006, the global manufacture of cement increased by 54% from 1.6 billion tons to 2.55 billion tons and increased to 4.4 billion tons in the year 2021. There is an anticipated increase in global cement production, which is expected to rise between 12% and 23% by 2050. Approximately 7% of worldwide carbon dioxide (CO_2) emissions come from the cement industry, which produces a minimum of 2.1 billion tons of carbon dioxide annually. Production of clinker also contributed to a negative impact on the environment. Apart from that, using the high-temperature kiln to produce cement will release air contaminants into the environment which causes adverse air pollution.

A circular economy is an economic concept that aims to build a closed-loop system that emphasizes resource recovery and reuse by reducing waste and resource consumption to produce new products. This strategy aims to decrease the usage of new resources and reduce greenhouse gas (GHG) emissions that cause environmental pollution and affect human health. In this method, the waste of the process will become the input to other processes (Nautiyal & Goel, 2021). Therefore, the reduction of cement in the brick will contribute to the reduction in CO_2 emissions and minimize air pollution. This research also complies with the SDGs to create a more sustainable future. Besides that, since textile dyeing sludge is hazardous waste, recycling sludge to replace the cement in the brick to form an eco-friendly construction material is a sustainable and environmentally friendly method.

1.2 Problem Statements

Nowadays, due to urbanization and population growth, the construction industry is rapidly expanding and developing in many parts of the world. On top of this, the country's economic growth has also increased construction activity. As a result, it drives the demand for residential areas and infrastructure. Brick is the most suitable material for the construction of residential and commercial areas as it is cost-effective, has low maintenance, and has high durability. Fired brick also called conventional brick is the common type of brick used in masonry which will gain strength via the firing process. This process releases several toxic gases that can lead to air pollution and also affect human health if accidentally inhaled. Thus, non-fired brick is more environmentally friendly compared to fired brick as it does not require a firing process and uses fossil fuel to cause depletion of non-renewable energy.

Cement is a significant material used in brickmaking as it binds clay, sand, and aggregates together and helps to enhance the mechanical properties of the brick which can be used in the construction of buildings and infrastructures. The hydration process will occur when the cement is mixed with water to solidify the brick. The cement industry is classified as the major contributor to GHG emissions, responsible for approximately 7% of worldwide CO_2 emissions. Based on global CO_2 emission data, cement plants were accountable for 2.9 billion tons of CO_2 emissions in 2021 which is an increase from 0.57 billion tons released in 1990 (Supriya et al., 2023). During the manufacturing process, a large amount of carbon emissions will lead to climate change and increase the global temperature. Besides that, it will also contribute to dust pollution since particulate matter such as PM10 and PM2.5 will be emitted throughout the extraction, packaging, loading, and unloading processes, affecting the air quality, and reducing visibility. In addition, it has the potential to cause water pollution and bring a negative impact on animals and human health if the released dust is not managed properly. Hence, the textile dyeing sludge is being used to replace cement partially in the CSB while enhancing the strength and durability, at the same time reducing the environmental issues and aligning with Sustainable Development Goal 12: Responsible consumption and production.

1.3 Aims and Objectives

The goal of the feasible study is to investigate the reaction of the TDS as the partial substitution of cement in the manufacturing of CSB to reduce cement usage. Thus, the optimum replacement percentage of TDS in the fabrication of CSB is evaluated in this research study. The objectives of this feasibility study are listed below:

i) To study the feasibility of the fabrication of the eco-friendly cement sand brick with partial replacement of sludge from dye industry wastewater treatment.
ii) To analyse the engineering properties and durability properties of the CSB.
iii) To evaluate the optimum replacement percentage of textile dyeing sludge in the fabrication of CSB.

1.4 Outline of Study

The purpose of this study is to determine the feasibility of the fabrication of CSB using textile dyeing sludge from dye industry wastewater treatment sludge. Two different particle sizes range of textile dyeing sludge will be used in this study. The efficiency of the cement sand brick is going to be tested in the lab after the different percentages of cement substitution with textile dyeing sludge (fine particles of 5, 10, and 15%, coarse particles of 10, and 15%). In order to compare results and evaluate the performance of CSB with various partial replacement percentages of TDS, a control specimen with 0% replacement is fabricated. The CSB is moulded into a standard brick using a steel mould with the dimensions of 210mm x 90mm x 90mm. A constant compression force of 3.5 metric tons is applied to all the specimens. The curing process is conducted for all the specimens for 7, 14, and 28 days respectively. The specimens are brought to the lab for laboratory tests to determine and analyse the engineering and durability characteristics of CSB. Examples of the engineering properties test are the compressive strength test, flexural strength test, and microstructure analysis while the bulk density test, porosity test, and water absorption test are for the durability properties of CSB.

1.5 Overall Thesis Framework

Table 1.1 Research Thesis Framework

Chapter	Title	Scope of Chapter
1	Introduction	• Introduction to brick. • Introduction to fired bricks and their impacts on the environment. • Introduction to non-fired bricks and their advantages. • Introduction to textile dyeing sludge and its impacts on the environment.

		• Introduction of the disposal method of textile dyeing sludge. • Introduction to cement, cement industry, and its impacts on the environment. • Introduction to circular economy. • Research study's aim and objective.
2	Literature Review	• General background of the bricks. • General background of the clay brick. • Properties and disadvantages of clay brick. • Relevant past research on the fabrication of clay brick. • General background of the compressed stabilizer earth brick (CSEB). • Properties and disadvantages of CSEB. • Relevant past research on the fabrication of CSEB. • General background of cement sand brick (CSB). • Properties and advantages of CSEB. • Relevant past research on the fabrication of CSB. • General background of cement. • Properties and disadvantages of cement. • General background of textile dyeing sludge (TDS). • Properties and disadvantages of TDS. • Current disposal method of TDS. • General background of circular economy and SDGs.
3	Research Methodology	• Introduction of research methodology.

		• Materials preparation of the cement sand brick such as sand, cement, and textile dyeing sludge. • Materials mixing design of CSB. • Moulding, demoulding, and curing process of the CSB specimens. • Details procedures of laboratory tests for CSB.
4	Result and Discussion	• Characteristics of textile dyeing sludge. • Evaluate data obtained from the different laboratory tests. • Analyse mechanical and durability properties of CSB. • Comparison evaluation of CSB. • Economic evaluation of CSB. • CO_2 emission comparison of CSB.
5	Conclusion and Recommendation	• Conclusion of the feasibility study. • Recommendation for future feasibility study of CSB.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Three different types of brick which are clay brick, compressed stabilizer earth brick and cement sand brick are covered in this chapter including general background, properties, advantages, disadvantages, and relevant previous research. Besides that, the properties and disposal methods of textile dyeing sludge are discussed. Apart from that, circular economy and sustainable development goals are introduced in this literature review.

2.2 History of Brick

Brick is one of the earliest construction materials. In Egypt, hand-moulded and sun-dried bricks were discovered in the lower layer of the Nile as early as 14,000 BC. The first recorded use of brick was attributed to the ancient city of Ur (Modern-day Iraq), which was built of mud around 4,000 BC. Similarly, the first walls of Jericho were constructed of bricks in 8000 BC. The knowledge of the preservation of clay bricks through firing has been recorded since 500 BC. Early civilizations living along the Euphrates, Tigris, and Indus left archaeological evidence of fired and unfired bricks. In addition, the Romans also used fire bricks and introduced this technique to England. However, after the Romans left England in 412 AD, brick production experienced a decline until a later recovery by Flemish brickmakers. Most countries across the world continued to produce various types of brick which proved versatile and useful in construction. Bricks were among the items sent by the First Fleet to Australia together with the moulds and skilled bricklayers (Kadir and Sarani, 2012).

The brick industry offers a wide range of products, providing an unlimited range of colours, textures, and patterns. In 1996, the industry in Victoria produced 300 million bricks and it has many export markets such as New Zealand, Japan, the Middle East, and other Asian countries (Kadir and Sarani, 2012). Besides that, the brick industry has evolved and expanded dramatically because of the large part of modern equipment such as heavy excavating equipment, tunnel kilns, electric motors, and others. It has significantly increased brick manufacturing capacity. (Zhang et al., 2018). Currently, the global annual manufacturing of bricks has reached 1391 billion units due to the constant advancement of construction technology and the increased demand for building materials globally (L. Zhang, 2013) Hence, brick remains an important and versatile building material, connecting the historic heritage and modern construction practices, and meeting the evolving needs of the construction industry on a worldwide scale.

2.2.1 Clay Brick

Clay brick is a burnt block formed after the firing process in a kiln. Clay brick masonry remains the earliest and strongest human construction technique. Mansory is composed of tiny, sturdy, pieces that are carefully assembled by hand. This technique can involve either the use of mortar or not. It was used as an important architectural element in civilizations such as Mesopotamia, Egypt, and during the Roman era (Fernandes, Lourenço, and Castro, 2010). Clay bricks are normally used in the construction of interior and exterior walls, foundations, piers, foundations, and other load-bearing constructions. The development of masonry could be recognized as the initial phase of civil engineering history. Clay bricks have been used to build several significant global landmarks. For instance, the Colosseum in Rome, the pyramids, the

Great Wall of China, and the Taj Mahal in India (Phonphuak and Chindaprasirt, 2015). Over time, the utilization of clay bricks increased and improved, reaching a unique level and increasing its benefits. Furthermore, clay brick building was utilized throughout the medieval and contemporary periods. Despite various adjustments to the application, shape, and production of clay bricks throughout thousands of years, the fundamental simplicity that contributed to its effectiveness has remained unchanged. Many popular buildings constructed using clay bricks have persisted until the 21st century, which showed the ability of the material to withstand centuries of snow, sunlight, rainstorms, earthquakes, and degradation caused by human activity (Fernandes, 2019).

The main components of the clay brick are clay, along with clayey soil, shale, and soft slate. These raw materials are normally extracted from open pits which can damage the vegetation, wildlife habitats, and drainage system. Clay was a significant raw material in ancient Mesopotamia where many buildings were constructed using clay bricks. The composition of the clay used to make brick greatly depends on the soil's source area. Clays are produced by the breakdown of rocks like granite and pegmatite while those clays employed for brick production are often obtained from alluvial or watery deposits (Kadir and Sarani, 2012). The process of clay formation takes millions of years as the sediment accumulates and undergoes the lithification process. Clay minerals consist of kaolinite, illite, talc, montmorillonite and pyrophyllite. The major components of their complicated chemical composition are silica (SiO_2) and alumina (Al_2O_3). Therefore, clay minerals are mostly silicate which is the biggest and most complicated mineral class. Besides silica and alumina, iron oxide (Fe_3O_4) is also common in clay deposits. The colour of fired bricks is given by the iron oxide, and it also can decrease the fusion point to allow the firing process to become easier (Fernandes, 2019).

Due to the growth of urbanization, the demand and the quality of bricks increased as well to meet the requirement. Various methods have been used to enhance the brick quality. In its early stages, sun-baked brick was initially produced using natural heat. After that, to reduce the brick deformation and cracking, grass and chopped straw were added to the clay mixture. Around 4000 BC, an important development in brick quality occurred with the introduction of clay brick firing to improve strength and durability (Phonphuak and Chindaprasirt, 2015). Based on the fundamental principles used for thousands of years, there are four stages of manufacturing fired clay bricks. These four stages include choosing and preparation of clays, mixing and moulding, drying the raw materials, and firing clay bricks. At first, the raw clay is extracted and placed in an outdoor storage area to undergo decomposition over a few days or weeks. The raw material is mixed during this phase to reduce the number of soluble salts and maintain its uniformity. Besides that, the selection of good-quality raw materials is significant as it influences the durability and strength of the brick. However, it also depends on the location of the construction site (Fernandes, Lourenço, and Castro, 2010).

After that, the raw materials are crushed and mixed with water. The amount of water added to the raw materials is determined by the size of the materials usually the finer the finished product, the more water added. In addition, the products should have enough plasticity for easy moulding as over-plasticity in the raw clays cause severe shrinkage during the drying process. To solve this issue, sand is added to reduce the plasticity of clay. The well-mixed clay is then dried for a week or even more times. The drying process will be faster in the hotter climate, but direct sun exposure should be avoided to prevent the bricks from cracking. On the other hand, the drying process needs to take longer when in the cold region due to the high humidity level and low temperature. However, the excessively quick drying process will lead to the surface of the brick hardens before the core hardens, leaving the core of the brick unfinished for a longer time. The final stage is to put the brick into the kiln for a firing process of around 1000°C to enhance the chemical and mechanical properties of the brick as well as the durability of the brick. Different firing temperatures and clay qualities produce different ceramic products. In addition, the firing conditions are critical to the final performance of the brick, as it will significantly affect the durability and strength of the masonry (Fernandes, 2019).

The main properties of fired clay bricks are compressive strength and porosity. These properties are highly dependent on the manufacturing process and the quality of the raw materials. Besides that, the chemical composition and colour of bricks are also affected by porosity and compressive strength. Porosity is a significant parameter as it will affect the chemical reactivity, mechanical strength, quality, and durability of bricks. Clay bricks undergo a variety of mineralogical, structural, and physical changes throughout the firing process that will influence porosity (Cultrone et al., 2004). According to López-Arce et al. (2003), the number of big pores increases while the interconnection of the pores decreases as the firing temperature rises. Furthermore, it has been found that the carbonate in the raw clays forms thin pores (<1mm) when the firing temperature is between 800 to 1000°C. Thus, it will reduce the durability of bricks (Cultrone et al., 2004). Compressive strength is another significant property of clay brick as it determines the ability of the structure to sustain compressive loads. Besides quality and manufacturing process, texture and mineral composition can affect the compressive strength of brick as well. Therefore, adequate time and firing temperature with good quality raw material can produce a durable brick (Fernandes, 2019).

The high temperature of the firing process in the kiln, not only requires large amounts of energy but also generates large amounts of GHG. It used the average embodied energy of 2.0kWh per brick and emitted about 0.41kg of CO_2 each brick (Zhang, 2013). It seriously affects the environment if the production of clay bricks increases due to the rapid growth of urbanization. Global warming will occur since the concentration of CO_2 increases and it will cause the global temperature increases as well. Therefore, the aquatic ecosystem and the wildlife habitat will also be affected due to the increasing CO_2 emissions. In addition, excessive inhaled CO_2 will affect human health such as dizziness, shortness of breath, fatigue, increased blood pressure, and headache.

In the manufacturing of fired clay brick, the most used raw material is clay. The process of extraction of clay via quarrying operations consumes much energy, creates an enormous amount of waste, and affects the landscape (Zhang, 2013). Besides that, huge exploitation of natural clay deposits may lead to a shortage of natural clay resources. Due to the requirement for good quality clay, it will use the nutrient-rich upper layer of fertile soil and cause land degradation. Thus, the removal of nutrient-rich topsoil depleted the soil (Paul Levi and Raut, 2021). Based on Gupta and Narayan (2010), the removal of topsoil to manufacture bricks caused a decrease in manganese level by around 35% and a significant decrease in zinc level by about 63%. Other than that, every hectare loses 34kg of potash, 38kg of nitrogen, and 3kg of phosphorus. Therefore, many countries started to minimize the amount of clay used in the production of bricks to decrease the depletion of natural resources and environmental impact. Hence, producing eco-friendly brick is another alternative way to reduce environmental pollution.

Table 2.1: Overview of Relevant Research Literature (Clay Brick).

Title	Type of Brick	Type of Materials	Replacement percentage, %	Compressive Strength, MPa	References
Potential Use of Wastewater Treatment Plant Sludge in Fabrication of Burnt Clay Bricks	Fire Clay Brick	Water Treatment Sludge	5.0, 10.0, 15.0, **20.0**, 30.0, 40.0	14.2	(Amin et al., 2022)
Influence of tea waste concentration in the physical, mechanical and thermal properties of brick clay mixtures	Fire Clay Brick	Tea Waste	**2.5**, 5.0, 7.5, 10, 12.5	29.4	(Ozturk et al., 2019)
Evaluation of waste glass powder to replace the clay in fired brick manufacturing as a construction material	Fire Clay Brick	Waste Glass Powder	10.0, 15.0, **20.0**, 25.0, 30.0	24.78	(Tripathi and Chauhan, 2021)
Recycling of Olive Pomace Bottom Ash (by-Product of the Clay Brick Industry) for Manufacturing Sustainable Fired Clay Bricks	Fire Clay Brick	Olive Pomace Bottom Ash (OPBA)	**5.0**, 10.0, 15.0, 20.0	11.5	(El Boukili et al., 2021)

2.2.2 Compressed Stabilizer Earth Brick (CSEB)

For more than 10,000 years, people have used earth or mud as a construction material as it is an abundant resource on the planet. Earthen walls are widely used in Africa, the Middle East and Latin America, Asia, North America, and some European countries. Currently, around 8-10 % of the population lives in earthen houses and around 20 - 25 % of this proportion comes from low and middle-income countries. Earth, also called soil is a commonly available material composed of solid aggregates (or particles) such as silt, sand, clay, and gravel. Among all the aggregates, clay is the smallest particles that serve as binders. Besides that, water, salts, and other organic minerals are also frequently found in the soils (Bredenoord and Kulshreshtha, 2023).

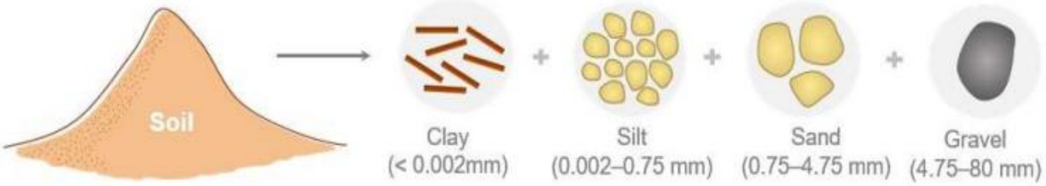


Figure 2.1: The Varying Sizes of these Aggregates in the Soil (Bredenoord and Kulshreshtha, 2023).

The advantage of earth construction is that it is able to be built using on-site materials with a low carbon footprint. The main elements that encourage the building of earth structures are also the accessibility of soil and the ease of construction. The rapidly increasing urbanization and technological progress have led to a higher demand for unique architectural design and new building materials which cause the reduction of earth construction globally. Therefore, new products including fire clay bricks and concrete blocks are introduced globally and become more popular and widely used in many constructions. However, the process of manufacturing these bricks emits a significant amount of carbon dioxides that cause environmental pollution. In addition, the firing process also consumed high amounts of energy. Thus, using raw earth as an environmentally friendly and sustainable construction material to produce brick has attracted the attention of developed countries again. In recent years, several researches have been carried out to use earth as a sustainable construction material and this effort has resulted in the new product, Compressed Stabilized Earth Block (CSEB). Compressed Earth Block (CSB) is produced by compressing the soil under high pressure while CSEB is produced when an adequate amount of stabilizer is added to the mix of CSB. A suitable amount of stabilizer used in the manufacture of CSEB helps to overcome the shortcomings of the soil and enhance the strength and durability of the bricks (Islam et al., 2020).

The main components of CSEB consist of clay, sand, soil, water, and stabilizer. As the production of CSEB is very simple compared to fired clay brick, it only requires employees with medium to low skill levels. There are 3 steps of the manufacture which are soil preparation, mixing and compression, and lastly is curing process. At first, the selection of soil is important as it will directly affect the result of the brick. Thus, the quality of soil needs to be selected carefully and accurately to achieve the greatest results. Furthermore, an adequate compressive force is applied when the soil is mixed with other materials and placed in the mould. Besides that, the brick undergoes a curing process. For the curing process of CSEB, the conventional method was used the naturally wet bricks after pressed immediately. However, the strength of the brick increases over time. Hence, the bricks are cured under polyethylene sheets in the open-air area with air relative humidity of more than 70% to avoid rapid drying which may cause cracking and enable maximizing the hydration when using a stabilizer such as cement. The curing time usually takes around 28 days (Fetra, Ismail, and Ahmad, 2010).

There are many stabilizers that have been tested such as cement, gypsum, lime, coal combustion residues, fibres, and sugarcane ash. Among these stabilizers, cement is the most suitable stabilizer due to its good performance in a variety of soil ranges and ease of finding (Islam et al., 2020). The stabilizer in the CSEB is significant in forming the link between soil-stabilizer mixes. By building a solid framework with the soil, the stabilizer is used to reduce the limit of the expansion properties of the soil and enhance its strength and durability. The most common stabilizer used is Portland cement as soils with a plasticity index of less than 15 are ideal for cement stabilization. In general, 4% to 10% of the dry weight of the soil is added as a cement binder. Nevertheless, the manufacturing becomes unprofitable when the cement is added more than 10% while bricks with a cement percentage of less than 5% are also hard to handle as it is brittle and difficult to shape. On the other hand, lime is recommended for use as a stabilizer when the plasticity of soil is above 15 or consists of clay content in the soil. Lime can be added to improve the stabilization process and reduce the plasticity of the soil. When lime is added to clay soil, lime fixation will occur as the lime initially gets adsorbed by the clay minerals until reaches a specific point. The quantity of lime used by weight is typically in the range of 1 to 3%. After this process, the following lime was added to help in the pozzolanic reaction to produce the hydrated gel. Therefore, the strength of the brick will increase slowly over time (Fetra, Ismail, and Ahmad, 2010).

However, there are also some drawbacks to using CSEB. Soil excavation is required for the manufacture of CSEB, and it can contribute to soil deterioration and erosion. Heavy soil extraction can cause land degradation and decrease the vegetation cover over time, which can have an adverse effect on ecosystems and biodiversity as it will destroy the habitats of plants and animals. Apart from that, the extraction of raw materials such as stabilizers will lead to energy consumption. Although the energy consumed is much less than fired brick but still contributes to greenhouse gas emissions. The utilization of stabilizers like cement is common in CSEB fabrication. The manufacturing process of cement will release large amounts of CO_2 into the environment and lead to adverse air pollution. At last, plastering is used to prevent surface erosion on the CSEB wall surface which is usually exposed to harsh weather. According to Kolawole, Olalusi, and Orimogunje (2020), it has been found that when walls are exposed to excessive moisture over a few decades following the construction of the building, these plaster coatings tend to detach due to a weak bond between the CSEB and the cement mortar. It becomes a problem for these water-prone areas, which include the bathroom, toilet, laundry room, and kitchen. Therefore, CSEB employed in these areas loses their strength due to prolonged exposure to moisture.

Table 2.2: Overview of Relevant Research Literature (Compressed Stabilizer Earth Brick).

Title	Type of Brick	Type of Materials	Replacement percentage, %	Compressive Strength, MPa	References
Evaluation of compressed stabilized earth block properties using crushed brick waste	Compressed Stabilizer Earth Brick	Crushed Brick Waste	6.0, 12.0, 18.0, **24.0**	9.57	(Kasinikota and Tripura, 2021)
Experimental analysis of Compressed Earth Block (CEB) with banana fibers resisting flexural and compression forces	Compressed Stabilizer Earth Brick	Banana Fiber	1.0, 2.0, 3.0, **4.0**, 5.0	6.19	(Mostafa and Uddin, 2016)
Effectiveness of saw dust ash and cement for fabrication of compressed stabilized earth blocks	Compressed Stabilizer Earth Brick	Saw Dust Ash	2.0, 4.0, 6.0, **8.0**, 10.0	2.00	(Elahi et al., 2020)
Potential of waste rice husk ash and cement in making compressed stabilized earth blocks: Strength, durability and life cycle assessment	Compressed Stabilizer Earth Brick	Rice Husk Ash	5.0, **10.0**, 15.0, 20.0	6.95	(Paul, Islam and Elahi, 2023)

2.2.3 Cement Sand Brick (CSB)

CSB is one of the non-fired bricks. CSB does not undergo a high-temperature firing process to increase its structural performance. The main raw materials to produce cement sand bricks are sand, water, and cement. They are usually used in construction for a variety of purposes, including walls, pavement, foundations, drainage systems, and railways. Besides that, they are commonly used in the construction of low-to-medium-cost housing and other commercial buildings in Malaysia. However, at the moment, the manufacturing of cement sand bricks is facing several difficulties in some developing areas. For instance, the depletion of resources in mining regions and riverbanks, the suspension of quarry licenses by the state government, and the temporary shutdown of quarrying activities due to environmental issues. Thus, it will lead to a shortage of natural aggregates to produce cement sand bricks (Ismail and Yaacob, 2010).

The production of CSB is much easier than fired brick. There are three steps that same with compressed stabilizer earth brick which are preparation, mixing and compression, and curing. The raw materials are prepared such as sand, cement, and water. The sand used for the manufacture should be well-graded, clean, and free of any impurities while the cement used is Portland cement. After the preparation, the raw materials are mixed. The mixing process can be done manually or by using the mixer to ensure the materials are mixed properly. After that, the mixed materials are placed into the brick mould to compress A constant compression force is applied to each brick mould to ensure that the bricks are the same size and shape. Once the brick is formed, a curing process needs to be taken for the brick to gain strength. It usually takes about 28 days to reach optimum strength.

CSB and fired clay brick both are bricks that are commonly used in construction. However, there are some advantages of using cement sand brick compared to fired clay brick. CSB is usually more cost-effective to manufacture and requires less maintenance compared to fired clay brick as the raw material used for the CSB such as cement and sand is cheaper than clay (Sani and Muftah, 2012). On the other hand, the firing process is not required for CSB, and it saves the cost of purchasing highly specialized equipment. Besides that, the high-temperature kiln is not required as well for CSB production, and it leads to a substantial decrease in carbon dioxide and other greenhouse gas emissions. The lower energy needs of cement sand brick manufacture result in lesser emissions, which contribute to enhanced air quality and reduced climate impact. In addition, the CSB usually has lower water absorption than clay brick and is less prone to absorb moisture from the surrounding environment. Therefore, it can avoid brick cracking and erosion easily and retain structural integrity over time.

The shortage of sand is one of the main drawbacks of CSB. Sand is a major component in cement sand brick. The main reason for causing a shortage of sand is the rapid growth of construction development and the substantial increase in demand for CSB. This has resulted in excessive extraction of river sand which the river sand is the most suitable material to manufacture cement sand brick due to its size, but it also has negative impacts on the environment. For example, excessive sand mining can cause riverbanks to become unstable and accelerate erosion as the function of sand in rivers is to regulate the water flow and avoid erosion. Therefore, the absence of large-scale sand in the river will cause the loss of land along riverbanks and increase the possibility of flash floods. Furthermore, sand mining activity also affects the aquatic ecosystems in the river that rely on stable riverbeds to survive. These ecosystems can be destroyed by excessive sand mining, which will result in a loss of biodiversity (Rentier and Cammeraat, 2022). Hence, the sand has become much more expensive which has impacted the pricing of cement sand brick (Ismail and Yaacob, 2010).

Cement serves as a binder in the CSB. The production of cement increased when the demand for CSB increased. Therefore, it releases significant amounts of CO_2 into the environment. According to Chen et al. (2010), the cement industry sector is contributing around 5-7% of total anthropogenic CO_2 emissions. CO_2 is emitted from various sources during the cement production process, with 50% caused by the calcination of limestone ($CaCO_3$) to generate CaO and CO_2, 40% resulting from the burning of fossil fuels, and the remaining 10% coming from electricity usage and transportation (Supriya et al., 2023). Clinker is a key component of cement, and the process of production of clinker contributes to greenhouse gas emissions and global warming by heating limestone. Besides that, high-temperature kiln operations used to make cement cause the discharge of air pollutants including particulate matter, sulphur dioxide (SO_2), and nitrogen oxides (NO_x). These contaminants will affect the human health and air quality of nearby communities.

Table 2.3: Overview of Relevant Research Literature (Cement Sand Brick).

Title	Type of Brick	Type of Materials	Replacement percentage, %	Compressive Strength, MPa	References
Influence of Ground Granulated Blast Furnace Slag (GGBS) as Cement Replacement on the Properties of Sand Cement Brick	Cement Sand Brick	Ground Granulated Blast Furnace Slag (GGBS)	**10.0**, 20.0, 30.0, 40.0, 50.0, 60.0	40.4	(Mat Dom et al., 2022)
Polyethylene Terephthalate Waste Utilisation for Production of Low Thermal Conductivity Cement Sand Bricks	Cement Sand Brick	Polyethylene Terephthalate Waste	**2.5**, 5.0, 7.5	5.1	(Rafikullah et al., 2021)
Properties of Cement Brick with Partial Replacement of Sand and Cement with Oil Palm Empty Fruit Bunches and Silica Fume	Cement Sand Brick	Silica Fume	**10.0**, 15.0, 20.0,25.0	12.4	(Ling et al., 2019)
Fabrication of Cement Sand Brick (CSB) using Aluminium Dross	Cement Sand Brick	Aluminium Dross	**5.0**, 10.0, 15.0, 20.0, 25.0	17.8	(Ong, 2022)

2.3 Cement

Cement is the most significant binding construction material as it forms a paste that can solidify when mixed with water. In the absence of cement, buildings, industrial construction, dams, roads, and infrastructure facilities will not be constructed (Igliński and Buczkowski, 2017). All the bricks manufactured nowadays require cement to bind the raw material together to form a durable and solid brick such as clay brick, CSEB, and CSB. Cement manufacturing has progressed dramatically since it began about 2000 years ago. Global cement output has reached 2.8 billion tonnes per year and is predicted to continue increasing to over 4 billion tonnes per year. There are many countries that expect this major development, such as India and China, the Middle East, and North Africa region (Schneider et al., 2011).

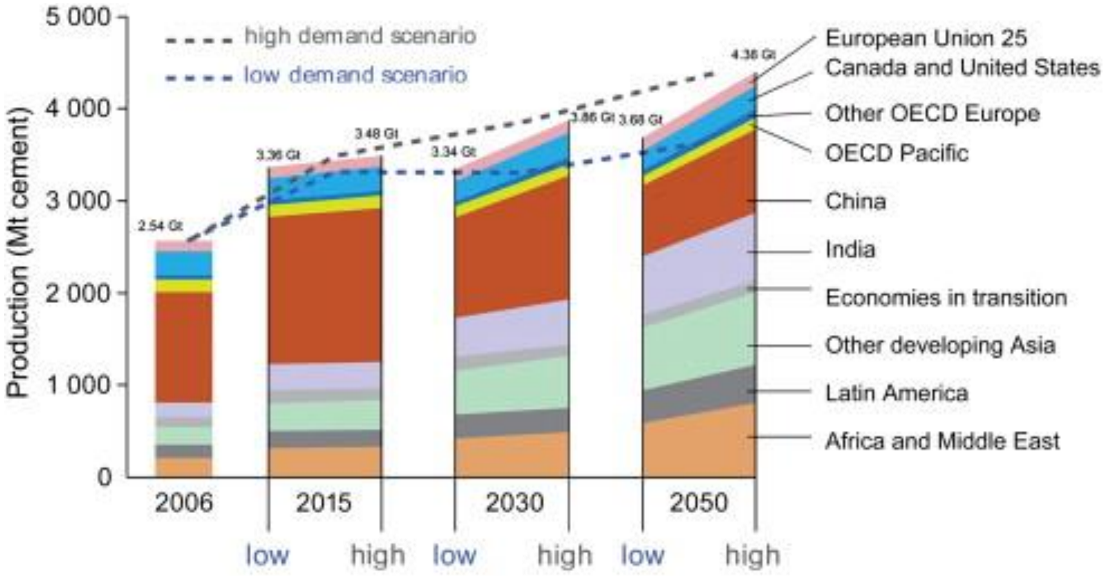


Figure 2.2: Cement Production Globally (Schneider et al., 2011).

The use of cement has a long history, and industrial cement production began in the mid-19th century. Joseph Aspdin is considered to be one of Portland cement's inventors. In 1824, he was awarded a patent on the procedure of creating a binder formed from a roasted combination of limestone and clay, and he called it "Portland cement" for the first time. The binder is made by the combustion of calcium carbonate in the stone until completely broken down. However, this process happens at very low temperatures. This is where Isaac Johnson comes into the picture, who in 1845, found the perfect ratio of limestone to clay after several efforts had been made. He is also called one of the inventors of modern Portland cement. Besides that, he established higher-temperature roasting, which helped in the development of compounds with greater binding properties. Cement production has become a very important industry for the economic development of Poland. In 1857, the first cement plant in Poland which also the fifth in the world is started to produce cement shown in **Figure 2.3**. The rapid growth in the cement industry field in Europe and the United States in the second half of the 19th century is due to this simple and straightforward process of cement manufacture. After World War II, cement production increased substantially to 134 million in 1950 and keeps increasing from 183 million in 1980 to over 1600 million nowadays (Igliński and Buczkowski, 2017).

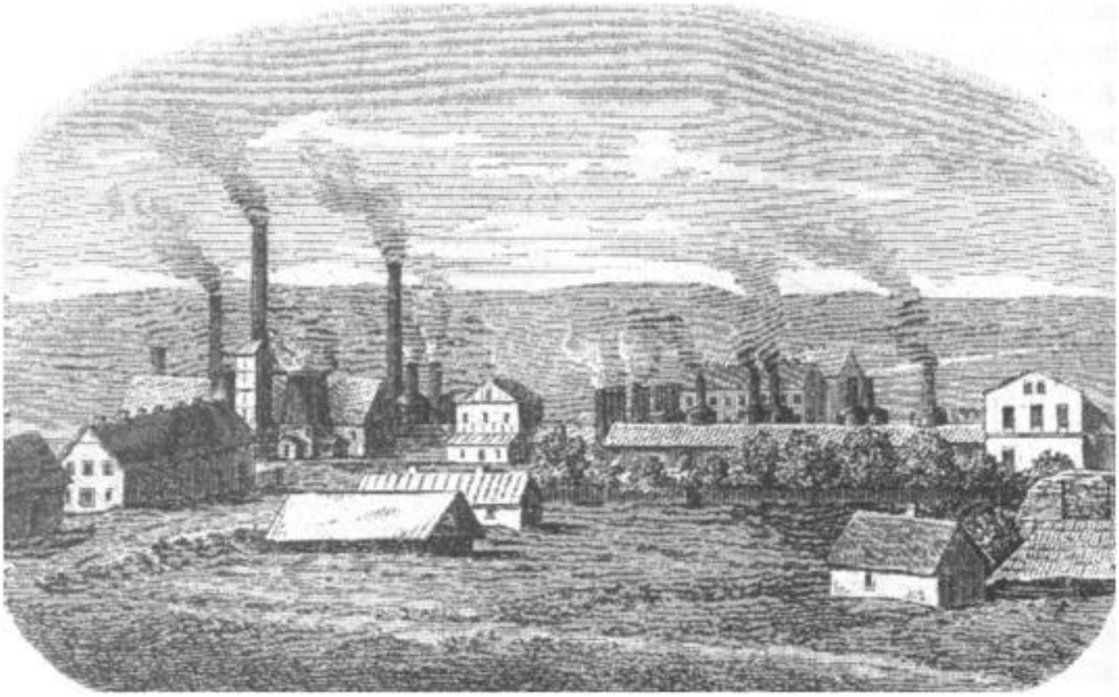
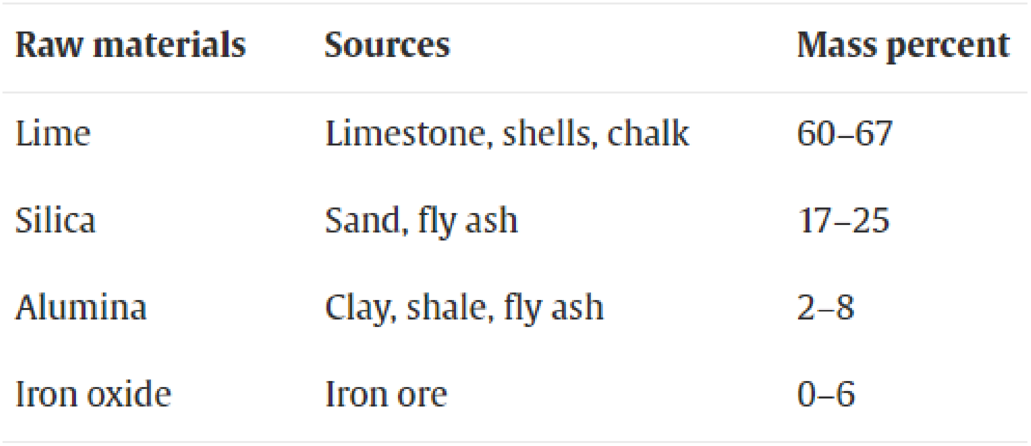


Figure 2.3: First Cement Plant in Poland (Igliński and Buczkowski, 2017).

Traditional Portland cement consists of mainly calcium silicate minerals. The production plant receives the quarried or mined raw materials which are then crushed and ground into fine powder. After that, the fine powder entered the preheater and finally into large rotary kilns and heated to temperatures above 1400 °C. The heat that is excess after cooling the clinker is often sent back to the preheating equipment. Gypsum is added to the clinker before packing to modify the setting time of the clinker.

As a result, Portland cement is formed with a very fine-grained mixture (90% x 10 microns). The raw material composition of clinker is shown in **Figure 2.4** (Huntzinger and Eatmon, 2009).



Raw materials	Sources	Mass percent
Lime	Limestone, shells, chalk	60–67
Silica	Sand, fly ash	17–25
Alumina	Clay, shale, fly ash	2–8
Iron oxide	Iron ore	0–6

Figure 2.4: The Components of the Clinker (Huntzinger and Eatmon, 2009).

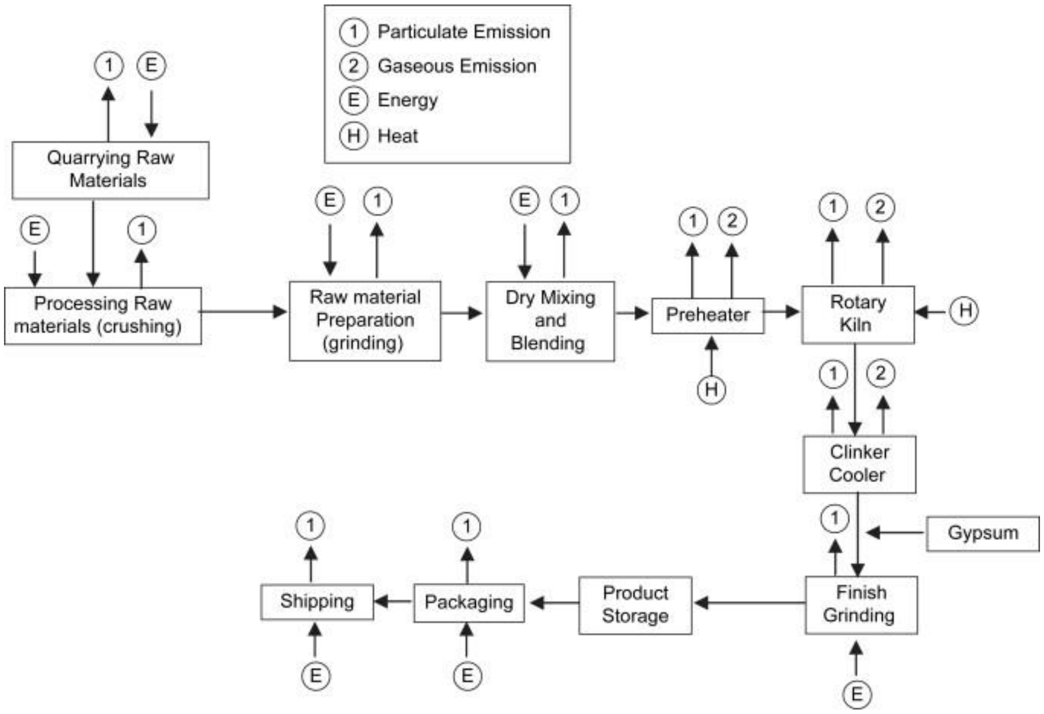


Figure 2.5: Flowchart of the Cement Production Process (Huntzinger and Eatmon, 2009).

The figure above shows a comprehensive flow chart of the cement manufacturing process with heat and energy consumption. Besides that, gaseous and particulate matter emissions are also shown in the figure. Particulate control devices are utilized in the preheater and kiln systems to tray tiny particles of unburned or partially burnt raw materials that are embedded in the combustion gases. This accumulated particle matter is known as cement kiln dust (CKD) (Huntzinger and Eatmon, 2009). Cement kiln dust is a by-product of the cement production process. CKD is a very fine powder that same as Portland cement in appearance. t is made up of micron-sized particles that were gathered from electrostatic precipitators during the cement clinker manufacturing process. Depending on the type of kiln process utilized and the level of separation of the dust collection system, cement kiln fresh dust can be divided into one of four groups. There are two different types of cement kiln processes known as dry-process and wet-process kiln. Raw materials are accepted in slurry form for wet-process kilns while dry-process kilns accept raw materials in dry ground form (Siddique, 2006).

On the other hand, gaseous emissions such as carbon dioxide also contribute to adverse air pollution to the environment. Magnesium oxide (MgO) and calcium oxide (CaO) both are major clinker components that make up about 64-68% of clinker weight while the primary raw material used to produce cement is limestone. Inside the limestone raw material, there is around 75-90% $CaCO_3$ content used in cement production. The majority of carbon dioxide is emitted through the conversion of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) to CaO and MgO which are shown in **Equation 2.1** and **Equation 2.2**. Calcination happens when the temperature rises above 900 degrees and CO_2 is released into the surrounding environment (Gao et al., 2015). The cement industry is classified as a major source of greenhouse gas emissions, especially CO_2. The amount of CO_2 keeps increasing due to construction development and the excessive CO_2 affects the environment and human health as mentioned above.

$$\mathrm{CaCO_3} \rightarrow \mathrm{CaO} + \mathrm{CO_2} \uparrow \tag{2.1}$$

$$\mathrm{MgCO_3} \rightarrow \mathrm{MgO} + \mathrm{CO_2} \uparrow \tag{2.2}$$

2.4 Textile Dyeing Sludge

Rapid urbanization and industrialization have resulted in a massive rise in infrastructure construction activities, and it has also caused several environmental issues. Industries all over the world generate enormous amounts of waste, and managing these solid wastes has become a significant concern for the human community. The textile industry is one of the earliest and biggest industries in worldwide (Goyal et al., 2019). According to Körbahti and Tanyolaç (2008), about 125-150 litres of water are needed to produce 1kg of textile product. Textile wastewater consists of processing bath residue from dyeing, cutting, finishing, and pretreatment as well. If these residues are not appropriately handled before being discharged into the environment, they can contribute to pollution. The dyes and auxiliary chemicals employed in textile industries have been adapted to withstand environmental impacts to improve performance. Consequently, it is difficult to remove from the dyeing process wastewater. In order to ensure that the final discharge of effluent complies with the legal requirements set by various pollution control bodies, an effective and comprehensive treatment system for the effluents is significant (Goyal et al., 2019).

The wastewater from the textile industry is treated in several phases which is shown in **Figure 2.6**. The equalization tank is first used to collect the discharged effluent from the textile industry and transfer it to the neutralization tank. Textile industry wastewater comprises various harmful substances and has a high alkaline concentration. Before proceeding to the next treatment procedures, the alkalinity of effluent is neutralized in the neutralization tank by using H_2SO_4 and HCl (Amanuel, 2019). After that, particles are often extracted from microemulsions using a two-step process called flocculation and coagulation. The particles are then grown steadily until they become sludge and move to the settling tank. Chemical coagulants such as bentonite clay, aluminium salt, and iron salt are used as catalysts to boost the process in the coagulation basin (Herek et al., 2012). Lastly, the wetland is a system to treat the wastes that remain in the settling tank via various physical, chemical, and biological processes. This system relies on gravity and includes both an inlet and an outlet. (Amanuel, 2019).

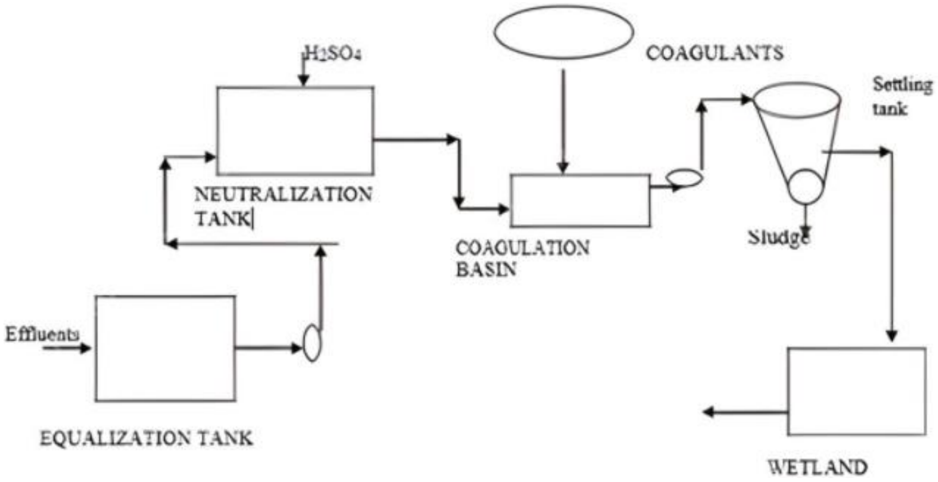


Figure 2.6: The Flow Diagram of the Textile Wastewater Treatment System (Amanuel, 2019).

Sludge is the residues produced from the wastewater, environmental, or industrial treatment process. It is a highly viscous and semi-solid slurry that consists of a mixture of solids, water, organic matter, and different contaminants. Sludge is produced when solid particles separate and precipitate from a liquid in the settling tank and the composition and the concentration of the sludge are highly dependent on its source. There are three major types of sludge, namely sewage sludge, industrial sludge, and environmental sludge. In this research study, the focus is placed on textile dyeing sludge (TDS) which belongs to the category of industrial sludge. TDS is a by-product of wastewater treatment systems used in the textile industry (Yao et al., 2023). It is difficult to treat due to the complex chemical composition and consists of more toxic organic matters such as additives, dyeing agents, perishable organics matter, microorganisms, parasites, polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Cd, Zn, Cu, Cr, etc) compared to sewage sludge (Xie et al., 2018).

According to Liang et al. (2013), it was found that among all the heavy metals, Zn was the metal with the highest concentration at 42.5 – 1210 mg/kg, followed by Cr (69.2 – 577mg/kg), Cu (61.5 -571mg/kg), and Ni (31.5-193 mg/kg). The Cd and Pb were in small quantities with amounts of 1.16–5.66 mg/kg and 6.32–36.9 mg/kg respectively. The heavy metal level of sludge produced by the textile industry has a similar amount to municipal sludge, but the TDS had more Cr and Ni and less Pb. This can be explained by domestic wastewater and surface runoff are the main sources of Pb but not in the textile industry. On the other hand, Cr and Ni were widely used in industry, which led to increasing Cr and Ni levels in textile dyeing sludge. The high zinc and copper concentration levels in the sludge will cause the accumulation of zinc in the soils or crops, potentially contaminating food crops and posing a risk to human health. Zinc also may enhance the concentration of trace elements (TEs) in edible tissues of plants grown in sludge-amended soil and lead to negative health effects for humans (You et al., 2020). Apart from that, the high Cr content in sludge can reduce microbial biomass in soil and adversely affect soil enzymatic activity and overall soil health (Araujo, de Araujo Pereira, and Mendes, 2022). Thus, TDS is not recommended to be reused on agricultural land.

Polycyclic aromatic hydrocarbons (PAHs) should be given extra attention as dyes contain high levels of PAHs. PAHs have a low solubility in water, and this solubility decreases as their molecular weight increases. Sludge particles in wastewater in the solid phase are able to rapidly adsorb PAHs (Ning et al., 2014). Additionally, the US Environmental Protection Agency (US EPA) has classified 16 PAHs as priority pollutants because of their hazardous, carcinogenic, and mutagenic properties (Liu et al., 2012). High amounts of PAHs in TDS can decrease its quality and inappropriate for specific uses such as composting or land application. Therefore, the industry is required to spend high disposal costs on it which also leads to negative environmental impacts. Besides that, PAHs are also recognized for their carcinogenic properties and their potential to cause health problems in humans including, skin irritation, respiratory problems, and other health concerns.

Textile dyes are the most prevalent organic contaminants in wastewater and sludge from the textile industry. Azo dyes are the most widely used dye in the industry and are the majority of the various textile dyes (more than 60%). Azo dyes are composed of one or more azo groups in their chemical structure (Al-Tohamy et al., 2022). Based on Singha et al. (2021), 15-50% of azo dyes that are not bonded to the fabrics and fibres are discharged into the wastewater or become sludges due to an ineffective textile dyeing process which not only giving significant ecotoxicological risks but also endangers various organisms. Hence, proper handling and reusing of TDS is important to ensure environmental sustainability and reduce health issues.

2.4.1 Current Disposal Method

According to Zou et al. (2019), the recommended method of sludge treatment is a land application such as agricultural usage as it helps enhance soil fertility and water retention due to the high concentration of nitrogen, phosphorus, potassium, organic matter, and trace elements. It was found that 77% of EU Member states have adopted agricultural sludge reuse (Kelessidis and Stasinakis, 2012). However, TDS contains heavy metals, PAHs, and dyeing agents that will constitute a substantial threat to the environment. These substances will accumulate to toxic levels in the topsoil when reused TDS. In addition, they have the potential to bioaccumulate within terrestrial ecosystems and endanger human health via the food chain. (Zou et al., 2019), Hence, landfills and incineration are the two main disposal methods of TDS.

The landfill is a common method for disposing of TDS, but it has an adverse effect on environmental impacts such as water, air, and soil quality. The unrestricted release of landfill gases including carbon, volatile organic carbons, traces of non-methane, and methane will increase the global temperature and lead to global warming (Iqbal, Mahmud, and Quader, 2014). Besides that, these gases degrade the air quality of nearby residential areas, affecting human health. The landfill also contributes to deforestation as it requires large land space for the disposal of wastes due to population growth and urban area expansion. Thus, the forest will be converted into landfill sites leading to the fragmentation of forested area. The local groundwater being contaminated by the leachate produced by the disposal of sludge in landfills is the most significant environmental consequence. The leakage of leachate into the soil causes the degradation of soil quality and soil pollution (Iqbal, Mahmud, and Quader, 2014). Leachate may infiltrate groundwater sources if it is not properly managed. Therefore, it has an immediate effect on human well-being as groundwater is one of the important drinking water sources. The aquatic ecosystem will be affected as well when the polluted groundwater flows into the river.

Incineration is another disposal method of TDS that is recognized as the most effective method to treat TDS due to its reduction of volume in the limited space, power regeneration, complete stability, and destruction of pathogens compared to the landfill method. However, incineration will also bring adverse environmental impacts due to the presence of heavy metals in the TDS that contain concentrated levels in incineration by-products including fly ashes, bottom ashes, air pollution control residues, and exhaust gas via physicochemical processes (Lin et al., 2014). Therefore, proper management of residues is needed to avoid leaching into the water and soil. Heavy metals can be released in the form of steam or particulate matter into the atmosphere during the incineration process. It causes air pollution and constitutes a health danger to humans and wildlife. According to Huang et al. (2021), the sulphur content of TDS is higher than sulphur-rich coal. The incineration of TDS leads to acid rain and corrosion of incineration equipment due to the large emission of air pollutants, especially SO_2. In addition, carbon dioxide (CO_2) and methane (CH_4) produced by incineration will contribute to global warming and climate change. Thus, it is necessary to explore an eco-friendly, sustainable, and practical solution to manage the TDS. One of the sustainable approaches is to reuse the textile dyeing sludge in the building materials.

2.5 Circular Economy and Sustainable Development Goals

In this research study, the focus will be placed on reusing the textile dyeing sludge from the textile industry wastewater treatment plants to partially substitute the cement in the fabrication of cement sand bricks. The objective of the feasible research is to identify the optimum replacement percentage of TDS to enable the application of CSBs in the construction industry in compliance with the circular economy. The circular economy concept provides a closed economic model that generates products and services in a sustainable way by minimizing resource consumption and waste generation (Jørgensen and Remmen, 2018). The goal of the circular economy is to enhance efficiency and preserve the environment across the product’s life cycle, setting it apart from the linear economy. Thus, embracing the circular economy concept may significantly benefit sustainable development. The major goal of the circular economy concept is to encourage sustainable development. Besides that, the International Organization for Standardization (ISO) has also established the ISO/ TC 323 circular economy standard to define its approaches, guidelines, tools, etc (Nautiyal and Goel, 2021). The circular economy idea also aligns with the United Nations Sustainable Development Goals (SDGs).

SDGs are a series of interrelated global goals established by the United Nations in 2015 which are used to solve a variety of global issues such as inequality, poverty, environmental issues, peace, and justice. (SDGs) offer a roadmap towards achieving a fairer and more sustainable world by 2030 incorporated with governments, civil society, businesses, and individuals. The SDGs consist of 17 goals (Figure 2.7) and 169 targets which involve economic, social, and environmental improvement in both developed and developing countries. In these recent years, SDGs have attracted significant attention. The SDGs also involve enhancing education especially higher education institutions to help with sustainable development and achieve the goals (Leal Filho, Salvia and Eustachio, 2023).

The research closely links with the circular economy concept and SDGs. The circular economic concept helps in the reduction of cement production, conserving natural resources, and decreases waste by using TDS in the fabrication of cement sand bricks. This process also promotes the environment by reducing TDS disposal via landfills or incineration and the environmental footprint of textile industry waste. Apart from that, the research complies with several SDGs including SDG 1: No Poverty, SDG 9: Industry, Innovation and Infrastructure, SDG 11: Sustainable Cities and Communities, SDG 12: Responsible Consumption and Production and SDG 13: Climate Action. The usage of TDS in the fabrication of CSB creates job opportunities in the construction sector to combat poverty. This practice also promotes construction sector innovation and contributes to building sustainable infrastructure which aligns with SDG 9. In addition, SDG 11 is achieved by decreasing waste disposal and implementing responsible resource management, leading to a more environmentally friendly construction practice. This approach matches the concept of SDG 12 by reusing TDS and promoting resource conservation in the construction industry. Moreover, this research helps to reduce CO_2 emissions from the cement industry which aligns with SDG 13. Thus, it helps reduce the environmental impacts brought by TDS and cement while also enhancing the sustainability of construction practices.

Figure 2.7: 17 Sustainable Development Goals (Halkos and Gkampoura, 2021).

CHAPTER 3

METHODOLOGY

3.1 Introduction

The complete methodology of the research project is shown below such as the materials preparation, fabrication of cement sand brick, and laboratory test. Cement is replaced by different percentages of TDS in this research study to fabricate the CSB. The laboratory test is carried out based on the British Standard (BS EN) and American Society for Testing and Materials (ASTM) to determine the durability and engineering properties of cement sand brick and get an optimum percentage of textile dyeing sludge substitution with cement.

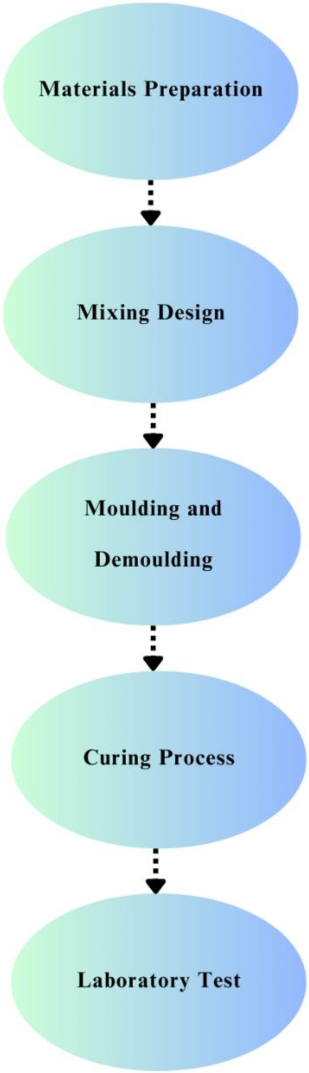


Figure 3.1: Methodology Flow of the Research.

3.2 Material Preparation

Some precautionary steps are required in the material preparation to ensure the materials are not affected by external factors. All the materials are labelled correctly to ensure the fabrication process goes smoothly and to avoid other people from misusing the materials. The containers are placed inside the workshop to prevent direct sunlight and rainfall which will affect the quality of the materials.

3.2.1 Cement

The cement used in the fabrication process is manufactured by YTL Corporation Berhad and it acts as a binder in the CSB. A waterproof protective cover is used after opening the cement packaging to prevent cement from moisture absorption as it can lead to a hydration process and affect the quality of the cement before we use it. The figure below shows the Ordinary Portland cement used in the research study.

Figure 3.2: Cement.

3.2.2 Sand

The second material used in the fabrication of CSB is fine sand which is shown in the figure below. A simple sieving process is conducted to ensure the standard size of sand is used.

Figure 3.3: Sand.

3.2.3 Textile Dyeing Sludge

In this research study, the textile dyeing sludge was collected from Sincerely Dyeing & Finishing Sdn. Bhd. The sludge is a semi-solid slurry form and has a slightly pungent odour. A hammer is used to break the sludge into smaller pieces. After that, the sludge is placed into the oven for drying process at 120’c. Following the drying process, the dry sludge will be ground into powder form using a mechanical blender, as shown in **Figure 3.5**, and then sieved to ensure that the size of the sludge is consistent before the mixing process.

Figure 3.4: Textile Dyeing Sludge after the Drying Process.

Figure 3.5: Textile Dyeing Sludge in Powder Form.

3.3 Mixing Design

Several trial mixing processes were conducted by previous relevant research studies to develop an optimal mixing ratio for the fabrication of CSB. The optimum mixing ratio of cement and sand is fixed at 1: 3.4 while the water-cement ratio is 0.5. Different substitution percentages of cement with textile dyeing sludge (5%, 10%, and 15%) are mixed. In addition, two particle sizes range of TDS are also mixed in this research study. The fine particle size is below 300µm while the coarse particle of TDS is between 300µm and 1.7mm. A 0% replacement specimen is produced to act as a control specimen for comparison purposes.

Table 3.1: Replacement Percentages of Cement with TDS for the Fabrication of CSB.

Design Mix Code	**Replacement Percentage (%)**	
	Cement	Textile Dyeing Sludge
Control	100.00	0.00
5FTDS	95.00	5.00
10FTDS	90.00	10.00
15FTDS	85.00	15.00
10CTDS	90.00	10.00
15CTDS	85.00	15.00

Table 3.2: Mixing Portion for the Fabrication of CSB.

Design Mix Code	Mixing ratio (%)			
	Sand	Water	Cement	Textile Dyeing Sludge
Control	68.00	12.00	20.00	0.00
5FTDS	68.00	12.00	19.00	1.00
10FTDS	68.00	12.00	18.00	2.00
15FTDS	68.00	12.00	17.00	3.00
10CTDS	68.00	12.00	18.00	2.00
15CTDS	68.00	12.00	17.00	3.00

Table 3.3: Mixing Weight for the Fabrication of CSB.

Design Mix Code	Weight of the materials (g)			
	Sand	Water	Cement	Textile Dyeing Sludge
Control	2244.00	396.00	660.00	0.00
5FTDS	2244.00	396.00	627.00	33.00
10FTDS	2244.00	396.00	594.00	66.00
15FTDS	2244.00	396.00	561.00	99.00
10CTDS	2244.00	396.00	594.00	66.00
15CTDS	2244.00	396.00	561.00	99.00

Notes:

XTDS: CSB specimen with 0% replacement cement with TDS.

5FTDS: CSB specimen with 5% replacement cement with fine TDS.

10FTDS: CSB specimen with 10% replacement cement with fine TDS.

15FTDS: CSB specimen with 15% replacement cement with fine TDS.

10CTDS: CSB specimen with 10% replacement cement with coarse TDS.

15CTDS: CSB specimen with 15% replacement cement with coarse TDS.

Figure 3.6: Mixing Process of CSB Specimens.

3.4 Moulding and Demoulding

The mould for the fabrication CSE is 210mm x 90mm x 90mm which is shown in Figure 3.7. At first, the mixture was manually compacted using a hand after being placed into the mould until the required height. The mixture was then compressed using a 20-ton hydraulic shop press as seen in Figure 3.8. To eliminate the air voids between the mixture and ensure consistent sizes of CSB, a constant compression force of 3.5 metric tons was applied to all the specimens. After compression, a cement sand brick specimen is formed, and the mould is dismantled to allow the brick specimen to be readily removed from the mould. Once the brick specimen was taken out of the mould, it was supported by plywood, as seen in **Figure 3.9.**

Figure 3.7: Mould for the Fabrication CSB.

Figure 3.8: Compression of Specimens using Hydraulic Shop Press.

Figure 3.9: CSB Specimens after Demoudling.

3.5 Curing Process

The specimen is placed in natural air for a day to harden the specimen. After that, the specimen is put inside the curing tank for the curing process. The curing process was conducted for a period of 7, 14, and 28 days for better strength and durability of the specimen. **Figure 3.10** below shows the CSB specimen immersed in the curing tank after being labelled properly.

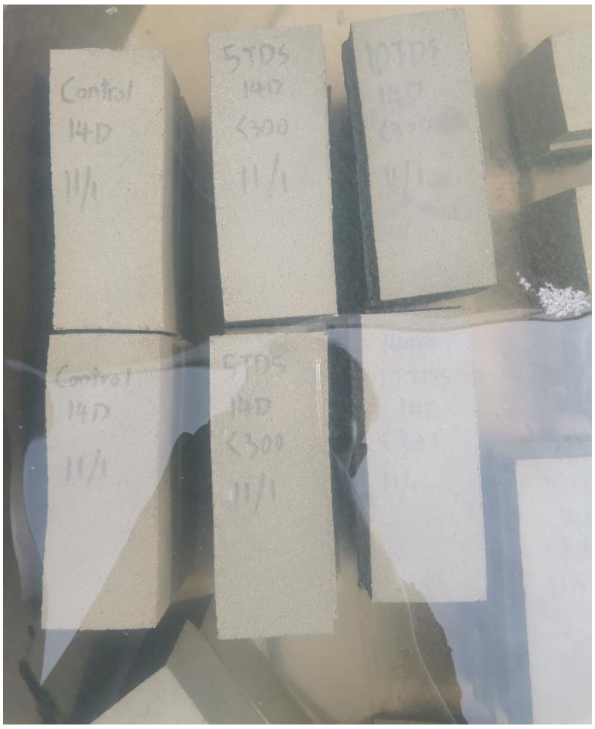


Figure 3.10: Curing Process for CSB Specimen.

3.6 Laboratory Tests

Cement sand brick has two important characteristics that must be tested in the laboratory which are engineering and durability properties. The main objective of the laboratory test is to identify the optimal cement replacement percentage with textile dyeing sludge. There are some tests are conducted to analyse the engineering properties of CSB such as compressive strength, flexural strength, and microstructure analysis while bulk density, porosity, and water absorption tests are conducted to determine the durability of CSB.

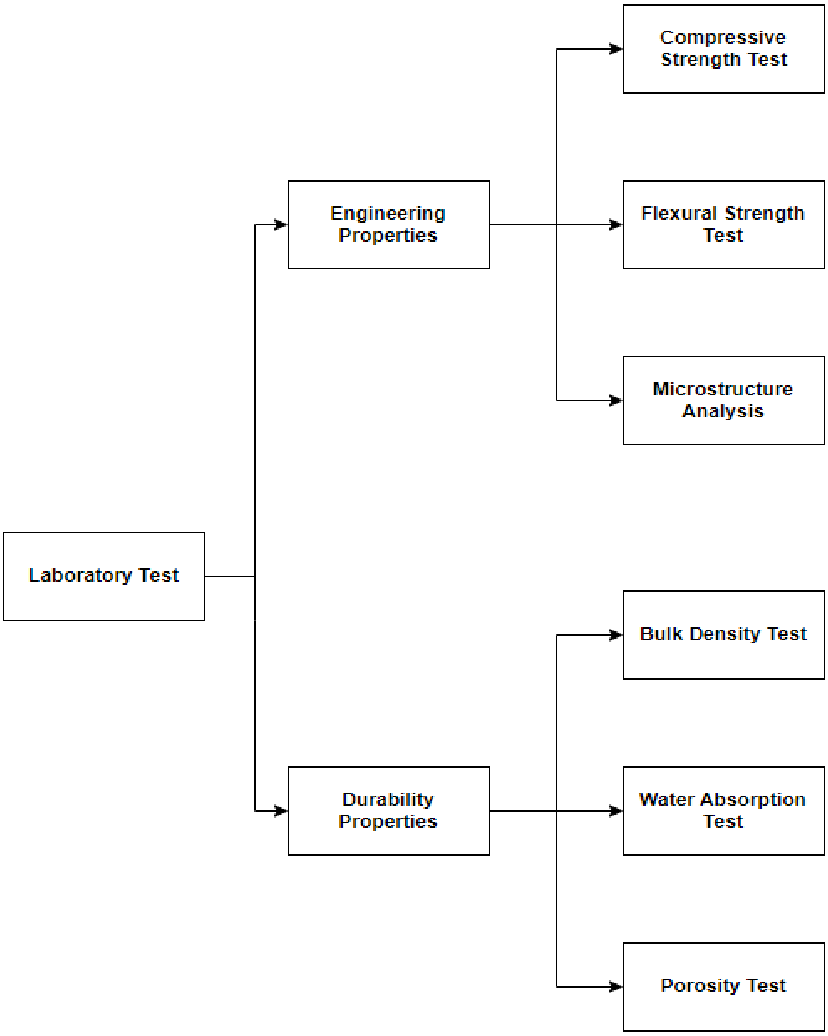


Figure 3.11: Laboratory Tests for CSB Specimens.

3.6.1 Compressive Strength

Compressive strength is significant as it is determined by the ability of CSB to withstand damage in the form of cracks. A compressive strength test is performed on the brick to determine the load-bearing capacity of CSB with the use of a compression strength machine which is shown in **Figure 3.12**. There are three brick specimen curing periods (7 days, 14 days, and 28 days) with different mixing portions involved in this test. Vernier calliper is used to measure the dimensions of the brick specimen and calculate the surface area of the specimen before the test is started. The maximum load reading is recorded when the bricks fail to resist the compression load from the machine. Hence, **Equation 3.1** below is applied to calculate the compressive strength of the brick.

$$P = \frac{F}{A} \tag{3.1}$$

Where,

P= Compressive Strength, MPa

F= Maximum load resist by the specimen, N

A= Surface area of the specimen, mm^2

Figure 3.12: Compression Test Machine.

3.6.2 Flexural Strength

A flexural strength test is conducted to determine the maximum bending stress of brick can sustain without cracks. This test is conducted with a t-machine universal testing machine **Figure 3.13**. There are three curing periods of brick specimens (7 days, 14 days, and 28 days) with different mixing portions involved in this test. The dimensions of the brick specimen and the distance between the supports are measured before the test is started. The specimen was first put on the machine and compressed until the specimen cracks. The maximum load reading is recorded when the specimen is unable to withstand the load applied by the machine. Thus, **Equation 3.2** below is applied to calculate the flexural strength of the brick.

$$f_v = \frac{F \times L}{b \times h^2} \tag{3.2}$$

Where,

fv= *flexural strength*, $\mathrm{N/mm^2}$

F=Maximum load resisted by the specimen, N

L= distance between the two supports, mm

b= width of the CSB specimen, mm

h= height of the CSB specimen, mm

Figure 3.13: T-machine Universal Testing Machine.

3.6.3 Microstructure Analysis

Microstructure analysis is a method applied to study the microscopic fine-scale structure of the materials. It gives important insights into material characteristics, behaviour, and performance of materials. Field Emission Scanning Electron Microscopy (FESEM) is used during this microstructure analysis to evaluate the microstructure properties of the specimen. The CSB specimen is first crushed into smaller pieces using a hammer and ground into fine powder form by a blender. The magnification levels of 1000, 5000, and 10000x were selected with 15kV of SEM voltage to analyse the detailed structure of CSB.

Figure 3.14: **SEM Test Machine.**

3.6.4 Bulk Density Test

The bulk density test is a method used to determine the mass per unit volume of a specimen. Different mixing portions of CSB with 7th, 14th, and 28th day curing time are tested. The CSB specimens are placed into the oven for 24 hours at 120°C to eliminate the moisture. The dried weight is recorded using the weighing balance after 24 hours of the drying process. The specimens are placed into the water tank for another 24 hours to obtain the saturation weight. The buoyance balance which is shown in **Figure 3.14** is used to measure the submerged weight of specimens in the water. At last, the specimens were taken out from the tank and the saturation weight of the specimens was recorded. Removed the surface water of the specimens using a cloth to avoid errors. The bulk density of the specimens is calculated using **Equation 3.3** below.

$$D = \frac{\mathrm{W_d}}{\mathrm{W_w} - \mathrm{W_i}} \times 1000 \qquad (3.3)$$

Where,

D= Bulk density, kg/m^3

W_d= Dried weight of specimen, g

W_w= Saturated weight of specimen, g

W_i= Immersed weight of specimen, g

Figure 3.15: Buoyancy Balance.

3.6.5 Porosity Test

The porosity test is a method to evaluate the number of voids or pores within a brick's structure. The porosity test is very important as it affects the durability and the performance of the brick in a variety of applications. In this research study, three curing times of brick specimens (7 days, 14 days, and 28 days) with different mixing portions are tested. At first, the CSB specimens are placed into the oven for 24 hours at 120°C to eliminate the moisture. The specimen is weighed for dried weight and recorded after 24 hours. A vacuum pump and desiccator are used in this test to place the specimen and the water is filled up to 1cm above the specimen which is shown in **Figure 3.16**. After that, the vacuum pump is switched on for 15 minutes to vacuum out the air. The specimens are then continued immersed in the desiccator for 3 hours, followed by another 15 minutes with a vacuum pump. The specimens are immersed in the water for a day after the vacuum pump is used. At last, remove the surface water of the specimens after taking them out of the water to avoid errors. The saturated weight and immersed weight are recorded to calculate the porosity of the specimens using **Equation 3.4** below.

$$n = \frac{W_w - W_d}{W_w - W_i} x1000 \tag{3.4}$$

Where,

n= Porosity, %

W_w= Saturated weight of specimen, g

W_d= Dried weight of specimen, g

W_i= Immersed weight of specimen, g

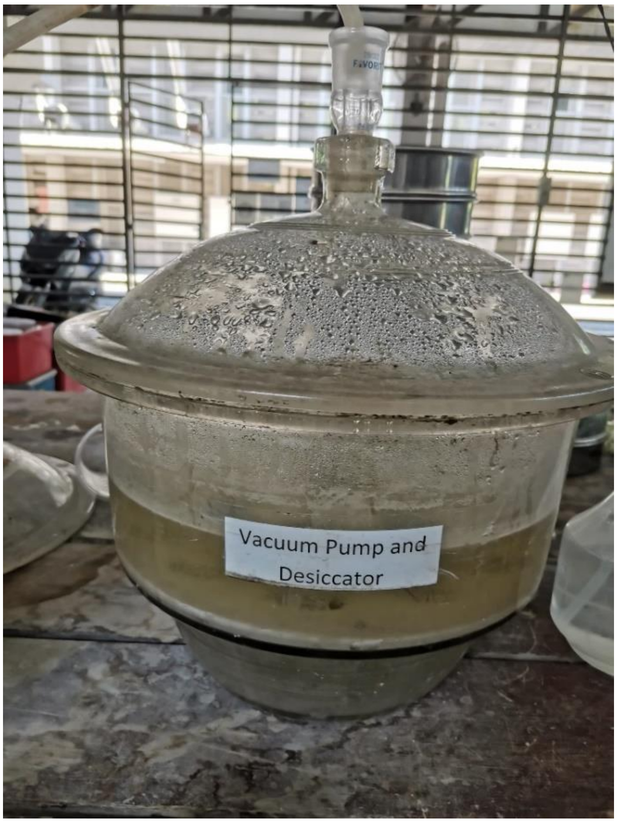


Figure 3.16: Vacuum Pump and Desiccator Used in Porosity Test.

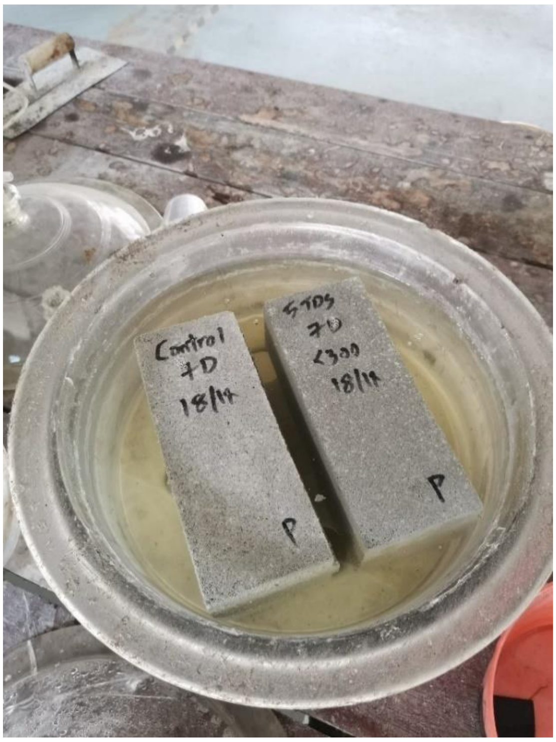


Figure 3.17: CSB Immersed in the Desiccator.

3.6.6 Water Absorption Test

The water absorption test is a method used to determine the total amount of water that can be absorbed by the specimen. This test helps to determine the water permeability of the specimen which will affect the durability of the CSB specimen. Three curing times of brick specimens (7 days, 14 days, and 28 days) with different mixing portions are tested. The CSB specimens are placed into the oven for 24 hours at 120°C to eliminate the moisture. After that, the dry CSB specimens are weighed and recorded to obtain their dry weight. After recording the dry weight, the specimens are placed into the water for another 24 hours to obtain the saturation weight which is shown in **Figure 3.17**. Removed the surface water of the specimens after taking them out of the water to avoid errors. At last, the saturated weight of the specimens is measured to calculate the water absorption rate using **Equation 3.5** below.

$$M = \frac{W_w - W_d}{W_d} \tag{3.5}$$

Where,

M= Water absorption percentage, %

W_w= Saturated weight of specimen, g

W_d=Dried weight of specimen, g

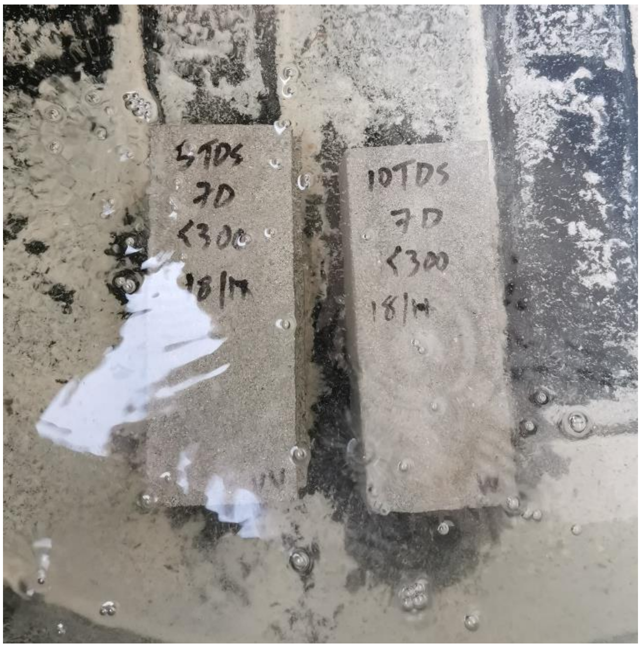


Figure 3.18: CSB Immersed in Water Tank.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The characteristics of TDS are discussed. The outcome of laboratory tests, mechanical, and durability properties of CSB after partial replacement of cement with TDS are analysed and discussed.

4.2 Characteristics of Textile Dyeing Sludge

Table 4.1: The Composition of TDS.

Compound	Concentration unit (%)
Al_2O_3	15.771
SiO_2	30.455
P_2O_5	5.825
SO_3	28.863
Cl	0.974
K_2O	1.882
CaO	4.656
TiO_2	0.865
MnO	0.218

Compound	Concentration unit (%)
Fe_2O_3	8.724
CuO	0.368
ZnO	0.700
Br	0.047
Sb_2O_3	0.116
PbO	0.150
LOI	77.95

The table above shows the composition of TDS in terms of various compounds and their concentration units (%). Based on **Table 4.1**, the major composition of the TDS are SiO_2 (30.455%), SO_3 (28.863%), Al_2O_3 (15.771%), Fe_2O_3 (8.724%), P_2O_5 (5.825%) and CaO (4.656%). SiO_2 and Al_2O_3, Fe_2O_3, and CaO are primary compounds of cement hydration and pozzolanic reaction to increase the strength and durability of CSB. Thus, TDS has an opportunity to replace the cement in the fabrication of CSB as it has a significant amount of SiO_2 which can promote the synthesis of tricalcium silicate (C_3S) for the early strength development and performance of CSB. C_3S is the primary binding agent in cement to react with water and produces calcium-silicate-hydrate (C-S-H) gel (Salah Uddin and Middendorf, 2019). SiO_2 retards the cement paste structure and fills the spaces between cement particles leading to an increase the cement hydration and produce more C-S-H gel (Wang et al., 2016). Apart from that, Al_2O_3 plays an important role in the formation of calcium aluminate hydrates (CAH) and provides early strength development. However, there is a high proportion of SO_3 and LOI values (77.95%) in the TDS that might reduce the durability and strength of the CSB.

Table 4.2: The Concentration Unit of the elements in TDS.

Compound	Concentration unit (%)
Al	13.103
Si	24.698
P	4.883

Compound	Concentration unit (%)
S	23.193
Cl	2.097
K	3.440
Ca	7.539
Ti	1.227
Mn	0.421
Fe	15.545
Cu	0.799
Zn	1.533
Br	0.132
Sb	0.265
Pb	0.391

According to **Table 4.2**, it was found that there are some elements in the TDS are in high concentration units such as Si (24.698%), S (23.193%), Fe (15.545%), Al (13.103%), Ca (7.539), P (4.883%), K (3.440%), and Cl (2.097%). Al and Fe are metal ions which toxic to aquatic organisms and can cause bioaccumulation in the food chain if released into the environment. These metal ions can infiltrate into soil and groundwater, affecting the quality of water resources. Thus, the TDS is classified as scheduled waste and disposed of in the secured landfill.

4.3 Compressive Strength

Table 4.3, **Figure 4.1**, and **Figure 4.2** shows the compressive strength of the CSB with three curing days. **Figure 4.3** shows the impact of TDS on compressive strength development of CSB at different curing periods (7 days, 14 days, 28 days).

Table 4.3: Compressive Strength of Cement Sand Brick Specimen.

CSB Specimen	Compressive Strength (MPa)		
	7 days	14 days	28 days
Control	13.67	13.93	14.30
5FTDS	10.45	10.58	13.73
10FTDS	6.97	9.09	10.30
15FTDS	6.39	6.67	8.07
10CTDS	6.20	6.48	8.93
15CTDS	5.94	6.18	7.39

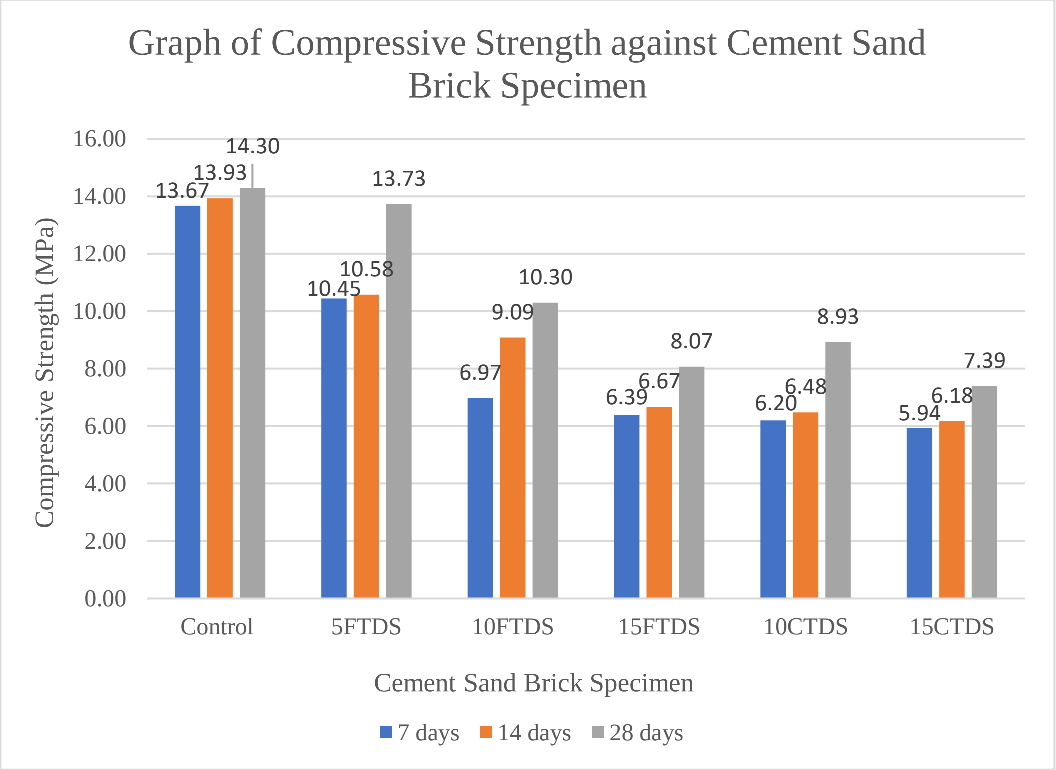


Figure 4.1: Graph of Compressive Strength against Cement Sand Brick Specimen.

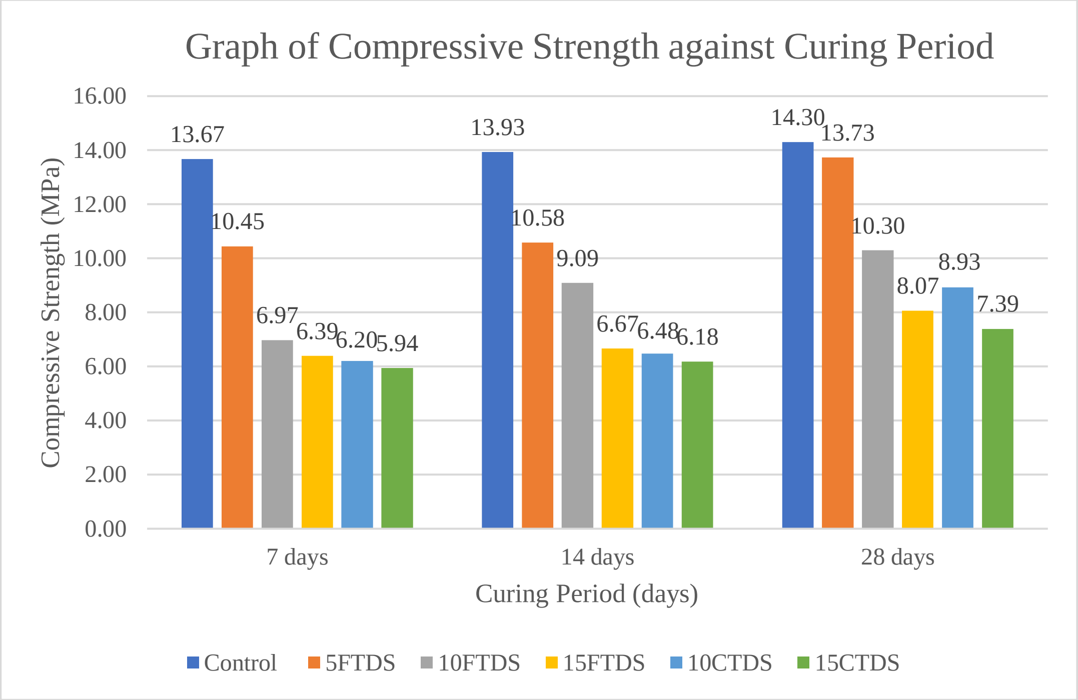


Figure 4.2: Graph of Compressive Strength against Curing Period.

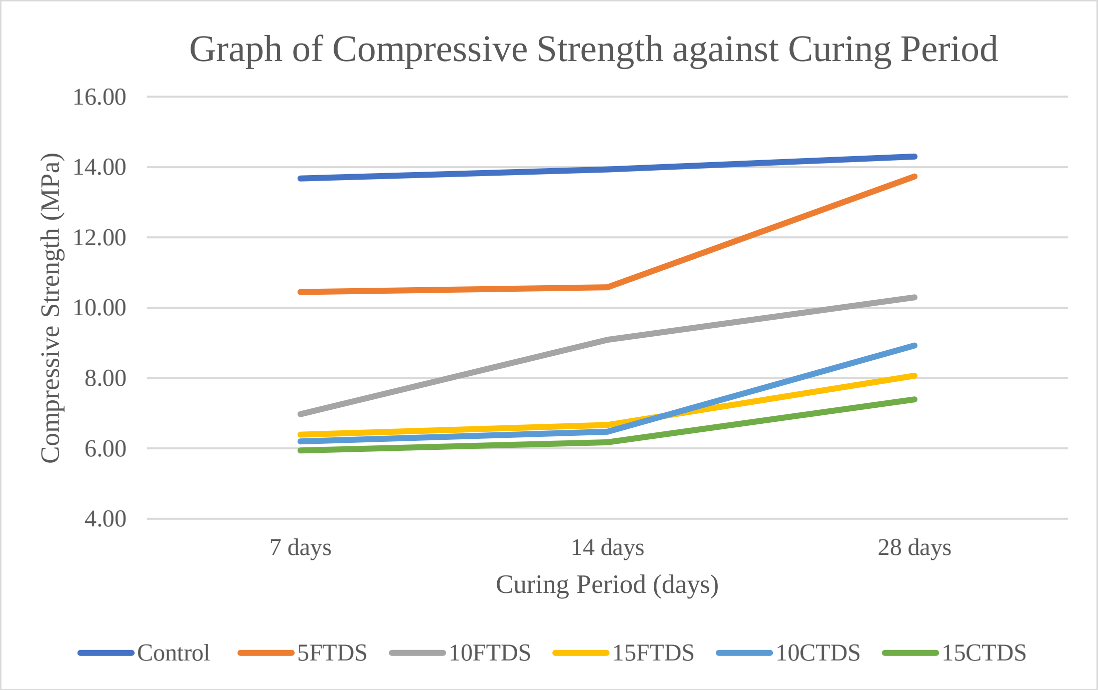


Figure 4.3: Graph of Development of Compressive Strength for CSB against Curing Period.

Compressive strength is a crucial parameter for CSB as it is used to determine the ability to withstand compressive loads without failure. Compressive strength in the CSB is mainly affected by the strength of the cement paste matrix and the bond between the cement paste and sand particles. Thus, the higher the compressive strength, the better the load-bearing capability of CSB. From the table and figures, the control specimen with no replacement of TDS serves as the benchmark, with the highest compressive strength throughout all the curing periods, reaching 14.30 MPa at 28 days. When the TDS replacement is 5%, it results in a slight reduction in compressive strength compared to the control, with a strength of 13.73 MPa at 28 days. As the TDS replacement level increases to 10% and further reaches 15%, the compressive strength reduction becomes more substantial. The 10FTDS specimen has a 10.30 MPa at 28 days and the 10CTDS specimen has a slightly lower strength of 8.93 MPa. On the other hand, 15FTDS has an 8.07MPa and 15CTDS reaches the lowest strength with 7.39 MPa at 28 days which is lost by 48.32% of strength compared to the control.

The reduction in strength when the replacement level of TDS increases implies a slower hydration reaction with the addition of TDS to mixtures. The lower hydration reaction might be attributed to a lower amount of CaO concentration in TDS compared to the CaO content of the cement (Goyal et al., 2019). According to Ali, Khan, and Hossain (2008), the standard Ordinary Portland Cement (OPC) consists of 65% of CaO while the TDS only consists of 4.656% of CaO. Cement is the primary binder in CSB that provides strength through the formation of cementitious compounds during hydration reactions. The decline in compressive strength can be attributed to a reduction in the amount of cement, resulting in a lower overall concentration of cementitious compounds. Thus, the dilution effects lead to the absence of cementitious action when the replacement levels increase. In addition, a high LOI value implies the presence of substantial organic and volatile compounds which might break down during the mixing or hydration process, leading to decreased compressive strength (Goyal et al., 2019).

Besides that, another reason that might cause the reduction of the compressive strength when the TDS replacement level increases is the presence of heavy metals such as Zn and Pb in the sludge, hindering the hydration reaction and affecting the compressive strength (Goyal et al., 2019). Zn and Pb can surround the cement grains by forming a protective coat that inhibits them from taking part in the hydration process. For instance, Zn creates a membrane of calcium hydroxyl zincate ($CaZn_2(OH)_6 \cdot 2H_2O$) when reacts with cement compounds which is shown in **Equation 4.1**. This membrane prevents the water flow and ions required for cement hydration (Goyal et al., 2022). Hence, heavy metals will reduce the formation of cementitious compounds, leading to lower compressive strength.

$$\mathrm{C_3S/O - Ca^{2+} + \ + 2ZnO_2^{2+} + 6H_2O \rightarrow C_3S/O - CaZn_2OH_6 \cdot 2H_2O + 2OH^-} \tag{4.1}$$

Apart from that, for both the 10% and 15% TDS replacement levels, the finer TDS particles have greater compressive strength than coarse TDS particles which is shown in **Figure 4.1**. This observation indicates that the compressive strength performance of the TDS may be affected by the particle size distribution. Based on Sugrañez et al. (2013), the compressive strength decreases when the particle size increases. Finer TDS particles provide a higher packing density and reactivity, leading to the synthesis of more cementitious compounds and improving the overall microstructure of the cement matrix. On the other hand, coarser particles might not engage effectively in pozzolanic reaction, contributing to lower strength. Furthermore, all specimens show an increase in compressive strength with longer curing periods which is shown in **Figure 4.2** and **Figure 4.3**. It indicates that hydration and pozzolanic processes continue over time, causing the formation of C-S-H gel and filling up the pores of the CSB. Thus, the compressive strength will increase with age if the curing conditions are appropriate (Seyam and Nemes, 2023).

Based on the Malaysia Standard (MS 76:1972) and British Standard 3921:1985, it stated that the minimum compressive strength for CSB is 7.0 MPa. It shows that all the specimens fulfilled the standard at 28 days even though the replacement of TDS in CSB did not increase the compressive strength. Thus, the substitution percentage of TDS up to 15% with cement in the fabrication of CSB is feasible.

4.4 Flexural Strength

Table 4.4, **Figure 4.4**, and **Figure 4.5** illustrate the flexural strength of the CSB with three curing days. **Figure 4.6** shows the impact of TDS on flexural strength development of CSB at different curing periods (7 days, 14 days, 28 days).

Table 4.4: Flexural Strength of Cement Sand Brick Specimen.

CSB Specimen	**Flexural Strength (MPa)**		
	7 days	**14 days**	**28 days**
Control	2.23	2.33	2.38
5FTDS	1.84	2.07	2.23
10FTDS	1.34	1.47	2.17
15FTDS	1.42	1.47	1.52
10CTDS	1.26	1.48	1.54
15CTDS	1.17	1.28	1.37

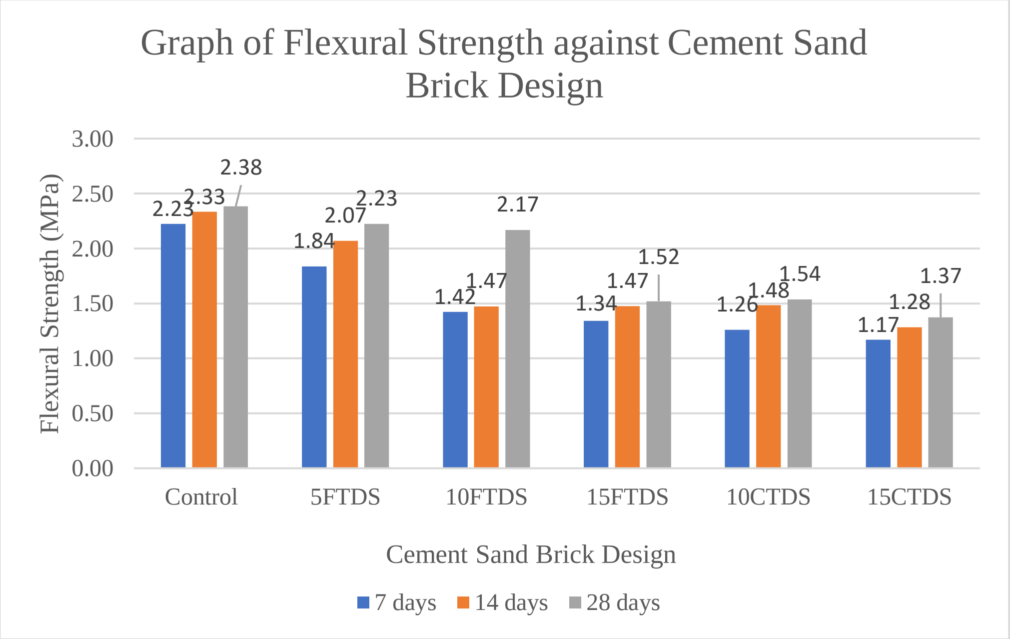


Figure 4.4: Graph of Flexural Strength against Cement Sand Brick Specimen.

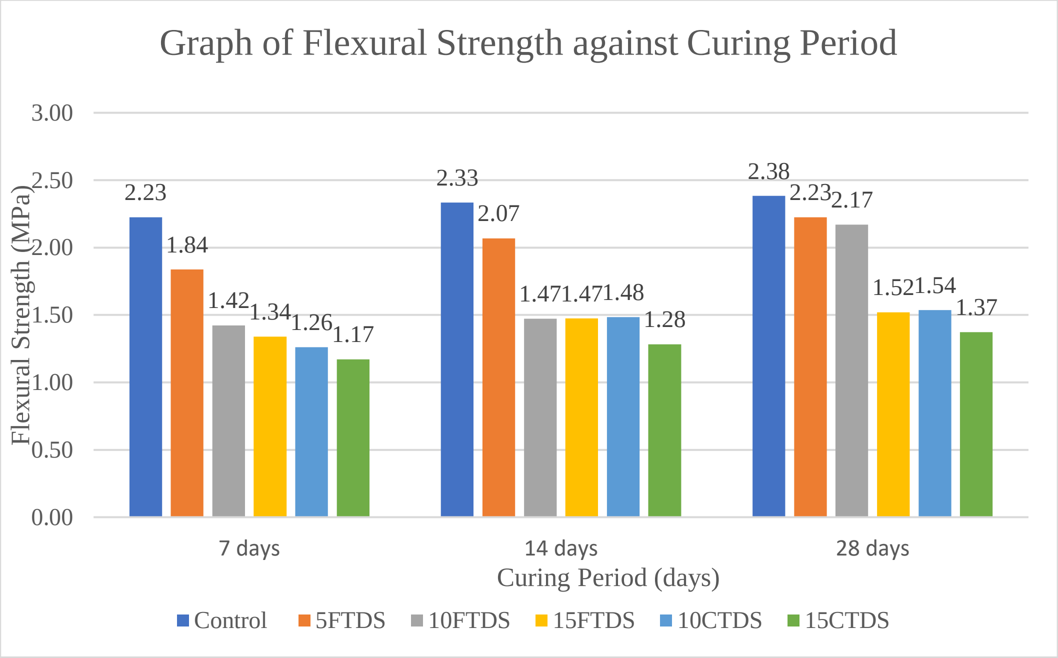


Figure 4.5: Graph of Flexural Strength against Curing Period.

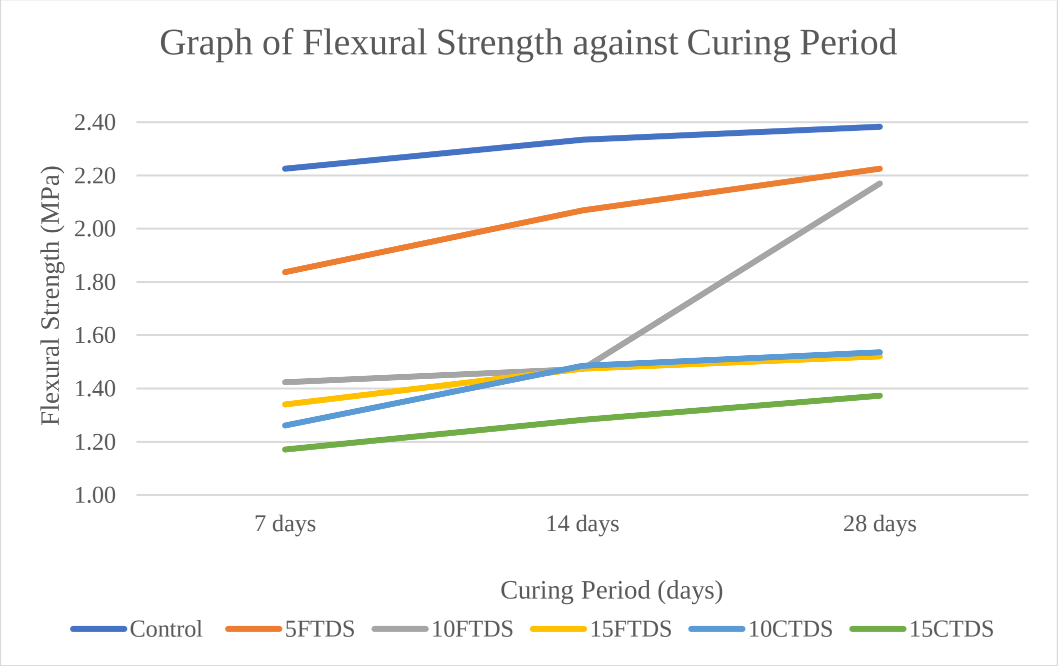


Figure 4.6: Graph of Development of Flexural Strength for CSB against Curing Period.

Flexural strength is a measure of the tensile strength of CSB. It is a significant characteristic that determines the ability of CSB to resist deformation under flexural or bending stresses. Thus, the higher the flexural strength of CSB, the higher its capability to withstand bending loads such as wind forces, the weight of the overlying structure, and seismic activity. According to **Figure 4.4**, the control specimen without any TDS incorporation acts as the standard which shows the highest flexural strength among all the specimens throughout the curing period, reaching 2.38MPa at day 28. This indicates that the control specimen contains the full cement content, allowing for proper hydration and strength development. As the replacement level increases, a clear trend of decreasing flexural strength is shown in **Figure 4.6**. The 5FTDS displays a 6.30% reduction in flexural strength compared to control at 28 days. Therefore, it illustrates that a low replacement level of TDS can be accepted with minimum impact on strength performance. Nevertheless, when the TDS replacement reaches 10% and 15 %, it shows a more significant reduction in flexural strength, by 42.44% for 15CTDS at 28 days.

The key root cause for the reduction of strength is due to low concentration of CaO in TDS, leading to the absence of cementitious action (Goyal et al., 2022). The quantity of C-S-H gel produced decreases when the TDS replacement level is higher as the dilution effect that caused by less cement content. Thus, it results in a lower hydration reaction and lower development of CSB flexural strength (Hossain et al., 2023). Another possible reason is the presence of high sulphate (SO_3) content in TDS. High sulphate levels in TDS might cause the cement paste in the brick mixture to delay setting as the formation of calcium sulfoaluminate hydrate (ettringite) which is shown in **Equation 4.2** This compound can interfere with the usual hydration reaction of cement and harm the strength development of CSB. Hence, it may cause dimensional stability problems and could lead to cracking, strength loss, expansion, and a decline in the modulus elasticity (Neville, 2011).

$$\begin{aligned} &2(3\mathrm{CaO.Al_2O_3.12H_2O}) + 3(\mathrm{Na_2}SO_4.\mathrm{10H_2O}) \\ &\rightarrow \mathrm{3CaO.Al_2O_3.3CaSO_4.32H_2O + 2Al(OH)_3 + 6NaOH + 17H_2O}. \end{aligned} \tag{4.2}$$

Moreover, some compounds such as Zn and Pb in TDS might reduce the CSB strength by interfering with the hydration and pozzolanic reaction. These heavy metals can produce calcium hydroxyl zincate ($CaZn_2(OH)_6 \cdot 2H_2O$) with cement particles, preventing water and ion transport for hydration by forming a membrane. Thus, the obstruction of hydration results in a loss in strength development (Goyal et al., 2019). Furthermore, another factor that contributes to the loss of flexural strength is the excessive LOI in the TDS. A high value of LOI shows an abundance of organic and volatile compounds that can decompose while mixing and hydration process which affects the flexural strength of the CSB (Hossain et al., 2023).

Apart from that, **Figure 4.4** also highlights the effect of TDS particle size distribution on flexural strength. The CSB specimens with coarse particle size (10CTDS and 15CTDS) had lower flexural strength than fine TDS (10FTDS and 15FTDS). 10CTDS had a 29.03% decrease in strength compared with 10FTDS while 15CTDS had 9.87% lower than 15FTDS. This indicates that the flexural strength declines with the increase in particle size (Sugrañez et al.,2013). This finding implies that coarser TDS particles might be less reactive to the pozzolanic process due to their lower surface area-to-volume ratio. Therefore, it may increase the porosity of the CSB which results in permeable and weaker microstructure, leading to decreased flexural strength. However, across all the specimens, **Figure 4.5** and **Figure 4.6** demonstrate a consistent trend of increasing flexural strength with increasing curing time. Hence, it shows that the flexural strength of all specimens at 28 days is greater than 7 days.

British Standard 6073 Part 1: 1981 stated that the minimum average flexural strength for CSB is 0.65 MPa. It shows that all the specimens fulfilled the standard at 28 days even though the replacement of TDS in CSB did not increase the compressive strength. Thus, the substitution percentage of TDS up to 15% with cement in the fabrication of CSB is feasible.

4.5 Microstructure Analysis

FESEM is used in this feasibility study to evaluate the microstructure of the specimens that have various TDS replacement percentages.

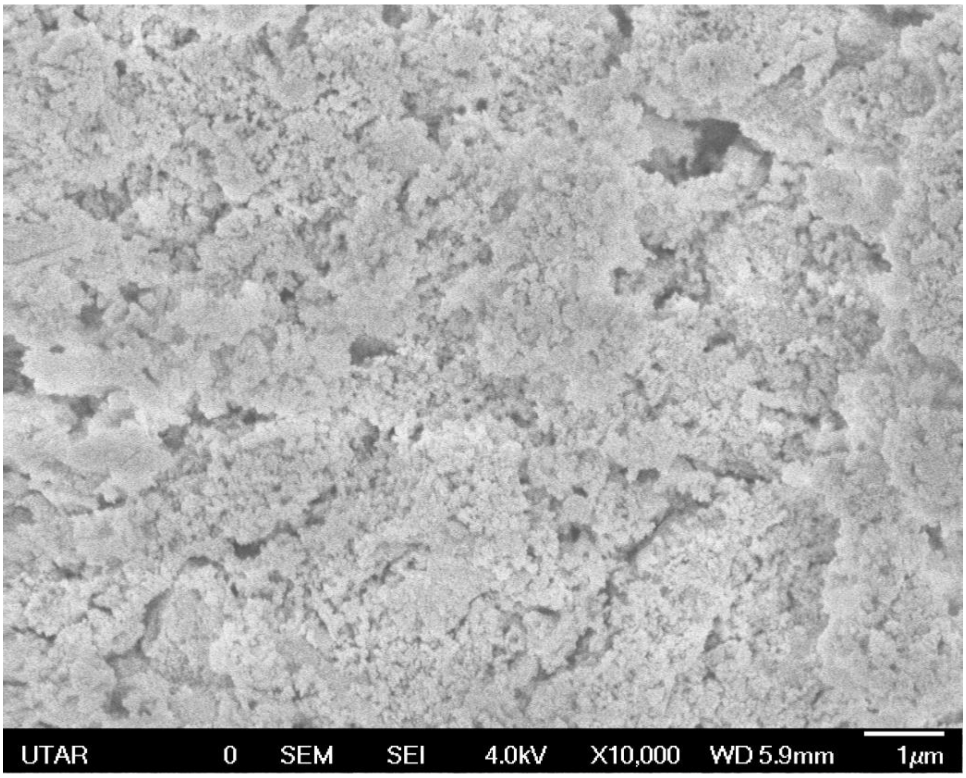


Figure 4.7: FESEM Image of Control Specimen.

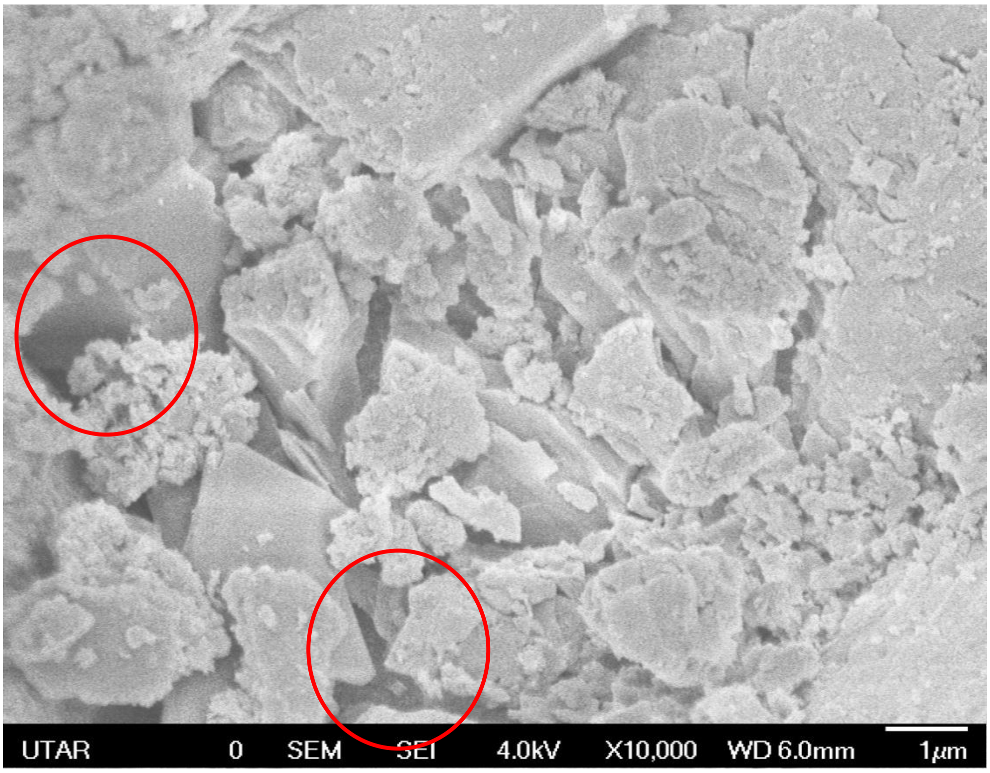


Figure 4.8: FESEM Image of 5FTDS Specimen.

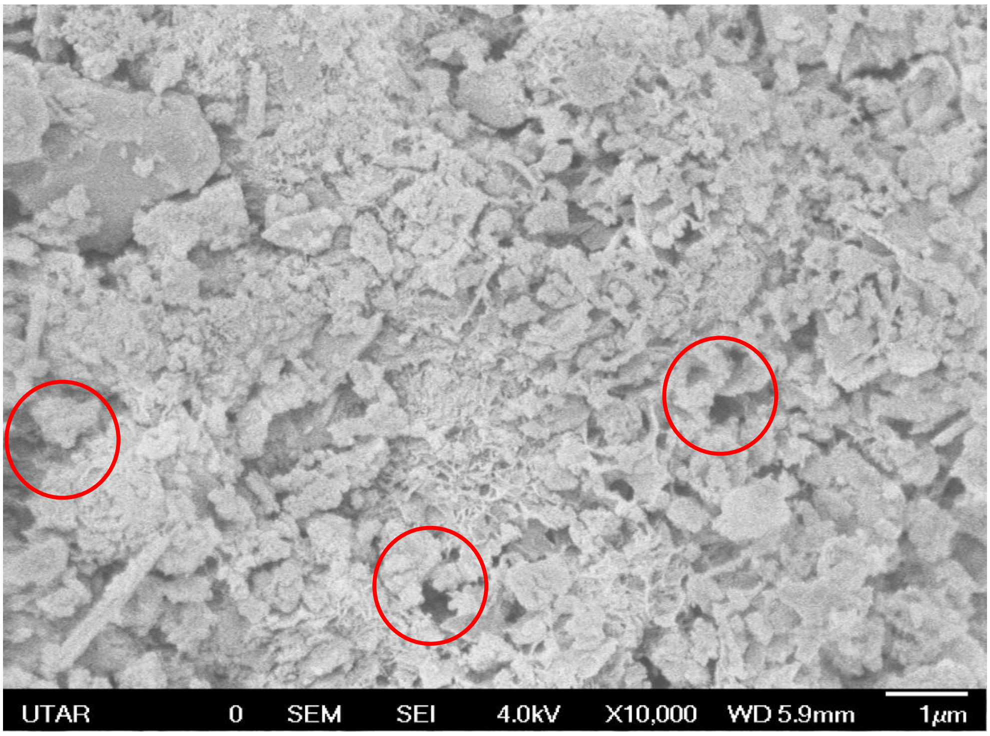


Figure 4.9: FESEM Image of 10FTDS Specimen.

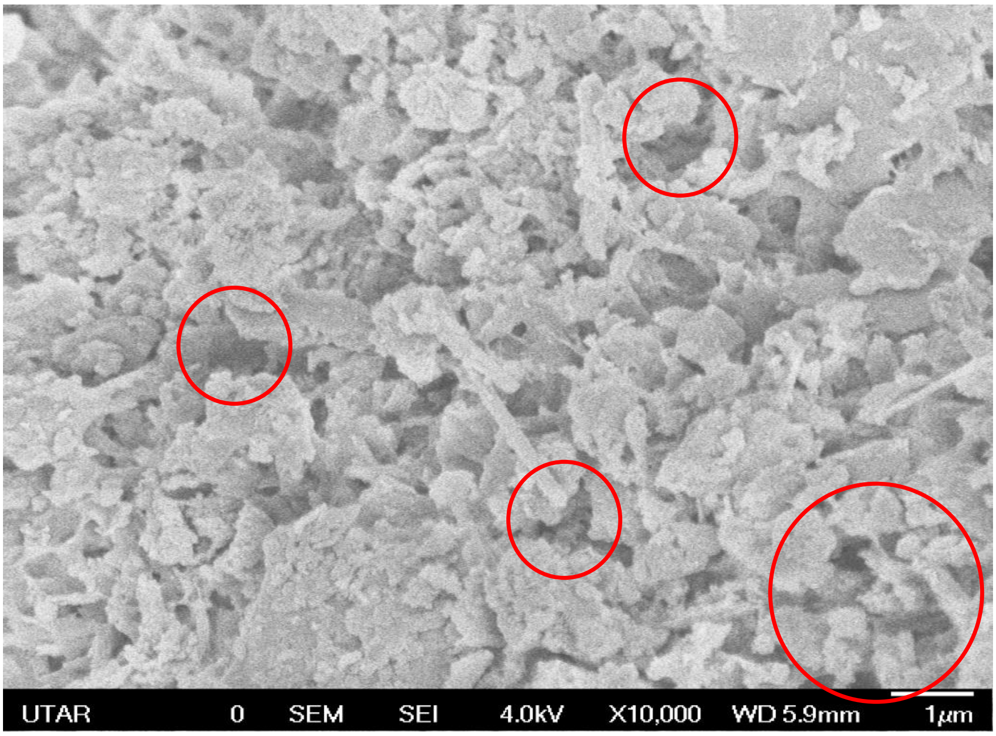


Figure 4.10: FESEM Image of 15FTDS Specimen.

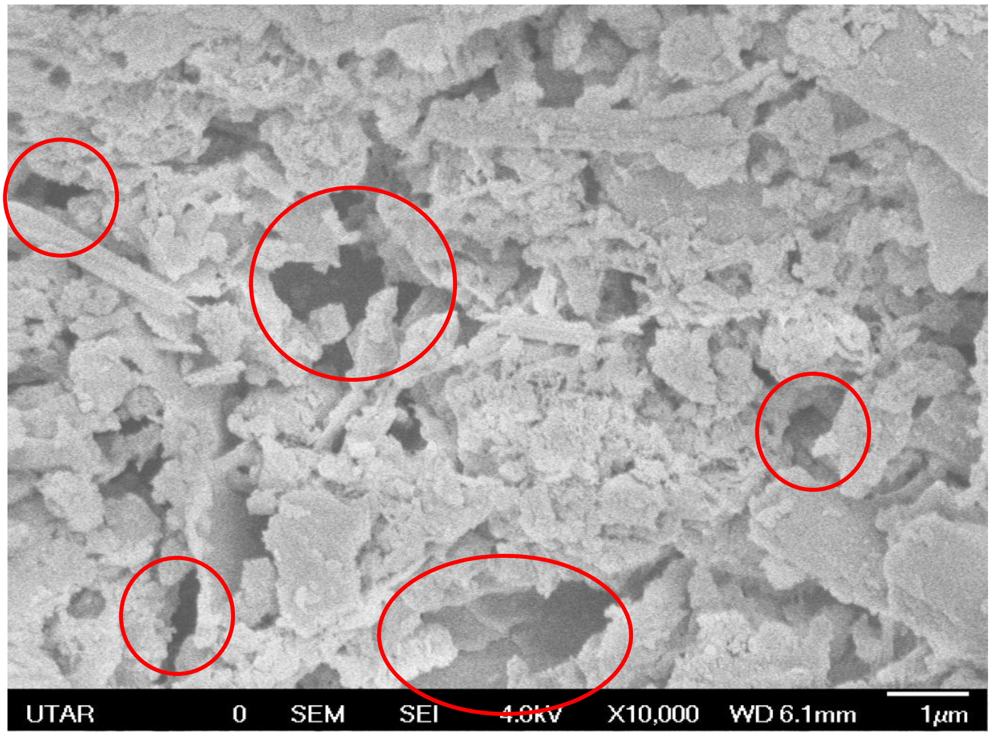


Figure 4.11: FESEM Image of 10CTDS Specimen.

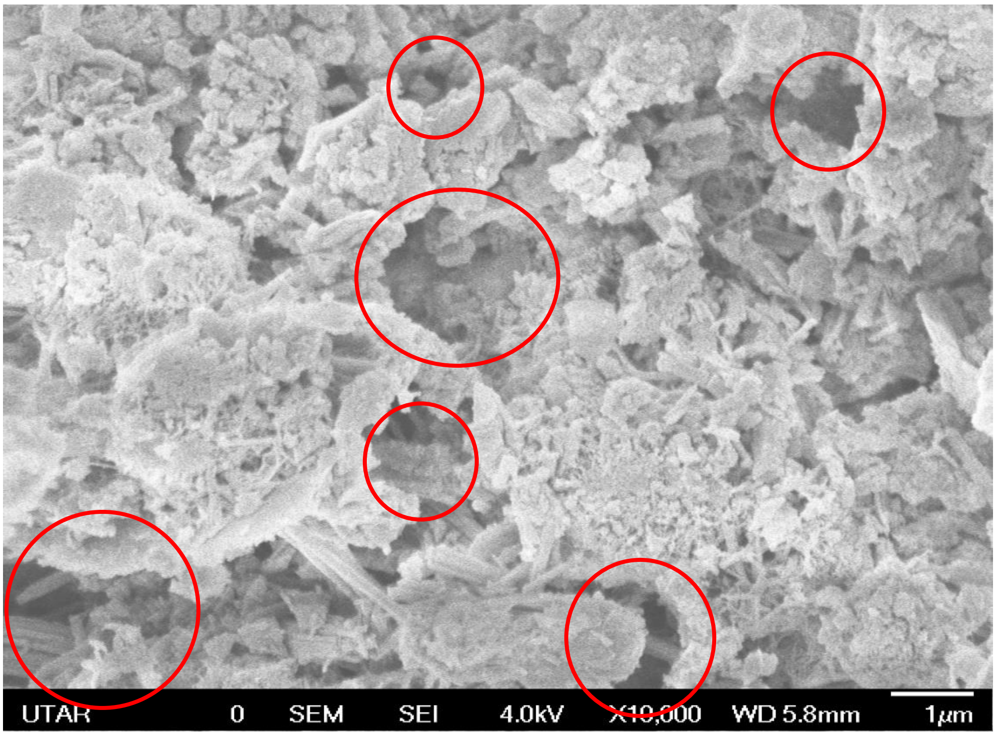


Figure 4.12: FESEM Image of 15CTDS Specimen.

Figure 4.7 shows the FESEM image of the control specimen with 10000x magnification at 28 days. The control specimen serves at standard without any partial substitution of cement with TDS. From the image, there were very few pores and voids present. It indicates that the hydration and pozzolanic processes have occurred effectively to form C-S-H gel and fill the pores between the cement and sand particles. **Figure 4.8** to **Figure 4.12** showed the FESEM image of different replacement percentages of TDS and different particle sizes. Based on the FESEM figures, as the replacement percentages increased, the amount of voids and pores increased within the specimens. Apart from that, the 10CTDS and 15CTDS specimens in **Figure 4.11** and **Figure 4.12** display more porous with larger voids and gaps as the coarser particles are substituted with cement. Pores and voids in the CSB can lead to a decrease in compressive strength and flexural strength. Besides that, it increases the permeability of CSB to moisture and gases. Therefore, the water absorption and porosity of CSB specimens might increase from 5FTDS to 15CTDS. Based on the images shown above, 5FTDS is the most suitable specimen to select among all the specimens due to the fewer voids and pores and a more compact microstructure.

4.6 Bulk Density

Table 4.5, **Figure 4.13**, and **Figure 4.14** illustrate the bulk density of the CSB with different curing days. **Figure 4.15** shows the effect of TDS on bulk density development of CSB at different curing periods (7 days, 14 days, 28 days).

Table 4.5: Bulk Density of Cement Sand Brick Specimen.

CSB Specimen	Bulk Density (kg/m^3)		
	7 days	14 days	28 days
Control	1835.89	1840.65	1850.79
5FTDS	1805.28	1830.01	1846.96
10FTDS	1782.05	1781.22	1786.00
15FTDS	1745.05	1755.01	1784.51
10CTDS	1731.96	1762.98	1763.07
15CTDS	1704.79	1723.82	1731.10

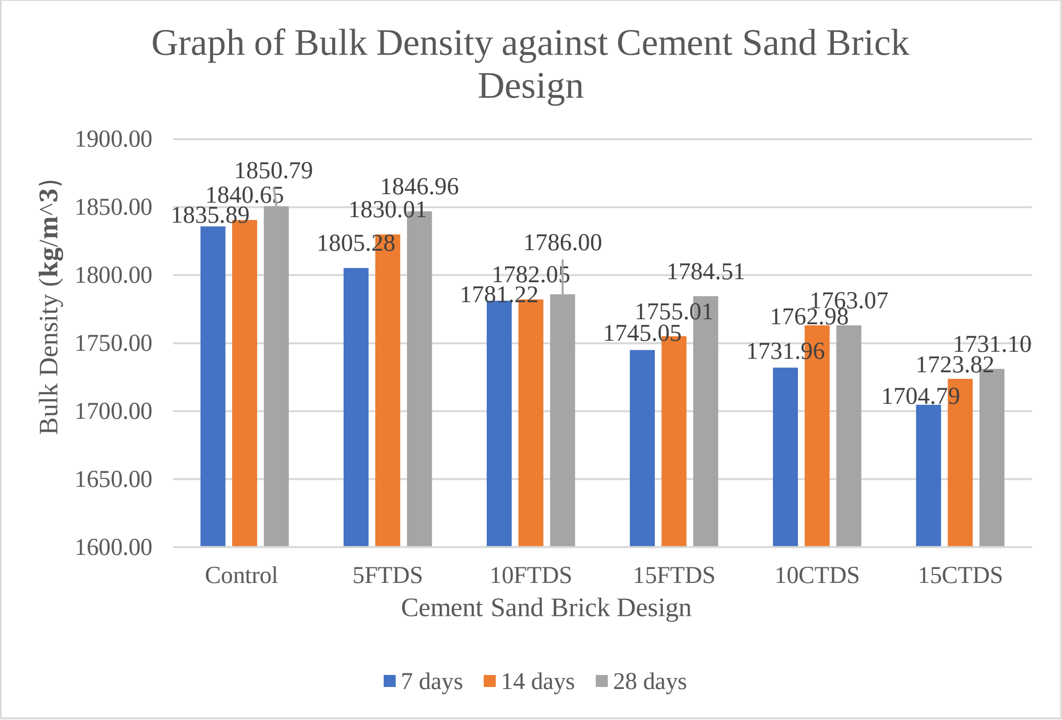


Figure 4.13: Graph of Bulk Density against Cement Sand Brick Specimen.

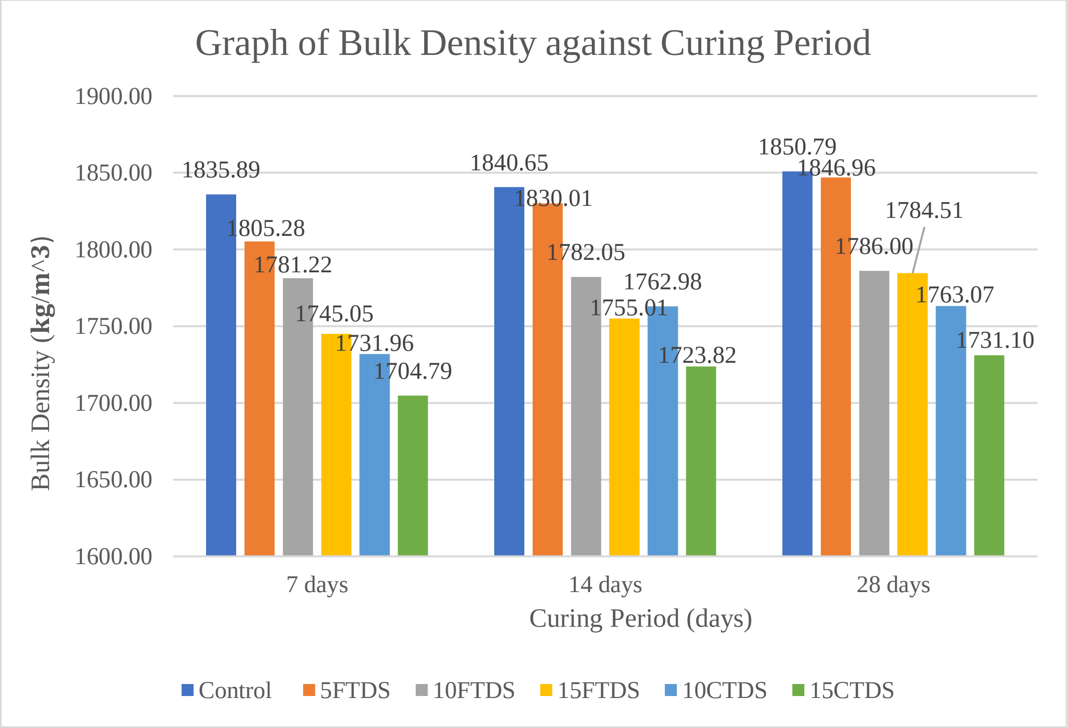


Figure 4.14: Graph of Bulk Density against Curing Period

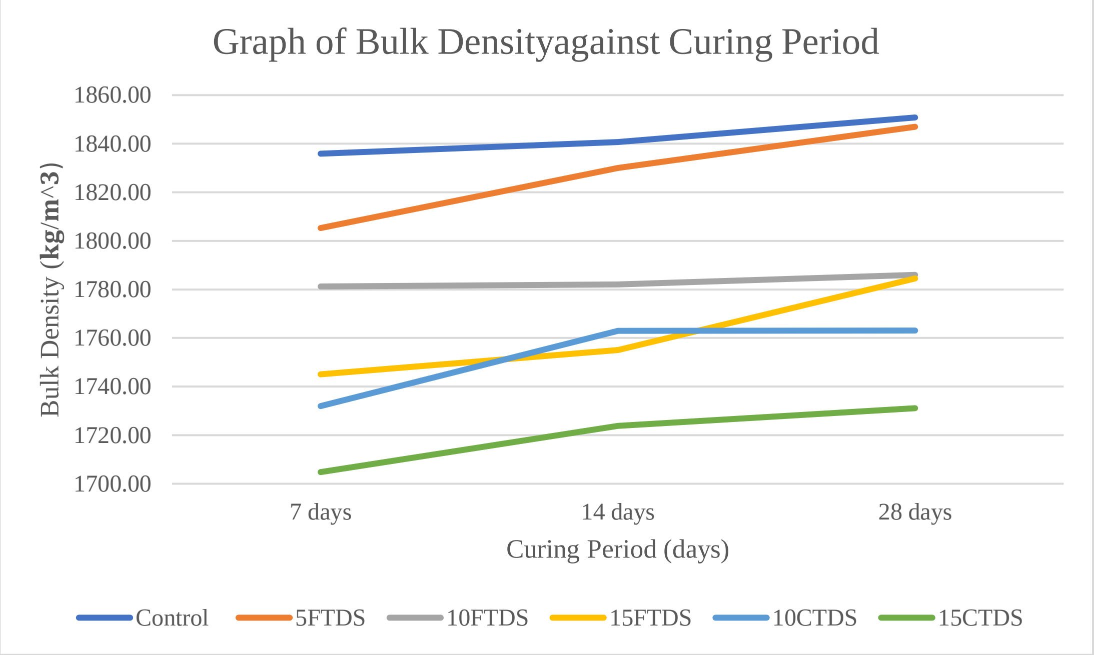


Figure 4.15: Graph of Development of Bulk Density for CSB against Curing Period.

Bulk density refers to the ratio of the total mass of CSB to its volume. It is used to indicate the overall compaction and quality of the CSB specimen. In general, a high bulk density CSB is usually denser, more compact, and has fewer pores and voids. Based on **Figure 4.13**, the control specimen had the highest bulk density over all the curing periods which is 1850.79 kg/m^3 at 28 days. Besides that, the 5FTDS achieved the highest bulk density (1846.96 kg/m^3) and the 15CTDS achieved the lowest bulk density (1731.10 kg/m^3) among all the TDS-containing specimens at 28 days. **Figure 4.14** illustrates the trend of decreased bulk density as the TDS replacement percentage increases.

On the other hand, the use of fine TDS has a higher bulk density compared to coarse TDS at the same replacement percentages. This is due to the lower CaO content in the specimen when the cement is partially substituted by TDS in the fabrication of CSBs which reduces the degree of hydration reaction (Goyal et al., 2022). Thus, it leads to less efficient packing of particles in CSB specimens, creating more pores and increasing the porosity of specimens. Apart from that, another reason is that TDS has a lower density compared to cement. The common density of OPC is 1500 kg/m^3

(Helsel, Ferraris, and Bentz, 2016) while the TDS has 850.50 kg/m^3 (Saha et al., 2022). Hence, the overall density of the CSB mixture decreases as the replacement percentages increase, resulting in lower bulk density. Furthermore, **Figure 4.15** demonstrates that bulk density increases with longer curing times as the cement hydration process continues over time, which produces a denser and more compact structure.

The standard of the bulk density for CSB stated in Malaysia Standard (MS 76:1972) is between 1300 $\mathrm{kg/m^3}$ to 2200 $\mathrm{kg/m^3}$. It shows that all the specimens fell within the range of standard and the replacement of TDS in CSB had decreased the bulk density. Thus, the replacement percentage of 15% TDS with cement in the fabrication of CSB is optimum as it has the lowest bulk density among all the specimens.

4.7 Porosity

Table 4.6, **Figure 4.16**, and **Figure 4.17** show the porosity of the CSB with three curing days. **Figure 4.18** represents the impact of TDS on the porosity development of CSB at different curing periods (7 days, 14 days, 28 days).

Table 4.6: Porosity of Cement Sand Brick Specimen.

CSB Specimen	Porosity (%)		
	7 days	**14 days**	**28 days**
Control	22.15	22.03	20.65
5FTDS	22.11	24.81	22.96
10FTDS	25.73	26.25	21.27
15FTDS	26.09	26.78	23.14
10CTDS	27.45	27.83	24.28
15CTDS	28.75	28.93	28.13

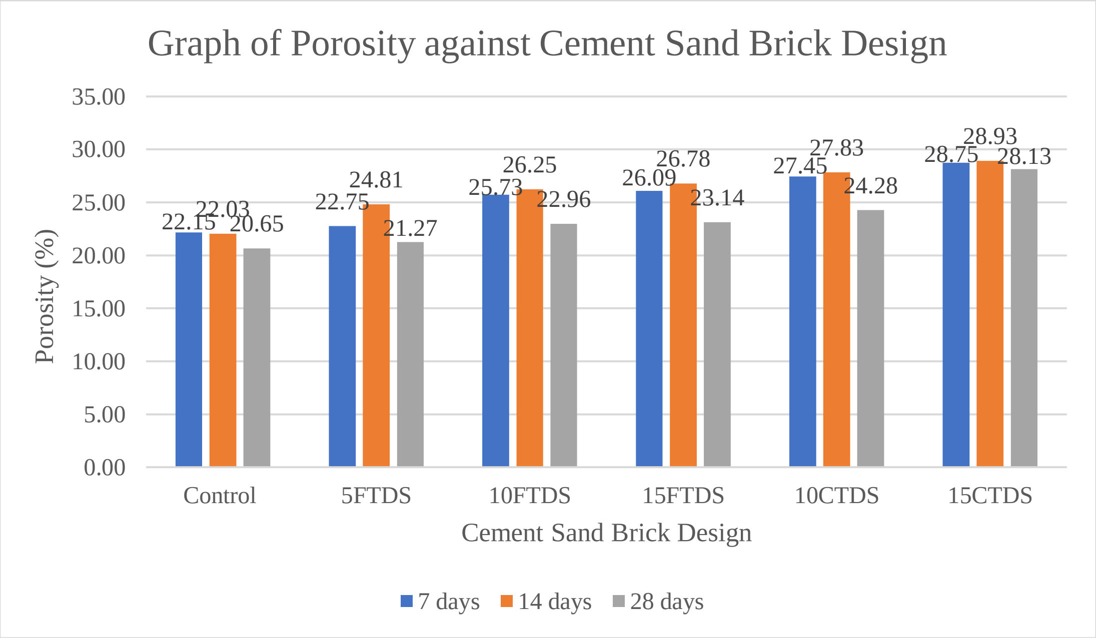


Figure 4.16: Graph of Porosity against Cement Sand Brick Design.

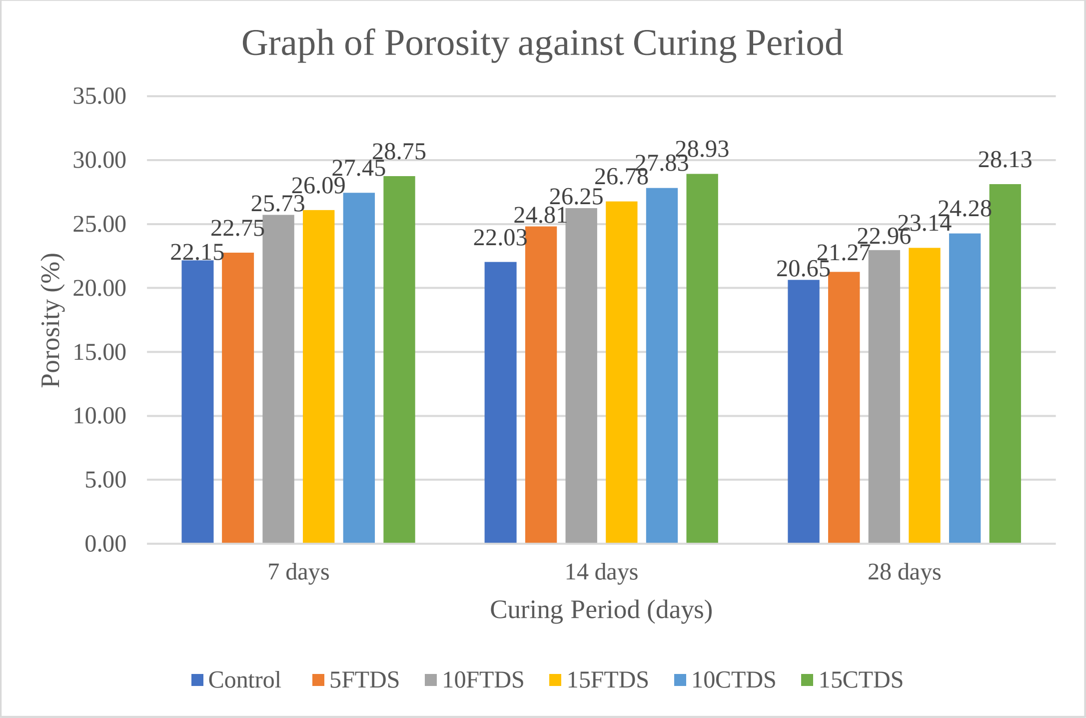


Figure 4.17: Graph of Porosity against Curing Period.

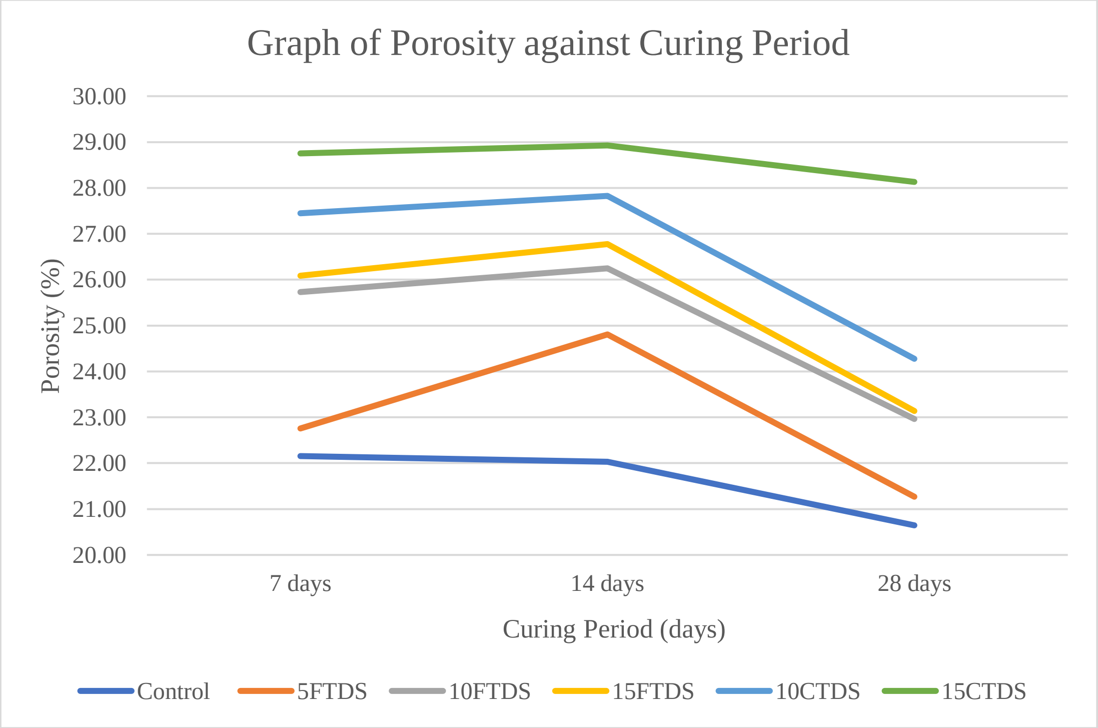


Figure 4.18: Graph of Development of Porosity for CSB against Curing Period.

Porosity is a fundamental parameter of CSB that is used to determine the presence of pores and void spaces within the brick. Porosity also known as the ratio of volume of pores to the overall volume of CSB. A low porosity of CSB indicates a more compact and denser internal structure which leads to higher density and compressive strength. **Figure 4.16** shows the control specimen acted as a standard exhibiting the lowest porosity throughout all the curing periods with values of 22.15%, 22.03%, and 20.65% at 7, 14, and 28 days respectively. This illustrates that the control specimen without replacement of TDS has the most dense and compact internal structure among all the specimens. A key trend that can be observed is that as the TDS replacement percentage increases, the porosity of CSB also rises. The 5FTDS achieved the lowest porosity while the 15CTDS achieved the highest porosity with values of 21.27% and 28.13% respectively among all the TDS-containing specimens. This shows that incorporating more TDS creates a porous CSB structure.

The primary reason for the increase in porosity is due to the decreased CaO concentration in the specimen when TDS is partially replaced for cement in the fabrication of CSB which lowers the hydration and pozzolanic process of cement particles. (Goyal et al., 2022). Thus, it results in less compact particles in CSB, producing more pores and enhancing the porosity of specimens. Besides that, the high LOI value shows a significant quantity of organic and volatile compounds in the TDS which might break down during the mixing and hydration processes (Goyal et al., 2019). These compounds can disrupt the normal hydration between the TDS particles and cement which causes more pores and voids in CSB specimens. Another possible reason for the increase in porosity is the TDS that used in this research study consists of high concentrations of SO_3. This may cause the formation of calcium sulfoaluminate hydrate (ettringite) which can affect the cement hydration and reduce the CSB strength development (Neville, 2011). Hence, fewer C-S-H gels are produced, and more pores and voids are generated within the specimens. On the other hand, from **Figure 4.7** to **Figure 4.12**, it can be observed that the number of voids and pores in the FESEM images increases. Thus, the porosity of specimens increases with the replacement percentage, Based on **Figure 4.16**, it also highlights the effect of TDS particle size distribution on porosity. For both 10% and 15% replacement, the coarse TDS particles have higher porosity than fine TDS particles. The porosity of 10CTDS is 24.28% at 28 days, which is higher than the 22.96% of 10FTDS, and a similar trend is observed at the 15% replacement level. Therefore, particle size has a significant impact on the pore structure as the coarser TDS particles lead to the formation of more porous CSB. Moreover, **Figure 4.17** and **Figure 4.18** reveal the influence of the curing period on the porosity of the specimens. The porosity of CSB increases from the curing period (7 to 14 days) as the hydration process might not be completed. The incomplete hydration causes the porosity of CSB to increase as the voids and pores are not yet filled within the specimen. As the curing period from 14 to 28 days, the hydration reaction continues and the CSB becomes more compact and denser. Therefore, porosity decreases in the late curing stages due to the densification process and the pores are filled by the formation of C-S-H gels.

4.8 Water Absorption

Table 4.7, **Figure 4.19**, and **Figure 4.20** shows the water absorption of the CSB with different curing days. **Figure 4.21** shows the effect of TDS on water absorption development of CSB at different curing periods (7 days, 14 days, 28 days).

Table 4.7: Water Absorption of Cement Sand Brick Specimen.

CSB Specimen	Water Absorption (%)		
	7 days	14 days	28 days
Control	12.33	11.28	6.49
5FTDS	12.45	12.11	6.78
10FTDS	12.87	12.66	7.82
15FTDS	13.10	12.89	9.09
10CTDS	15.52	13.49	11.29
15CTDS	16.39	14.87	12.31

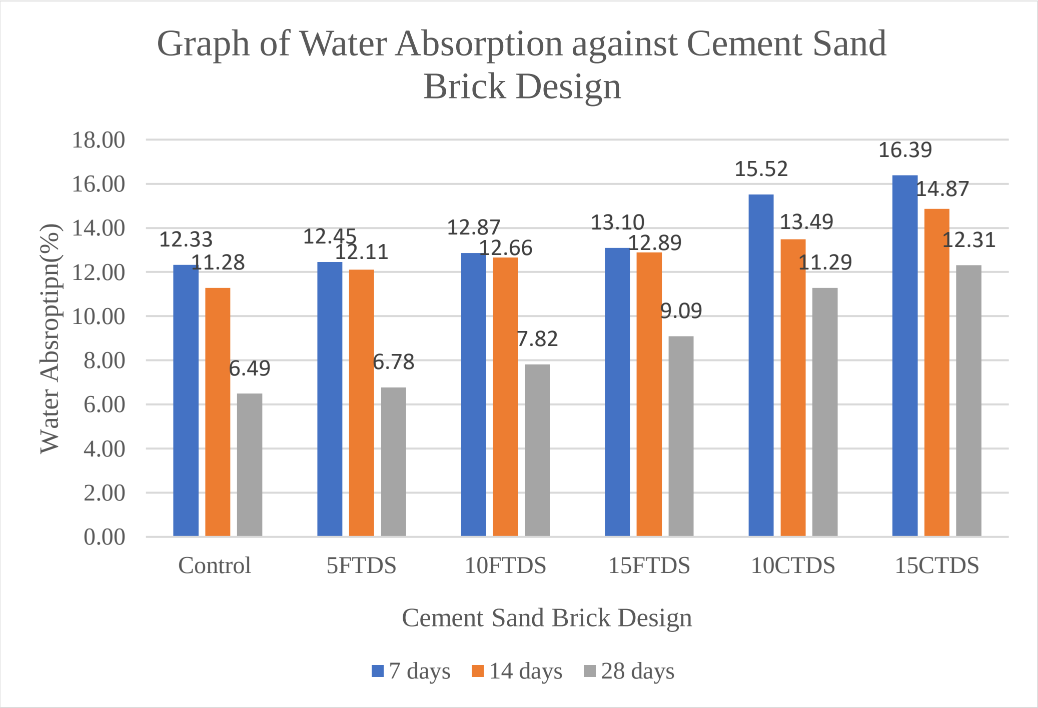


Figure 4.19: Graph of Water Absorption against Cement Sand Brick Design.

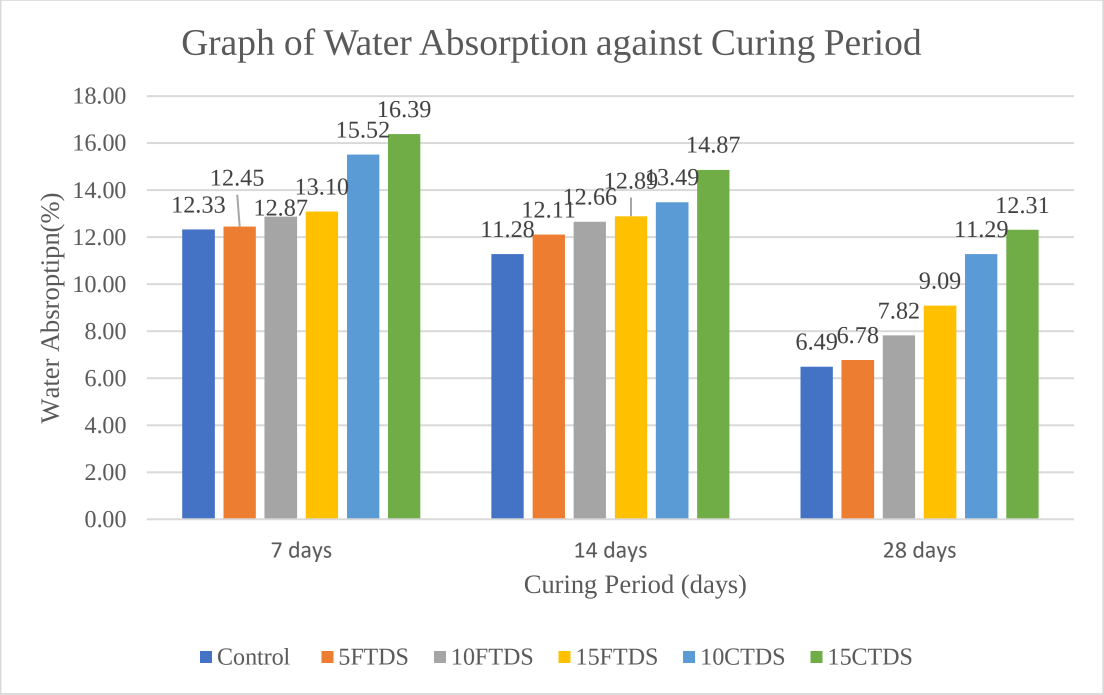


Figure 4.20: Graph of Water Absorption against Curing Period.

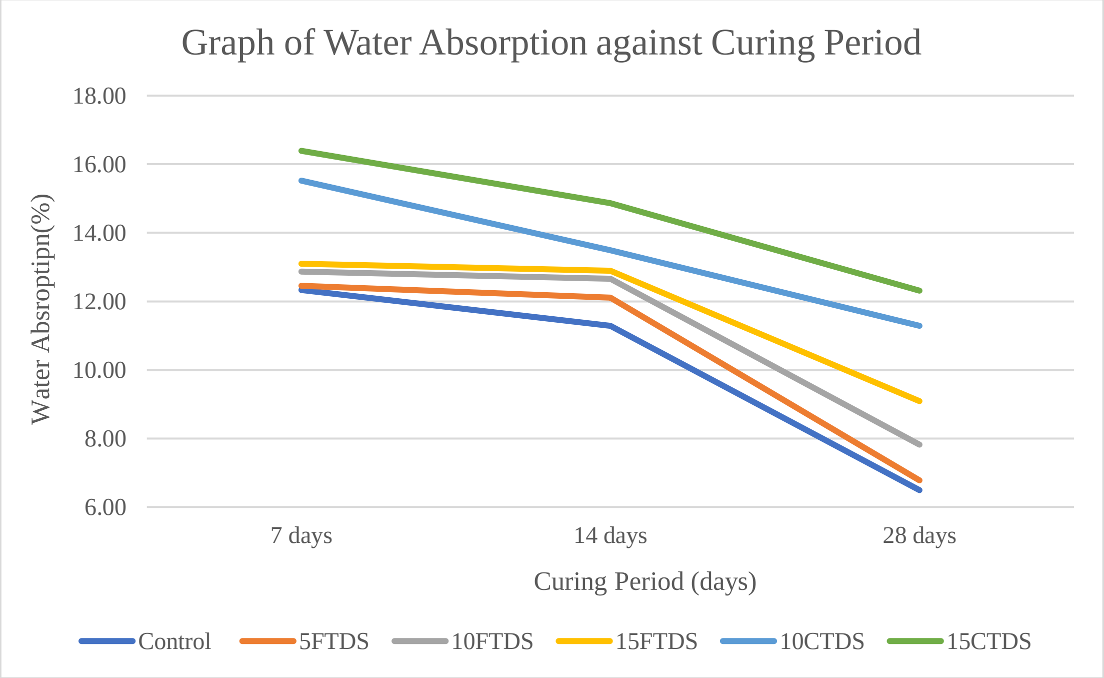


Figure 4.21: Graph of Development of Water Absorption for CSB against Curing Period.

Water absorption is an important parameter that shows the ability of the CSB to resist water penetration. It is used to measure the amount of water that CSB can absorb and retain within its structure. A lower water absorption percentage of CSB implies a more dense and compact structure, leading to more difficulty for water to penetrate and be absorbed while a higher water absorption percentage can affect the durability and strength of the specimen. **Figure 4.19** shows the control specimen serves as a standard and has the lowest water absorption percentage among all the specimens, with values of 12.33%, 11.28%, and 6.49% at 7, 14, and 28 days respectively. This reveals that the control specimen without incorporation of TDS has the most compact and dense microstructure which leads to lower water absorption. As the replacement level increases from the 5FTDS to 15CTDS, it shows a consistent trend of increasing water absorption percentage. The 5FTDS, 10FTDS, 15FTDS, and 10CTDS have higher water absorption of 12.45%, 12.87%, 13.10%, and 15.52% respectively at 7 days while the 15CTDS has the highest water absorption of 16.39%. At 14 and 28 days, the specimens continue to show an increasing trend in water absorption percentage as compared to the control.

The key explanation for increased water absorption is the reduced CaO concentration in CSB (Goyal et al., 2022). The quantity of C-S-H gel formed reduces as the TDS replacement level increases due to the diluting effect induced by the lower cement content (Hossain et al., 2023). Therefore, it leads to the absence of a cementitious effect and creates more pores and a less dense microstructure in the cement matrix. The porous structure formed by the TDS particles allows for better water penetration and absorption. Another possible reason is high LOI of TDS can lead to an increase in water absorption. The high LOI values indicated a high amount of organic compounds and volatile compounds present in the TDS which can degrade during the mixing process or hydration process (Goyal et al., 2019). The organic and volatile compounds in TDS can interfere with the hydration process and inhibit the pozzolanic reactions between the TDS particles and the cement. Thus, this can result in a more porous and irregular pore structure in the CSB specimen. Apart from that, the presence of high SO_3 concentration in the TDS might cause an increase in water absorption percentage in the specimen. High concentration of sulphate triggers the development of calcium sulfoaluminate hydrate (ettringite) that can disrupt the normal hydration process of cement and cause cracking of specimens, leading to more pores in the specimens (Neville, 2011). The cracks in the specimens enable water to penetrate, increasing the water absorption. **Figure 4.16** and **Figure 4.19** illustrate the porosity and water absorption increase with the substitution level increases.

Figure 4.19 also highlights the effect of TDS particle size distribution on water absorption. The coarse TDS particle specimens (10CTDS and 15CTDS) have a higher water absorption percentage than fine TDS particle specimens (10FTDS and 15FTDS). Based on the Sugrañez et al. (2013), the water absorption increases when the particle size increases. The larger particle sizes of TDS contribute to more pores and voids in the cement matrix which is shown in **Figure 4.11** and **Figure 4.12** compared to fine particles of TDS. This porous microstructure leads to poor bonding and compatibility between the cement and the TDS particles. The coarse TDS makes it easier to allow water to infiltrate into the specimen. Hence, the porosity of 10CTDS and 15CTDS are the highest and second highest among all the specimens which is shown in **Figure 4.16**. Besides that, **Figure 4.20** and **Figure 4.21** demonstrate a trend of decreasing water absorption with increasing curing period as the continuous hydration of the cement matrix over time. The early curing ages (7 days) have higher water absorption due to the cement hydration reaction still ongoing. However, as the curing period gets longer to 14 and 28 days, the continued hydration and pozzolanic reaction reduced the pores and permeability of the CSB specimens.

ASTM C62-13a stated that the water absorption percentage of CSB should not be more than 20%. It shows that all the specimens met the requirement of the standard at 28 days even though the replacement of TDS in CSB did not decrease the water absorption. However, the 5FTDS has the lowest water absorption percentage among all the specimens. Thus, the replacement percentage of TDS up to 15% with cement in the fabrication of CSB is feasible.

4.9 Comparison Evaluation of Cement SandBrick Specimens

Table 4.8: Comparison of CSB Specimens with Standard Requirement.

Properties	Standard Requirement	CSB Specimens (28days)					
		Control	5FTDS	10FTDS	15FTDS	10CTDS	15CTDS
Compressive Strength (MPa)	>7 MPa (MS 76:1972 & BS 3921:1985)	14.30	13.73	10.30	8.07	8.93	7.39
Flexural Strength (MPa)	> 0.65 MPa (BS 6073 Part 1: 1981)	2.38	2.23	2.17	1.52	1.54	1.37
Bulk Density (kg/m^3)	1300 – 2200 kg/m^3 (MS 76:1972)	1850.79	1846.96	1786.00	1784.51	1763.07	1731.10
Water Absorption (%)	<20% (ASTM C62-13a)	6.49	6.78	7.82	9.09	11.29	12.31

Table 4.8 shows all the CSB specimens with the partial TDS replacement meet the standard requirements mentioned above such as compressive strength, flexural strength, bulk density, and water absorption. However, the 15FTDS specimen is the optimum specimen among all the TDS-containing specimens as it has the highest TDS replacement percentage and also satisfies all the standard requirements. Although 15CTDS and 15FTDS specimens have the same substitution percentage, 15FTDS achieved greater strength and a lower water absorption rate.

4.10 Economic Evaluation

Table 4.9: Cost Comparison of One Unit Control CSB with 15FTDS.

		Control		**15FTDS**	
Composition	Price per kg (RM)	Unit (kg)	Total (RM)	Unit (kg)	Total (RM)
Cement	0.5	0.66	0.330	0.561	0.281
Sand	0.037	2.244	0.083	2.244	0.083
Water	0.0012	0.396	0.00048	0.396	0.00048
Total Cost			**0.413**		**0.364**

Notes:
The cost of sand and cement refers to Man Tong Hardware and Machinery (Kampar) SDN BHD.
The cost of water refers to Lembaga Air Perak.

Table 4.9 shows the cost of production of one unit of control is RM0.413 while the 15FTDS specimen is 0.364. The total cost of one unit of 15 TDS is reduced by 11.86% compared to the control specimen. The market price for cement sand brick is RM0.40 per unit based on Mybig Warehouse in Malaysia which is 9% higher than manufacturing one unit of 15FTDS specimen. Nevertheless, several improvements can be made to further reduce the manufacturing cost of the 15FTDS specimens such as partial replacement cement with alternative binders (fly ash and ground granulated blast furnace slag) and mixed with TDS. Therefore, it can reduce the production cost of CSB and align with SDG12: Responsible Consumption and Production. This research study helps in waste reduction and also improves resource efficiency in the manufacturing process which also helps contribute to circular production models by utilizing waste material from the dye manufacturing industry.

4.11 CO_2 Emission Comparison of Control with 15FTDS Specimen.

Table 4.10: CO_2 Emission Comparison of Control with 15FTDS Specimen.

Composition	**CO_2 Emission (kg/ton)**	**CSB Specimen (CO_2 kg)**	
		Control	**15FTDS**
Cement	900	0.5940	0.5049
Sand	6.6	0.0148	0.0148
Total Emission (CO_2 kg)		**0.6088**	**0.5197**

Table 4.10 shows the total emission of CO_2 from the manufacturing of one unit of control and 15FTDS specimens. According to Fayomi et al. (2019), the CO_2 emission of cement is 900 kg/ton while sand is 6.6 kg/ton (Zhu et al., 2023). The total CO_2 emission for the 15FTDS specimen is 0.5197 CO_2 kg, which 14.64% reduction compared to the control. For example, each double-storey terrace house is estimated to require an average of 15000 bricks, equivalent to 9132 CO_2 kg emissions. After the substitution of cement with TDS, the CO_2 emissions can be reduced to 7795.5 CO_2 kg. Thus, replacing cement with TDS decreases the carbon footprint and promotes a more environmentally friendly and sustainable future. In addition, this research also addressed the following SDGs:

- SDG 9 (Industry, Innovation, and Infrastructure): The substitution of cement with TDS promotes innovation in the construction industry and develops a more sustainable construction material.
- SDG 11 (Sustainable Cities and Communities): This research helps to reduce waste disposal and contribute to the development of sustainable and resilient cities.
- SDG 12 (Responsible Consumption and Production): The replacement of cement with TDS reduces the consumption of natural resources and converts waste from the textile dyeing industry into a sustainable building material.
- SDG 13 (Climate Action): The outcome of this research was able to reduce the carbon footprint of 14.64% per unit CSB and mitigate climate change.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The objectives stated in this feasibility study were accomplished. Some laboratory tests have been performed to analyse the engineering and durability properties of CSB specimens. All the CSB specimens incorporated with TDS in this project have fulfilled the standards mentioned above. Therefore, the conclusion of this study can be summarized:

- The partial replacement of TDS in the fabrication of CSB is feasible. However, it does not enhance the engineering and durability properties of CSB due to the insufficient CaO content and excessive LOI value in TDS, resulting in the increase of pores and reduction of C-S-H gel produced, which affects the durability of CSB.
- The most optimum replacement percentage is the 15FTDS specimen as it satisfies all the standard requirements without failure including compressive strength, flexural strength, bulk density, and water absorption while achieving the highest replacement percentage in this feasibility study.
- The substitution of 15% TDS in CSB can reduce the 14.64% CO_2 emissions per unit from the cement production industries. In addition, this also aligns with the SDGs and circular economy concept to develop a more sustainable construction practice in the future.

5.2 Recommendations

Several recommendations can be made for the future feasibility study of CSB incorporation with TDS, as listed below:

- Feasibility study on incorporating TDS ash for the substitution of cement.
- Feasibility study on incorporating alternative binders such as fly ash along with TDS for the substitution of cement.
- Explore further opportunities for usage of TDS such as fertilizer and energy recovery material.
- Additional tests such as chloride penetration test and efflorescence test are needed to further evaluate the durability properties of CSB.

The recommendations provided above depend on this research which might be useful for future feasibility studies on this relevant field.

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