FABRICATION OF CEMENT SAND BRICK (CSB) USING ALUMINIUM DROSS AS PARTIAL SAND REPLACEMENT

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
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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 **"FABRICATION OF CEMENT SAND BRICK USING ALUMINIUM DROSS"** was prepared by **Ong Zhe Yang** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Environmental Engineering at Universiti Tunku Abdul Rahman.

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Date : 07 September 2022

Specially dedicated to
my beloved grandmother, mother and father

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MANUFACTURING OF CEMENT SAND BRICK USING ALUMINIUM DROSS

ABSTRACT

Globalisation and rapid development have increased the world's human population, stimulating development projects in the construction sector. Rapid construction activities increase the brick demand, leading to the mass production of brick. Firing brick contributes a lot of carbon footprint to the air and consumes lots of energy. The CO_2 emission is causing climate change, threatening all the living organisms on Earth. Later, a more environmentally friendly non-fired brick, cement sand brick (CSB) is introduced to replace the use of conventional brick. However, the huge demand for CSB created another issue: the sand shortage. Increase in sand mining activities worldwide to solve the shortage problem and neglect the impacts of sand mining activities on the environment. Aluminium dross is a by-product of the aluminium industry. It exhibits hazardous characteristics because of the hydrolysed of aluminium nitride (AlN). Hence, incorporating AD is an effective solution to recycling hazardous AD while addressing the sand shortage and its impacts on the environment. The sand replacement percentage for this research ranged from 0 to 25 % of AD based on the requirement by DOE. All the CSB specimens were tested at 28 days of age to evaluate their engineering properties through bulk density, compressive strength, flexural strength, water absorption, porosity, microstructure analysis, and metal ions leaching test. In this research, the 20R specimen has the most optimum sand replacement percentage, as it fulfills the compressive strength, flexural strength, water absorption rate, bulk density, and leachability of metal ions stated in the standard. 20R specimen can reduce 29.44% of CO_2 emissions from sand mining and cost 36.71% lower than the selling price of CSB in the market after the AD treatment. Thus, treatment of AD before substituting AD into CSB is feasible to be implemented.

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LIST OF SYMBOLS / ABBREVIATIONS

cm	Centimetre
cm^3/s	Cubic centimetre per second
˚C	Degree Celsius
g	Gram
>	Greater than
≥	Greater than or equal to
kg	Kilogram
kg/m^3	Kilogram per cubic metre
kJ	Kilojoule
kN	Kilonewton
kV	Kilovolt
<	Less than
≤	Lesser than
MJ	Megajoule
MPa	MegaPascal
m	Metre
m^2	Metre square
m^2/kg	Metre square per kilogram
μm	Micrometre
mm	Millimetre
mm^2	Millimetre square
N	Newton
N/mm^2	Newton per millimetre square
%	Percentage
s	Second

Al	Aluminium
Al_2O_3	Alumina
AlN	Aluminium nitride
AD	Aluminium dross
NH_3	Ammonia
$CaCO_3$	Calcite
Ca	Calcium
CaO	Calcium oxide
$Ca(OH)_2$	Calcium hydroxide
C	Carbon
CO_2	Carbon dioxide
CO	Carbon monoxide
Cl	Chlorine
Ca_2SiO_4	Dicalcium silicate
H_2F	Fluoronium
H_2S	Hydrogen disulfide
Fe_2O_3	Iron oxide
MgO	Magnesium oxide
CH_4	Methane
NO_X	Nitrogen oxides
O	Oxygen
K_2O	Potassium oxide
SiO_2	Silica
Si	Silicon
Na_2O	Sodium oxide
S	Sulphur
SO_2	Sulphur dioxide
SO_X	Sulphur oxides
$Ca_4Al_2Fe_2O_{10}$	Tetracalcium aluminoferrite
$Ca_3Al_2O_6$	Tricalcium aluminate
Ca_3SiO_5	Tricalcium silicate
ASTM	American Society for Testing and Materials
BS EN	British Standard European Norm

C-A-H	Calcium Aluminate Hydrate
C-S-H	Calcium Silicate Hydrate
CSB	Cement Sand Brick
CSEB	Compressed Stabilized Earth Brick
XRF	X-ray fluorescence
MS	Malaysia Standard
OPC	Ordinary Portland Cement
PM	Particulate Matter
SEM	Scanning Electron Microscopy
Fe	Iron
Cr	Chromium
Zn	Zinc
Mn	Manganese
Cu	Copper
Cd	Cadmium
Pb	Lead
Ni	Nickel
NH_3	Ammonia gas
OH^-	Hydroxyl ions
AlOOH	Amorphous aluminium hydroxide
$Al(OH)_3$	Aluminium hydroxide

CHAPTER 1

INTRODUCTION

1.1 Research Background

Bricks are the oldest materials used as a filler for structure and are favourable in many substructures and superstructure projects, such as foundations, buildings, bridges, arches, and pavements. They had been playing a significant role as a building material thousands of years ago because of their superior performance in strength, durability, cost-effectiveness, and so forth. The composition of brick can be clay, sand, concrete materials, and lime. They are manufactured in several types, shapes, and sizes to serve different construction projects. Generally, there are two classifications of brick: fired bricks and non-fired bricks. Fired bricks are burned at a high temperature inside a kiln to gain strength and increase their durability to withstand harsh weather and water environment. In contrast, non-fired bricks must undergo curing but are not involved in the firing process.

Rapid construction activities increase the brick demand, leading to the mass production of brick but contributing to a bad environmental impact. Firing brick is energy-intensive and can consume up to 24 million tons of coal annually (P.N. et al., 2018). The firing process of bricks is extremely polluting the environment as the emission gases can be carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide (NO_2), hydrogen cyanide (HCN), ammonia (NH_3), chlorine (Cl_2) and carbon dioxide (CO_2) (Ukwatta, Mohajerani, Setunge and Eshtiaghi, 2018). Hence, the appearance of non-fired bricks minimises the environmental impacts of fired bricks' production process. There are several types of non-fired brick available in the market. They are cement sand brick, calcium silicate brick, and compressed stabilised earth brick (CSEB). Cement sand brick (CSB) comprises cement, sand, and water, while calcium silicate brick consists of sand, lime, and fly ash. CSEB is an earthen brick made mainly from subsoil, clay, sand, water, and stabiliser such as cement or lime. As compared to fire brick, these types of brick do not need firing. They are manufactured by high-pressure compression and undergo a curing process to achieve optimum strength. The non-fired bricks offer a faster and easier manufacturing process than fired bricks due to the absence of the firing process. Hence, producing non-fired bricks consumes less energy and contributes less to the carbon footprint.

CSB is a non-fired brick that does not require a firing process to gain durability and is energy efficient. The composition of CSB is sand, and cement acts as a binder. It only appeared after the cement's invention and became a substitute for conventional clay brick. It is favorable to be used in building and drainage system construction due to several advantages such as good durability, cost-effectiveness, and ability to withstand high temperatures. CSB manufacturing is simple compared to clay brick, which only involves compression without any firing process, which is required in clay brick.

Aluminium is a type of metal that does not exist as a single element on Earth. It usually exists in the form of bauxite or cryolite. Aluminium is widely used in several industries, especially aerospace, food & beverage, and packing, due to its low density, good thermal conductivity, high corrosion resistivity, and non-toxic. According to Aluminium Market Size (2020), the global market size of aluminium in 2019 was 164.23 billion USD and is expected to reach 242.44 billion in 2027. The expansion of the global aluminium market yielded the generation of aluminium waste known as aluminium dross (AD). AD is a by-product of the extraction of aluminium from bauxite. AD is categorised into two types which are primary AD and secondary AD. Primary AD has a higher aluminium content; hence it is recycled to form secondary AD. As a result, secondary AD has a lower metal aluminium content than primary AD, which is about 5 to 10 % per unit weight. AD is classified as hazardous solid waste as it releases toxic gases such as ammonia (NH_3) and methane gas (CH_4) when in contact with water. The harmful gases emitted into the atmosphere will potentially cause negative impacts on humans and the environment. The source of the gases emitted is due to the reaction of aluminium nitride (AIN) with water. According to Wang et al. (2021), 90% of secondary AD are landfilled without any treatment, while only a few portions of secondary AD are recycled into other usages. The untreated secondary AD may leach out into the soil. The toxic substances may infiltrate the soil and exfiltrate into the lake or pond, eventually polluting the surface and underground water. Since AD is hazardous, the cost of waste handling is very high; therefore, recycling AD for other uses is a sustainable and environmentally friendly solution to overcome the problem arising from AD's rapid production.

Sand is the second largest consumable natural resource in the world besides water. There are two origins of sand: riverbank and desert. The sand eroded from the riverbank is categorised as river sand. It is suitable for construction activities due to its angular shape and random particle size range from 0.05 to 2.00 millimeters. Desert sand formed from the wind effect is less suitable for construction activities as it is too fine and round in a rounded shape. Rapid development activities have caused the demand for river sand to grow tremendously. Based on Rentier and Cammeraat (2022), building a house consumed 200 tons, 30000 tons per kilometer of highway road, and 12 million tons of sand to construct a nuclear power plant. Eventually, sand mining activities are increasing daily to cater to the rapid demand for river sand. The sand mining activity is detrimental to the aquatic environment resulting in the shape change of riverbeds which causes riverbanks to be eroded faster. The extraction of sand induces the topsoil into the river, polluting the river and harming the aquatic organisms. Since the increasing sand mining activities have caused some impacts on the environment due to huge demand from the construction sector, the substitution of sand is a must.

A shortage of sand issues arises while sand mining activities are causing serious environmental problems; therefore, incorporating waste is one of the efficient methods to reduce the usage of sand. The reduction in sand usage will contribute to the minimization of environmental impacts caused by mining activities. In addition, AD is hazardous solid waste harmful to humans and the environment. Nevertheless, recycling AD as sand replacement in CSB is the most sustainable solution. With an optimum portion of AD, it can be used to replace the sand to form a sustainable green construction material, eventually overcoming the sand shortage and addressing environmental issues.

1.2 Problem Statements

Aluminium is widely used in various sectors due to its good physical properties, lightweight, and, most importantly, recyclable. However, the extraction of aluminium during manufacturing will generate a lot of aluminium dross (AD), which is hazardous solid waste. As AD contacts with water, it will emit toxic gases like NH_3 and CH_4. These gases will lead to significant air pollution issues and human health problems. The presence of AIN has a high tendency to react with the moisture in the air to release ammonia gas. For example, a strong ammonia odour is released when the opening of the container contains AD. During the mixing stage in the brick fabrication, the toxic gas emitted will irritate the eyes and nose as AD is contacted with water. Hence, a proper mask and goggles are needed. In addition, most AD will end up in the landfill without treatment, had contributed to the formation of hazardous landfill leachate. Landfill leachate will pollute the groundwater, affect soil salinization, and indirectly affect human health and aquatic life. Thus, AD recycling has become an essential step for environmental sustainability.

Recently, in this modern civilisation, rapid development in the economic sector has increased the demand for economic activity centers. The human population is moving towards the economic centers, increasing housing demand. Several residential and commercial development projects have been announced to address the increasing demand. Brick is the most common and cost-effective masonry unit for housing development. Hence, the rapid development activities will stimulate the high demand for bricks. Conventional brick, also known as fired brick, gains strength through a firing process at a high temperature. The firing process consumes lots of fossil fuels, a non-renewable energy source, and emits various toxic gases and particular matters which pollute the air and contribute to climate change. Once humans inhale the toxic gases, they may cause other health problems to humans. Hence, non-fired brick, for instance, CSB, is more suitable to be used as a masonry unit that does not require a firing process.

The scarcity of sand is another barrier to the rapid development of construction activities. As mentioned by Rentier and Cammeraat (2022), the usage of sand is around 50 billion tons per year, double the amount produced by nature. The huge extraction rate has shown that natural sand has been overexploited and is running out of sand soon. Once the supply of sand gets lesser while the demand keeps increasing, the price of the sand will increase. This issue will cause the use of CSB as a masonry unit to become unfeasible. As a result, the cost per unit of CSB will surge.

Also, sand mining imposes serious environmental impacts and affects aquatic organisms. The extraction of sand reduces the sediment amount in the river. The decrease of the sediment changes the water flow pattern, which erodes the river bank, causing the loss of topsoil in the river (Lusiagustin and Kusratmoko, 2017). Erosion of the river bank further pollutes the river water and increases the suspended solids and turbidity in the river. The aquatic plant will be affected as sunlight is not able to penetrate through the river water, and eventually not be able to survive and die. The riverbank erosion has altered the cross-section of the river; whether it is widening or narrowing will indirectly cause a flood in the affected area.

AD is being chosen as the waste to partially replace the amount of sand used in CSB fabrication to reduce environmental problems and eventually benefit waste management. Incorporating AD into the CSB is also in line with Malaysia’s goals toward the United Nation’s sustainable goals for sustainable cities and communities.

1.3 Aims and Objectives

This research is to determine the performance of treated aluminium dross (AD) incorporated with cement sand brick to reduce the usage of sand. Hence, the optimum portion of treated AD as a partial replacement for sand is obtained and evaluated. The main goals of this research study are stated as follows:

i. To fabricate sustainable cement sand brick by partial replacement of sand with treated aluminium dross.
ii. To evaluate the engineering properties and durability properties of the cement sand brick
iii. To determine the optimum ratio of treated aluminium dross in the production of cement sand brick.

1.4 Outline of Study

This research focuses on the feasibility of treated aluminium dross (AD) fabricating CSB. The efficiency of CSB with the incorporation of treated aluminium dross at different percentages of sand replacement will be examined in the lab. The various percentage of sand replacement are 5, 10, 15, 20, and 25 %. In this research, the water-cement used is 0.6. In addition, CSB will be cast into a real shape of a 210 x 90 x 90 mm rectangle specimen. After the curing process for 7,14, and 28 days respectively, all specimens will undergo engineering and durability properties through some laboratory tests such as the compressive strength test, flexural test, scanning electron microscopy, water absorption test, and porosity test. A heavy metal leaching test will be conducted to evaluate the concentration of metal ions leaked out from the CSB into the environment. A control specimen will be used for comparison purposes, which helps determine the efficiency of CSB with different sand substitution portions through the properties analysis.

1.5 Overall Thesis Framework

Table 1.1: Research Thesis Framework

Chapter	Title of Chapter	Scope of Chapter
1	Introduction	▪ General background on conventional fired-brick production and its influence on the environment. ▪ Introduction to Cement Sand Brick (CSB). ▪ Introduction of impacts of sand mining activities. ▪ Introduction of aluminium dross. ▪ Introduction of aluminium dross as partial sand replacement in CSB. ▪ Outline this research study's aim, objective, and scope.
2	Literature Review	▪ General background of aluminium dross. ▪ Properties and Impacts of aluminium dross. ▪ General background of fired brick and non-fired brick. ▪ Properties and drawback of fired brick. ▪ General background of CSB. ▪ Advantage and drawback of CSB. ▪ Relevant past research on CSB fabrication.

Table 1.1: Research Thesis Framework (continued)

3	Research Methodology	▪ General background of research methodology. ▪ Preparation of research material such as cement, sand, and aluminium dross. ▪ Treatment of aluminium dross. ▪ Mix design of CSB fabrication. ▪ The moulding, demoulding, and curing of the specimen. ▪ Laboratory test for CSB specimen.
4	Results and Discussion	▪ Preliminary analysis of incorporating aluminium dross in CSB. ▪ Discuss the characteristics of untreated AD and treated AD. ▪ Present and analyse the data obtained from the laboratory tests. ▪ Evaluate the engineering properties and durability of fabricated CSB. ▪ Deeply discuss the feasibility of sand replacement in CSB. ▪ Economical appraisal of fabricated CSB. ▪ Evaluation of environmental impacts of CSB fabrication.
5	Conclusion and Recommendation	▪ Overall summary of the research study. ▪ The recommendation suggested future improvements on CSB and other possibilities for utilising AD.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the properties and characteristics of aluminium dross will be discussed in detail. Furthermore, differences between fired brick and non-fired brick including the properties, advantages and drawbacks toward the environment are elaborated. Lastly, previous research findings on incorporating different types of waste into CSB fabrication are listed.

2.2 Aluminium Dross (AD)

Globalisation and rapid development have increased the world's human population, stimulating the growth of various industries, factories, and the construction sector. With the growth of industries, the amount of waste generated rapidly into the environment in terms of biodegradable and non-biodegradable. The non-biodegradable waste has resulted in a challenge in the disposal and ecological imbalance. Therefore, sustainability of the waste generated becomes one challenge for industries to reduce the significant environmental impact (Panditharadhya, Sampath, Mulangi, and Ravi Shankar, 2018).

Aluminium never exists in a single element on Earth but in the form of bauxite. Besides iron, aluminium is the second largest metal used due to its corrosion resistivity, lightweight, durable and non-ferrous properties. It is also less dense, has a low melting point, and can be easily processed into multiple shapes. Aluminum's good characteristics and properties are widely used in the aerospace, beverage, and construction industries. According to Li et al. (2021), the production of primary aluminium had surged from 97 million tons in the year 2020 to 63.70 million tons in the year 2019, with an increase of 33.3 million tons. The huge increase in aluminium production has shown a strong demand for aluminium usage. The industrial electrolysis method was suggested by Charles Martin Hall and Paul L.t. Heroult in 1886 to extract the aluminium from the aluminium ore. Cryolite or sodium hexafluoroaluminate is added to lower the melting point of the aluminium ore. Once the aluminium ore is in the molten state, it is channelled to an electrolytic bath with 150,000 amperes of electric current supply. During the process, the anode will be charged positively while the negatively charged in the cathode. Oxygen is produced in the anode and reacts with the graphite electrode, while aluminium is deposited in the cathode. The reaction gives the equation:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \qquad (2.1)$$

Currently, there are two pathways for manufacturing metallic aluminium: the extraction of alumina from bauxite ore through an industrial electrolytic process and secondary aluminium production from used aluminium products like extrusion, foils, and other aluminium scrap. Aluminium production is an industry that consumes lots of energy as compared to other industries. Abdulkadir, Ajayi, and Hassan (2015) mentioned on the primary extraction process of one kg of aluminium use up around 174 to 186 MJ, while the energy needed for secondary extraction is just 10 to 20 MJ per kg of aluminium.

Aluminium dross (AD) is a by-product of the aluminium manufacturing industry. As molten aluminium comes in contact with air, the formation of dross is a mixture of metal and non-metallic materials, mainly salt and metal oxides. Approximately 15 to 25 kg of AD will be yielded from the smelting of 100kg molten aluminium (Mahinroosta and Allahverdi, 2018). Based on the Environmental Quality Act Scheduled Waste 2005, AD is categorised as scheduled waste SW104 due to the presence of aluminium metal ions in the dross. The industries faced a major challenge in safely disposing of AD since it exerted hazardous characteristics (Verma, Dwivedi, and Dwivedi, 2021).

2.3 Properties of Aluminium Dross

AD is categorised into primary aluminium dross (PAD) and secondary aluminium dross (SAD). PAD is also known as white dross formed from the primary aluminium refining process. PAD is white-grey, containing 15 to 80 wt% of metal content and less than 6 wt% of fluorine and chloride salt. Since it is rich in metal ions, aluminium dross will be recycled several times through some pyrometallurgical process to reclaim the usable metal ions (Li et al., 2021). After a few times of recycling, the dross is in dark grey, called black dross, which is also SAD. Usually, the metal content in SAD is much lower than in PAD which is about 5 to 20wt% of the dross.

AD exhibits corrosive properties due to the presence of aluminium nitride (AIN) in the dross. AIN is formed during the aluminium extraction process, where the molten Al reacts with N_2 at a high temperature. The AIN generation is very unstable and highly toxic. AIN has a high surface reactivity, enabling it to react easily with the moisture in the air. Hydrolysis is the reaction between the AIN and water to form aluminium hydroxide ($Al(OH)_3$) and ammonia gas (NH_3), as shown in equation 2.2. NH_3 gas has an unpleasant pungent smell that can cause health problems to humans once inhaled for a long period. Since there are other contaminants such as aluminium carbide (Al_4C_3), aluminium phosphide (AIP), aluminium sulphate (AI_2S_3), and aluminium oxide nitride (AI_5o_6N) present in the AD, other gases rather than NH_3 that will be released from the hydrolysis of AIN. Phosphine, hydrogen sulphide, and methane have the potential to be released from the hydrolysis reaction, had been shown in the following equations 2.3 to 2.6.

$$\mathrm{AIN + 3H_2O \rightarrow Al(OH)_3 + NH_3 + Heat} \tag{2.2}$$

$$\mathrm{2AI_{5o6}N + 3H_2O \rightarrow 5AI_2O_3 + 2NH_3 + Heat} \tag{2.3}$$

$$\mathrm{AIP + 3H_2O \rightarrow Al(OH)_3 + PH_3 + Heat} \tag{2.4}$$

$$\mathrm{AI_2S_3 + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2S + Heat} \tag{2.5}$$

$$\mathrm{AI_4C_3 + 12H_2O \rightarrow 4Al(OH)_3 + 3CH_4 + Heat} \tag{2.6}$$

Among the gases released, NH_3 is the dominant gas. NH_3 is highly soluble in water and produces ammonium and hydroxide ions when it dissolves. As the AIN hydrolysed, a large amount of heat energy is released, causing a temperature rise. The heat further promotes the rate of hydrolysis and results in a large amount of ammonia gas being released. Simultaneously, the high concentration of hydroxide ions increases the pH to 9 or higher, contributing to the AD's corrosive properties (Mahinroosta and Allahverdi, 2018). Since the pH has been increased, it is favourable for the hydrolysis of metal aluminium. The hydroxide ions react with the unclaimed metal aluminium left in the AD to form alumina (AI_2O_3) and hydrogen gas with heat released, as stated in equation 2.7.

$$\mathrm{2AI + H_2O \rightarrow AI_2O_3 + 3H_2 + Heat} \tag{2.7}$$

In addition, AD also contains salt flux which is addictive in the processing of molten aluminium. The function of salt flux is to protect the metal ions from oxidation when exposed to the atmosphere, enhance the transfer of heat among the metals and prevent the agglomeration of the metals (Utigard, Roy, and Friesen, 2001). The utilisation of salt flux in aluminium production usually contains sodium chloride (NaCl), potassium chloride (KCl), and a little number of fluoride additives like calcium fluoride (CaF_2), sodium fluoride (NaF), cryolite (Na_3AlF_6), and potassium fluoride (KF). Non-metallic products (NMP) such as chlorides, carbides, sulfides, oxides, sodium and potassium chlorides, and some aluminium metals will be trapped in the salt flux during the aluminium extraction process. Gases emission will occur as the salt flux react with water and release some toxic gases like hydrogen chloride gas and hydrogen fluoride, shown in Equations 2.8 to 2.10.

$$NaCl + H_2O \rightarrow NaOH + HCI \tag{2.8}$$

$$KCI + H_2O \rightarrow KOH + HCI \tag{2.9}$$

$$NaF + H_2O \rightarrow NaOH + HF \tag{2.10}$$

2.4 Drawback of Aluminium Dross

Since 2000, SAD or black dross, has been classified as hazardous and toxic waste generated by the aluminium industry (Hu et al., 2021). SAD exhibits hazardous characteristics due to the non-metallic products (NMP) present in the black dross, which may cause skin irritation under prolonged or repeated contact. NH_3 is emitted from the hydrolysis of AD. The emission of NH3 gas leads to the poisoning of aquatic animals due to the ammonia-nitrogen (N-NH3) agglomeration phenomenon in water (Li et al., 2021). Human health issues, for instance, rhinitis, pharyngitis, and sore throat, are the effects of long-term exposure to ammonia (Wang et al., 2021). Excessive NH_3 gas in the environment will convert into nitrous oxides that cause acid rain, global warming, and an imbalance nitrogen cycle.

Moreover, the methane gas generation in the hydrolysis of AI_4C_3 may cause an explosion if the surrounding temperature is high. The hydrolysis of AD also produces H_2S that gives an offensive foul odour at 0.01 to 0.3 ppm and causes immediate breath difficulty at 1000 ppm. Sulphur dioxide and sulphuric acid are the product of H_2S that can cause respiratory problems in humans, destroy the aquatic ecosystem, and cause infertile soil (Attia, Hassan, and Hassan, 2018).

Additionally, most of the salt flux contained in AD is being landfilled. As water percolates through landfill cover, hydrolysis may occur due to leachate formation. The leachate from landfill might consist of SAD, which contains many toxic ions, such as heavy metals and fluorine. The leachate might pollute the underground water and result in groundwater, surface water pollution, and soil salinization. Soil salinization will affect the crop yield and destruct the nutrient level of the crop. The bioaccumulation of heavy metals from plants to other secondary or tertiary consumers in the food web eventually reaches humans. Human health will most probably be affected if the accumulated toxicity exceeds the human body's tolerance. Hence, it is classified as hazardous solid waste in some countries. However, due to the lack of efficient recycling methods, disposal of SAD is the major challenge for companies, and the common treatments used are still landfill and stockpiling (Li et al., 2021).

2.5 Fired Brick

Brick has played an important role in construction for a long time ago. Fired brick, also known as conventional brick, has been widely used in the construction of buildings and structures. It is the oldest construction material in the world. According to Bhairappanavar, Liu, and Shakoor (2021), around 1.83 trillion bricks are produced annually, and the demand may further surge to 2.76 trillion in 2027 due to the rapid development in the construction sector. However, the brick manufacturing industry uses many clay minerals, raising concerns about overexploitation and environmental issues. Furthermore, they also stated that the construction sector that involved the building sector generated about 40 % of greenhouse gases by consuming the world’s primary energy, mineral resources, and water resources due to the rise in the global population, especially in the urban area.

The main components that are present in clay are silica dioxide (SiO_2) and alumina (Al_2O_3), while the remaining components are calcium oxide (CaO), iron oxide (Fe_2O_3), and other minerals. Six phases are involved in the fabrication of fired clay brick: evaporation, dehydration, oxidation, vitrification, flashing, and cooling. First, the shaped bricks have to undergo evaporation at a temperature of 150℃ to remove any excess moisture. Cracking will happen in this stage as the temperature rise is not well controlled. Next, the dehydration phase where carbonaceous components and hydrates exist in the brick is allowed to decompose at the surrounding temperature between 150℃ and 650℃. In this phase, temperature control is critical to avoid bloating of brick. Then, excessive oxygen is provided for the complete oxidation of carbonaceous substances and metal ions in the combustion chamber for better brick quality. Afterward, the fabrication comes into the most critical phase, vitrification. During vitrification, the temperature rises to 900 to trigger the sintering process that partially liquefies some of the solid particles. As the temperature drop, the liquified particles will bind other solid particles together and solidify; hence, the brick gains strength. The last two phases are flashing and cooling. In the flashing phase, peak temperature and duration of temperature holding directly affect the colour of the fired brick. Lastly, the fired bricks are allowed to cool down for a certain time before being packed into pallets and sell in the market (Zhang, Wong, Arulrajah, and Horpibulsuk, 2018).

2.5.1 Properties of Fired Brick

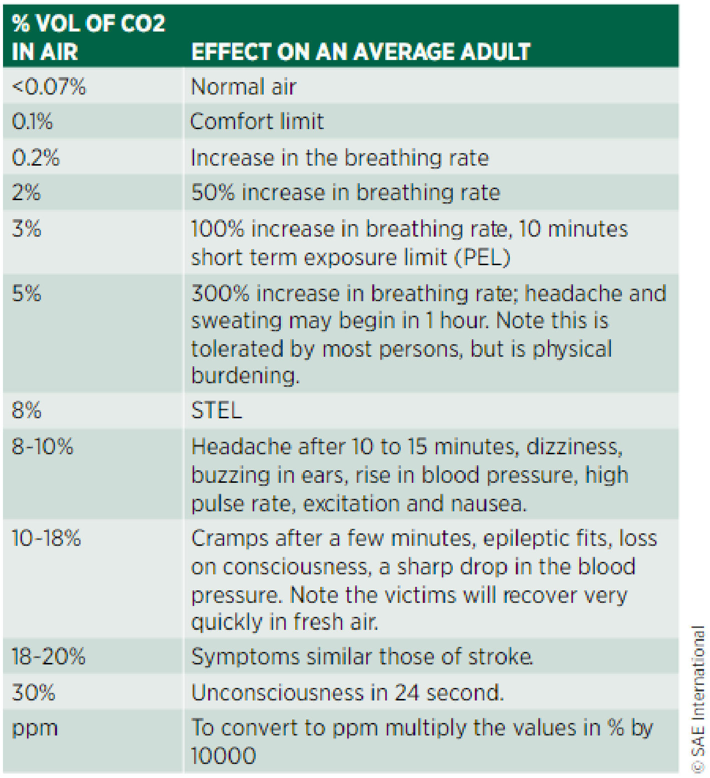
One of the critical properties of fired brick is its durability. The durability of fired brick mainly depends on the firing temperature. The higher the temperature, the stronger strength and the lower the water absorption rate of the brick produced. Besides that, fired brick is considered a weatherproof brick because of the fine capillaries that allow the absorption and release of water after the rain (Brick Industry Association, 2006). These capillaries can also help regulate the house's temperature during hot weather. Heat will not be trapped and can easily escape from the internal housing area favorable to be used in housing development.

Water is another key agent that affects the aging of clay bricks. Capillaries that are presented in fired brick allow the water to infiltrate into the internal structure of brick, causing the brick to be saturated. In later times, prolonged saturation in bricks can cause the brick to crack due to the expansion effect. Thus, the water absorption rate determines the durability of fired brick.

Usually, fired brick available in the market is red colour. However, fired brick has a darker colour and light yellow. According to (Fernandes, 2019), the metal oxide composition governed the brick colour. Iron oxide (Fe_2O_3) contributes to the red colour, titanium dioxide (TiO_2) to light yellow, and manganese oxide (MnO_2). The temperature and condition of the kiln during the firing process influence the appearance of the fired brick. Under proper control of the kiln condition, the appearance of fired brick is aesthetically pleasing, which is an added value when used as facing brick. Since it has a good appearance and is durable, plastering is not required to protect it, saving construction costs.

2.5.2 Drawback of Fired Brick

CO_2 is a greenhouse gas that governs the effect of global warming on the Earth. Elahi, T., Shahriar, A., and Islam, M. (2021) reported that fired brick production generated 143 *kg/ton* of CO_2 in the ambient air. Other than CO_2, toxic gases such as CO, SO_2, NO_x, PM_{10}, and $PM_{2.5}$ are released from the kiln. Global warming happens when the heat generated gets trapped by CO_2 and cannot escape outer space. The accumulation of heat melts the glacier resulting in the rise of sea water level. The area near the ocean will get flooded while flora and fauna will also be affected. Since the ocean is a large water body, it absorbs heat from the atmosphere, causing a rise in ocean temperature. Some aquatic animals that are sensitive to temperature will migrate to other colder regions to escape the heat. Climate change will alter the weather pattern and events around the world. Mathur (2018) listed the effect of CO_2 concentration in the air on the human body as shown in Figure2.1. The breathing rate will increase according to the increase in CO_2 concentration in the air until 10%. Humans will lose consciousness in 24 seconds and die when CO_2 concentrations reach 30%. Thus, the effect of CO_2 is also not just causing climate change. It also affects human health when going up to a certain concentration.



% VOL OF CO2 IN AIR	EFFECT ON AN AVERAGE ADULT
<0.07%	Normal air
0.1%	Comfort limit
0.2%	Increase in the breathing rate
2%	50% increase in breathing rate
3%	100% increase in breathing rate, 10 minutes short term exposure limit (PEL)
5%	300% increase in breathing rate; headache and sweating may begin in 1 hour. Note this is tolerated by most persons, but is physical burdening.
8%	STEL
8-10%	Headache after 10 to 15 minutes, dizziness, buzzing in ears, rise in blood pressure, high pulse rate, excitation and nausea.
10-18%	Cramps after a few minutes, epileptic fits, loss on consciousness, a sharp drop in the blood pressure. Note the victims will recover very quickly in fresh air.
18-20%	Symptoms similar those of stroke.
30%	Unconsciousness in 24 second.
ppm	To convert to ppm multiply the values in % by 10000

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Figure 2.1: Effects of Different Concentrations of CO_2 on humans (Mathur,2018).

The raw material of fired brick is clay mineral which originated from the topsoil in the land. Rapid demand for fired brick encourages the extraction of clay minerals from the soil in the clay brick manufacturing industry. The agricultural land becomes infertile, and toxic substances like heavy metals release arise due to the topsoil's overexploitation. The extraction of clay minerals reduced 35% of manganese and 63% of zinc in soil, resulting in the loss of 28kg of Nitrogen and 3kg of phosphorus, equivalent to 34kg of fertilisers per hectare of land. A 40 to 80% reduction in crop production was reported in the study by Biswas, Gurley, Rutherford, and Luby (2018). The decrease in crop yield is because insufficient nutrients in the soil support the healthy growth of crops. Moreover, brick kilns occupy a large space, and most of the kilns are built on fertile land to ease the extraction of clay minerals. Eventually, the soil further degraded and was no longer suitable for agricultural activities, threatening food security.

2.6 Non-Fired Brick

Sun-dried brick is the very first type of non-fired brick. It was created from 3100 to 2900 B.C with the help of hot weather. At that time, those bricks are used for temples and palaces construction. People over that time discover that the higher temperature, the higher strength of the brick. Therefore, the invention of baked brick is known as fired brick. Then, baked brick is widely used in construction rather than sun-dried brick (Fiala, Mikolas, and Krejsova, 2019). Until 20 Century, several countries realised that fired brick production was energy-intensive, causing climate change and topsoil degradation. For instance, China banned all the production of fired brick and its usage in construction in the year 2000 (AP NEWS, 2000). To reduce energy consumption and mitigate environmental impacts, non-fired brick is preferred.

Non-fired brick is categorised as brick do not gain strength through the firing process at high temperatures. It is more sustainable as it consumes lesser energy and emits less CO_2. The strength of non-fired brick is achieved through chemical reactions such as cement hydration and the reaction of lime and silica. There are several types of non-fired brick available in the market. They are cement sand brick, calcium silicate brick, and compressed stabilised earth brick (CSEB). Cement sand brick comprises cement, sand, and water, while calcium silicate brick consists of sand, lime, and fly ash. CSEB is an earthen brick made mainly from subsoil, clay, sand, water, and stabiliser such as cement or lime. The manufacturing of non-fired bricks is simple compared to fired brick. Only four steps are involved: material preparation, mixing, compression and curing. Therefore, non-fired bricks have become another alternative to replace the use of fired bricks.

2.6.1 Properties of Non-Fired Brick

The largest advantage of non-fired brick over fired brick is the price. Price is affected by production cost. Comparing the manufacturing process, the non-fired bricks offer a faster and easier manufacturing process than fired bricks due to the absence of the firing process. The curing of non-fired brick can be either natural air curing for 28 days or steam curing for a period of time. The bricks can be directly used in construction activities once it is properly cured.

Non-fired brick has a uniform shape since they undergo high-pressure compression in the mould and gain strength through a curing process. The shape is easily controlled compared to fired brick which is subjected to 2.5% to 4 % shrinkage due to the firing temperature (Brick Industry Association, 2006). Furthermore, producing non-fired bricks consumes less energy and contributes less to the carbon footprint. Production of non-fired bricks can reduce 3.8 million CO_2 emissions, approximately 36% compared to fired bricks (Promotion of Non-Fired Brick Production (NFB) Production and Utilization in Viet Nam, n.d.)

2.6.2 Drawback of Non-Fired Brick

Cement can act as a stabiliser to bind the soil or sand particles together to achieve desired strength through cement hydration. As the production of non-fired brick does not involve the firing process, the strength achieved is low and reliable on the cement for better strength development. Cement production contributes much to the carbon footprint and consumes huge amounts of fossil fuels. Therefore, cement usage is detrimental to the environment and causes climate change. The cement industry is also creating dust pollution that pollutes the air quality. The dust in the air inhaled by humans can cause breathing issues and lung cancer if the exposure time is long. Visibility is affected by dust particles, which indirectly retard the photosynthesis of the plant to produce crops.

Another drawback of non-fired brick is using natural resources like sand and soil. Soil is the major ingredient of CSEB, while sand is used to fabricate CSB. Overexploitation of soil cause loss of nutrient that leads to infertile land. The infertile agricultural land reduces crop yields and threatens food security in the long run. Excessive sand mining on the river changes the shape of riverbeds which causes riverbanks to be eroded faster. The extraction of sand also will induce the topsoil into the river, polluting the river and harming the aquatic organisms.

2.7 Cement Sand Brick

Cement sand brick (CSB) is a non-fired brick that does not require a firing process to gain strength and is energy efficient compared to a conventional brick. The main components of CSB are sand, and cement acts as a binder. It only appeared after the cement's invention and became a substitute for conventional clay brick. CSB has several advantages, such as good durability, cost-effectiveness, and the ability to withstand high temperatures; therefore, it is favourable for building, railway, and drainage system construction.

Cement sand brick manufacturing is simple compared to clay brick, which only involves mixing, moulding, compression, and curing. Figure 2.2 demonstrates the whole manufacturing process of CSB in Malaysia (Fine Technics Engineering Work, 2017). Firstly, the raw materials cement, sand, and water are prepared by the batching machine. Then, the mixture is mixed well with the help of a mixer to ensure homogenous mixing. Once the mixture is ready, it is transported into the moulding machine through a conveyor. At this stage, the mould will be filled with the mixture, vibrated, and compressed by the hydraulic system to a certain pressure. The compressed brick specimens are then compressed from the mould and formed bricks. Before packing into pallets, the bricks must undergo low-pressure steam curing at around 90°C for around 18 to 24 hours. The bricks can gain 70 to 80% of 28 days' strength in steam curing (CM04 Concrete Masonry Manufacture, 2014).

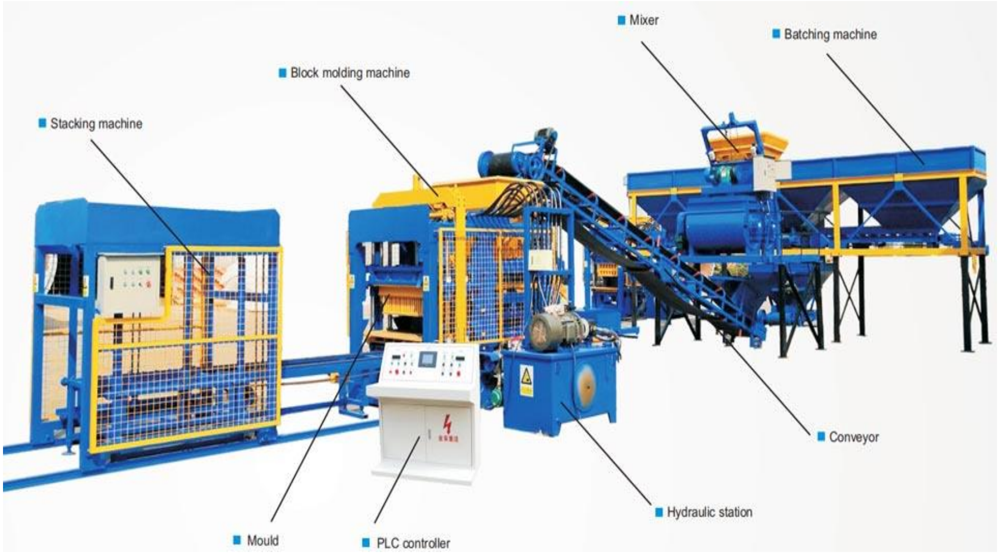

Figure 2.2: Manufacturing process of Cement Sand Brick.

2.7.1 Advantages of Cement Sand Brick

Since the gaining strength of CSB does not depends on the firing process, the production cost is much cheaper than conventional brick. Low production costs lead to low selling prices. One unit of cement sand brick costs around RM 0.30 while the conventional brick costs around RM 0.40 as quoted by AKTC eWarehouse Home Improvement Store; hence CSB is widely used in construction instead of normal clay brick.

Moisture is the key factor that affects the durability of brick. High moisture content in brick reduces durability, causing low resistance to weathering. Water absorption rate describes the ability to absorb water into the internal surface of the brick. The water absorption rate of CSB is low as compared to conventional brick. Hence, it is suitable to use outdoors and withstand bad weather conditions. As Mailar, G et al. (2016) discovered, water absorption is interrelated to porosity. Low water absorption means low porosity. The CSB is suitable for housing development in cold weather countries because it can retain heat from escaping into the environment.

As mentioned above, the compressive strength required for CSB is 7 N/mm^2, much higher than conventional brick requires 4 N/mm^2. The high requirements in CSB indicate it must be able to take more load from the structure and use it in multiple-storey buildings. The density of cement sand brick is around 2085 kg/m^3. The high-density property promotes the use of CSB as an interlocking brick that does not require cement to bind them together. In addition, CSB has another advantage over other types of brick, and it is stronger as time passes. Since it uses cement to bind the sand particles, the cement hydration process helps the CSB gain strength continuously with water.

2.7.2 Drawbacks of Cement Sand Brick

Cement is the major stabiliser used in the manufacturing of CSB. Cement production emits much carbon dioxide, which is detrimental to the environment. Cement is not an environmentally friendly material to be used as it significantly impacts humans, wildlife, and the environment. Around 8% to 10% of CO_2 emissions to the atmosphere are generated by the cement industry, which is the second largest carbon footprint contributor other than power plants Poudyal, L. and Adhikari, K. (2021). Mohamad, N., et al. (2021) also discovered that the global greenhouse gas emission from the cement industry in 2017 reached 4.1 Gt of CO_2 gas. Not just CO_2 is released. Other gases such as VOCs, nitric oxide, sulphur dioxide, and dust particles are emitted. These gases harm humans and cause many health issues once the exposure time is long enough.

The scarcity of sand is another drawback of CSB, as the main component is made up of sand. Although there are tons of sand available in the desert, the sand is less suitable due to its fineness and round shape. The majority of and that is suitable to be used in brick manufacturing comes from the riverbank. River sand has an angular shape and random particle size, which provides better mechanical support than desert sand. River sand is a product of the disintegration of rocks into smaller particles under the effect of weathering. The decomposition of rocks into sand is driven by the water flow, ocean tides, gravity, and wind, which take a few centuries or even millions of years (National Oceanic and Atmospheric Administration, 2021). Hence, the sand cannot be replenished in a short period of time. Rapid construction development increases the demand for sand, causing a shortage of sand. As the shortage issue persists, the cost of CSB will get higher, and eventually, CSB will lose its competitive advantage compared to other types of brick.

Destruction of water quality in rivers directly impacts sand mining activities. Water pollution contributes to the loss of biodiversity in the river and an imbalanced ecosystem, as aquatic life cannot survive in such a polluted environment. Besides, the excessive demand for sand leads to the overexploitation of sand. In addition, sediment extraction changes the riverbed structure, indirectly altering the river flow pattern. Later, this may destroy the public infrastructure, such as bridge piers and buried pipelines nearby (Ashraf et al., 2011). The sand mining industry also contributes to climate change through greenhouse gas emissions. Based on the greenhouse gas emission report done by National Stone Sand & Gravel Association (2021), the sand manufacturing industry generates 5.34 million tons of CO_2 per year. Each ton of sand produced emits 5.51 kg of CO_2 into the atmosphere. Thus, sand mining activities also contributed to the carbon footprint.

2.8 Relevant Past Research

Recently, sustainable development and zero waste concepts have been promoted and encouraged to be practiced in industries. Traditional brick production had many negative impacts on the environment, hence the appearance of non-fired brick as a substitution for fired brick. However, it creates another problem: the high consumption of sand resulting in river pollution issues and greenhouse gas emissions. Aluminium dross is a waste produced from the aluminium production industry and is an issue for disposal since it exhibits hazardous characteristics. Thus, there are many researchers have carried out investigations on substituting sand portions with waste materials in CSB fabrication. Most researchers researched waste materials such as plastic bottle waste, palm oil clinker, waste glass, blasted copper slag, and others. However, there is no researcher conducted a research investigation on the use of aluminium dross as sand replacement in CSB fabrication. The relevant past research on incorporating various waste materials in CSB fabrication to enhance the strength and reduce sand portion is illustrated as the following Table 2.1.

Table 2.1: Overview of Previous Research Literature on CSB Fabrication.

Title	Type of Material	Function	Substitution portion (%)	Compressive strength at 28 days (MPa)	Reference
Compressive Strength Behaviors of Lagoon Water Cured Cement-Aluminium Dross Concrete	Aluminium dross	Partial replacement of cement	0, 5, 10, 15, 20 and 25	15.50	Afolabi, Oladoye, Sadiq and Adeosun (2021)
Experimental Analysis on The Properties of Concrete Brick with Partial Replacement of Sand by Saw Dust and Partial Replacement of Coarse Aggregate by Expanded Polystyrene	Saw dust and expanded polystyrene	Partial replacement of fine aggregates and coarse aggregate	0, 10, 20 and 30	13.68	Ghimire and Maharjan (2019)
Properties of Cement Brick with Partial Replacement of Sand and Cement with Oil Palm Empty Fruit Bunches and Silica Fume	Oil palm empty fruit bunches and silica fume	Partial replacement of sand and cement	0, 10, 15, 20 and 25	12.4	Ling et al. (2019)

Table 2.1: Overview of Previous Research Literature on CSB Fabrication (continued).

Title	Type of Material	Function	Substitution portion (%)	Compressive strength at 28 days (MPa)	Reference
Palm Oil Clinker: A Potential Partial Sand Replacement in Brick Production	Palm oil clinker	Partial replacement of sand	0, 10, 20, 30 and 40	>12	**Muthusamy et al. (2017)**
Properties of Sand Cement Brick containing Ground Palm Oil Fuel Ash as Fine Aggregate Replacement	Ground palm oil fuel ash	Partial replacement of sand	0, 5, 10, 15, 20 and 25	17	**Muthusamy et al. (2018)**
Application of Waste Treatment Sludge from Water Treatment in Brick Production	Water treatment sludge	Partial replacement of sand	3, 5, 7, 10, 15, 20, 40 and 60	10.37	**Noruzman, Palil, Ahmad and Baharudin (2020)**
Ultilization of Cockle Shell (Anadara granosa) Powder as Partial Replacement of Fine Aggregates in Cement Brick	Cockle shell powder	Partial replacement of sand	5, 10 and 15	55.10	**Sainudin et al. (2020)**

Table 2.1: Overview of Previous Research Literature on CSB Fabrication (continued).

Title	Type of Material	Function	Substitution portion (%)	Compressive strength at 28 days (MPa)	Reference
Production of Bricks from Shipyard Repair and Maintenance Hazardous Waste	Blasted copper slag	Partial replacement of fine aggregates	0, 20, 40 and 60	50	**Salleh, Shaaban, B. Mahmud and Kang (2014)**
Utilization of Plastic Bottle Waste in Sand Brick	Plastic bottle waste	Partial replacement of sand	0, 5, 10 and 15	11.62	**(Wahid, Rawi and Md Desa, 2014)**
The Reuse of Waste Glass as Aggregate Replacement for Producing Concrete Bricks as an Alternative for Waste Glass Management on Koh Sichang	Waste glass	Partial replacement of fine aggregates	0, 10, 20, 30 and 100	48.49	**Warnphen, Supakata and Kanokkantapong (2019)**

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter showed the detailed methodology of this research study, including materials and apparatus needed, fabrication procedure of CSB, and laboratory tests for the determination of CSB engineering properties and durability. Various percentages of treated aluminium dross will be used for partial sand replacement in CSB fabrication. Several laboratory tests conducted was to determine the optimum sand substitution that can enhance the strength of the CSB. All the laboratory tests were conducted based on the ASTM and BS EN standard requirements. Figure 3.1 shows the flow of the research method.

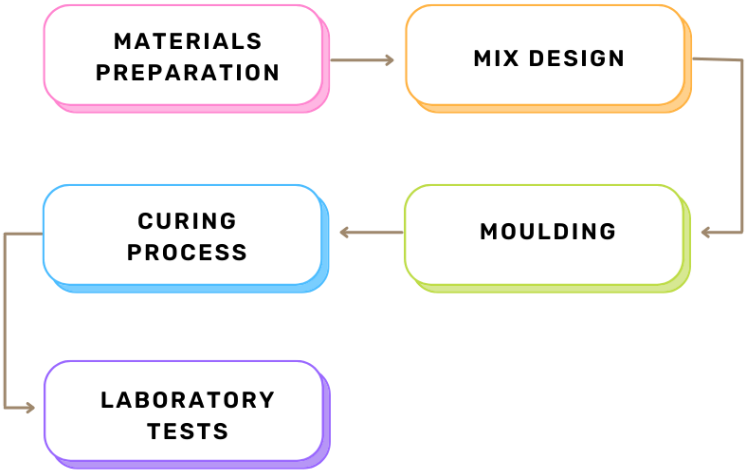

Figure 3.1: Methodology Flow of Research Study.

3.2 Material Preparation

During preparing research materials, precautionary steps were needed to ensure the external environment did not affect the materials. Airtight containers were used to store all the materials. The containers and materials were labeled and placed in the workshop where there was no direct exposure to sunlight.

3.2.1 Cement

In this research study, the cement was used as a stabilizer to bind the elements during the fabrication of CSB. The cement was manufactured by YTL Corporation Berhad, complying with the British Standard European Norm BS EN 197-1:2011 that is used widely in the construction activities such as concreting and bricklaying. The Ordinary Portland Cement used was shown in Figure3.2. Before the cement was used, removal of pre-hydrated cement clumps using a No.200 sieve to prevent any interruption in the hydration process.

Figure 3.2: Cement

3.2.2 Aluminium Dross

Aluminium dross used in this research was collected from KYH Recycle Industries Sdn Bhd. It is dark grey dross in dry powder form with a slightly pungent smell. Since the aluminium dross is a mixture of dross and salt cake, separation was required to obtain the dross. The aluminium dross had to pass through a 300µm opening sieve plate to ensure the aluminium dross was in powder and to sort out the undesired material. After that, the untreated AD must undergo treatment before being incorporated into brick.

Figure 3.3: Untreated Aluminium Dross (AD).

3.2.3 Sand

The aggregate required in this research study was fine sand purchased from Man Tong Hardware and Machinery (Kampar) Sdn Bhd., as shown in Figure 3.4. To remove the excess moisture content, the sand had to undergo a drying process in the oven at 105℃.

Figure 3.4: Dried Fine Sand.

3.3 Aluminium Dross Treatment

AD treatment was proposed to remove the hazardous substance, AlN to enhance its properties when incorporated into the CSB. Since AlN is easily hydrolysed under alkaline conditions, sodium hydroxide (NaOH) was used in the treatment. The amount of NaOH used, the ratio of untreated AD to NaOH, the temperature, and the duration of treatment were based on Lv et al. (2020). In the research, the untreated AD to distilled water ratio was 1:6, and 4wt% NaOH based on the mass of untreated AD was added. The treatment was carried out at the temperature of 90℃ for 3 hours. The overall treatment process is described in Figure 3.5.

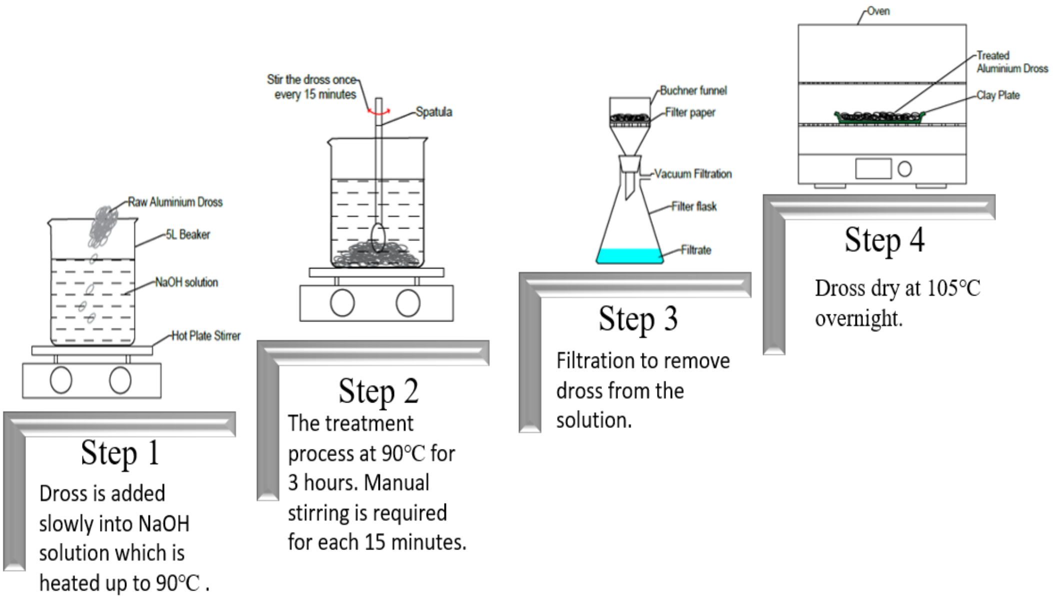

Figure 3.5: Overall Treatment Process of Aluminium Dross Using Sodium Hydroxide.

3.4 Mix Design

Based on the past relevant research study, several trial mixes were carried out to design the mix portion ratio for the fabrication of CSB. The mix portion ratio by weight for cement to sand was 1:3.4, and the water-cement ratio is fixed at 0.60. The various substitution portions of sand with treated aluminium dross are 5%, 10%, 15%, 20%, and 25%, as shown in Tables 3.1 and 3.2. The dimension of the beam specimen is 210mm x 90mm x 90mm.

Table 3.1: Mix Proportion for Cement Sand Brick Fabrication.

Design Mix Code	**Materials (%)**			
	Cement	Water	Sand	Treated Aluminium Dross
XR	20.00	12.00	68.00	0.00
5R	20.00	12.00	63.00	5.00
10R	20.00	12.00	58.00	10.00
15R	20.00	12.00	53.00	15.00
20R	20.00	12.00	48.00	20.00
25R	20.00	12.00	43.00	25.00

Table 3.2: Weight of Composites for Each 210mm x 90mm x 90mm Specimen.

Design Mix Code	**Weight of Materials Per Specimen (g)**			
	Cement	Water	Sand	Treated Aluminium Dross
XR	660.00	396.00	2244.00	0.00
5R	660.00	396.00	2079.00	165.00
10R	660.00	396.00	1914.00	330.00
15R	660.00	396.00	1749.00	495.00
20R	660.00	396.00	1584.00	660.00
25R	660.00	396.00	1419.00	825.00

Notes:

XR – Controlled CSB specimen without sand replacement

5R – CSB specimen with 5% Treated AD for sand replacement

10R – CSB specimen with 10% Treated AD for sand replacement

15R – CSB specimen with 15% Treated AD for sand replacement

20R – CSB specimen with 20% Treated AD for sand replacement

25R – CSB specimen with 25% Treated AD for sand replacement

Figure 3.6: Mixing of CSB Specimen.

3.5 Moulding & Demoulding

Since the mould size is 210mm x 90mm x 90mm, only one specimen size was prepared to undergo various laboratory tests. First, the mixture was shoveled into the mould, as shown in Figure 3.7, and compacted by hand. This process was repeated until reaching the desired height. Afterward, the mixture was compacted by a 20 tons hydraulic shop press in Figure 3.8. A force of 3.5 metric tons equivalent to 1.82 MPa in pressure was applied to the mixture to remove the air voids. Once the mixture had been fully compacted, the brick specimen was immediately removed from the mould. During the demoulding process, each step had to be extra cautious to prevent damage to the brick specimen. A piece of plywood was used to support the specimen after being removed from the mould, as shown in Figure 3.9.

Figure 3.7: Specimen Mould.

Figure 3.8: Compression of the CSB Specimen by 20 Tons Hydraulic Shop Press.

Figure 3.9: Demoulding of the CSB specimen.

3.6 Curing Process

The CSB specimen was allowed to gain strength in the natural air overnight to ensure the specimen was hardened. The curing process was carried out by immersing the specimens in water for 7, 14, and 28 days, as demonstrated in Figure 3.10, to promote the cement hydration process for better strength gain. The specimen was labeled properly before immersing in the curing tank.

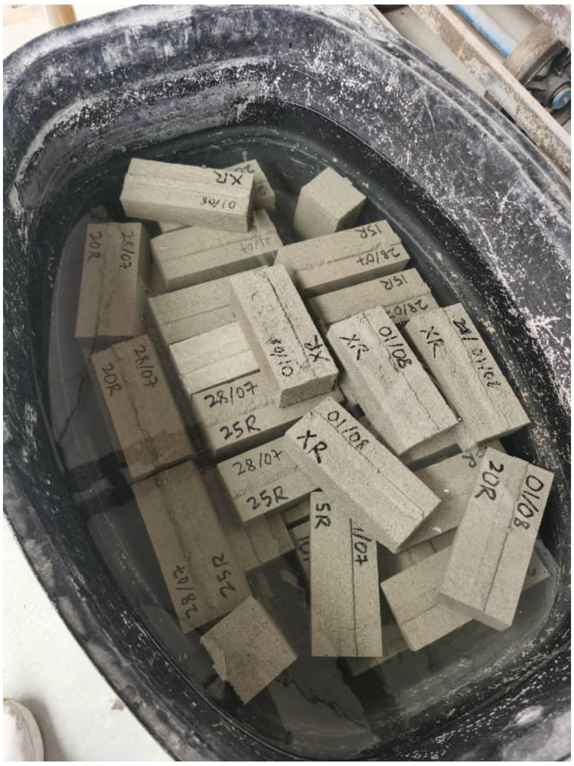

Figure 3.10: Curing Process.

3.7 Laboratory Tests

Since AD is categorized as a scheduled waste that contains harmful metal ions, additional leaching of metal ions test was conducted to evaluate the environmental impact of CSB. There are two important properties of CSB: engineering properties and durability properties to be tested in the laboratory. The laboratory tests were aimed to determine the optimum substitution portion of sand by treated AD in the fabrication of CSB. The laboratory tests conducted are shown in Figure 3.11. Compressive, flexural, and scanning electron microscopy tests were performed to determine the engineering properties, whereas porosity, bulk density, and water absorption test were for the durability properties. The required quantity of the brick specimen has been tabulated in Table3.3.

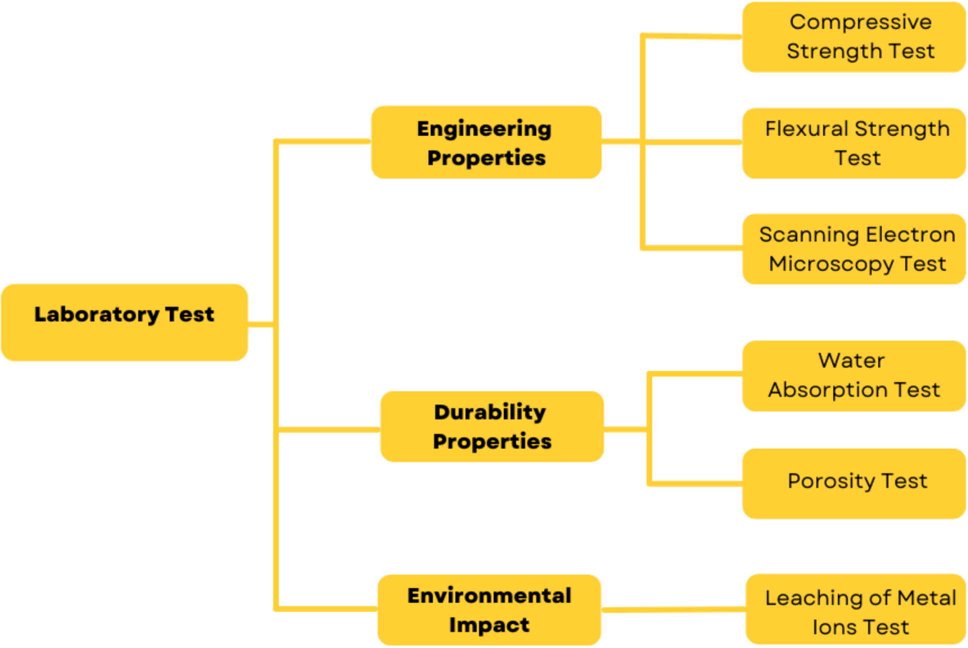

Figure 3.11: Laboratory Tests.

Table 3.3: Quantity of Cement Sand Brick Specimen Needed for Laboratory Test.

Test	Specimen Age (Day)	Number of Specimen
Compressive strength	7	3
	14	
	28	
Flexural strength	7	3
	14	
	28	
Bulk density	7	3
	14	
	28	
Water Absorption	7	3
	14	
	28	
Porosity	7	3
	14	
	28	
Leaching of metal ions	-	3

3.7.1 Compressive Strength

The compressive strength machine, as shown in Figure 3.12, was used to determine the compressive strength of the CSB specimen. The BS EN 12390-3:2009 was complied with in conducting the compressive strength test. The test involved three brick specimens aged 7 days, 14 days, and 28 days, respectively. Before the test, the dimension of the specimen must be measured using a Vernier caliper. Two pieces of plywood were placed on the top and bottom of the brick specimen to ensure a uniform load from the compression machine was applied to the brick specimen during the test. The machine compresses the specimen until the specimen fails to resist the force applied, and the maximum load reading is recorded. The compressive strength of the specimen was calculated by applying Equation **3.1,** as shown below.

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

where

P = Compressive strength, N/mm^2

F = Maximum load applied on the specimen, N

A = Specimen surface area, mm^2

Figure 3.12: Compressive Strength Test Machine.

3.7.2 Flexural Strength Test

A t-Machine universal testing machine, as shown in Figure 3.13, determines the specimen's flexural strength. The flexural strength test complies with the BS EN 12390-3:2009 standard. The test involved three brick specimens aged 7 days, 14 days, and 28 days, respectively. Before the test, the center and 40mm displacement from the end of both sides on each specimen was marked. The specimen was placed on the machine to conduct the test, as shown in Figure 3.14. The machine compresses the specimen until the specimen fails to resist the force applied and records the maximum load reading. The fracture point was observed as well. The flexural strength of the specimen was calculated by applying **Equation 3.2,** as shown below.

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

where

f_v = flexural strength, in N/mm2
F = maximum load applied on the specimen, in N
L = distance between supports, in mm
b = width of the specimen, in mm
h = height of the specimen, in mm

Figure 3.13: T-Machine Universal Testing Machine.

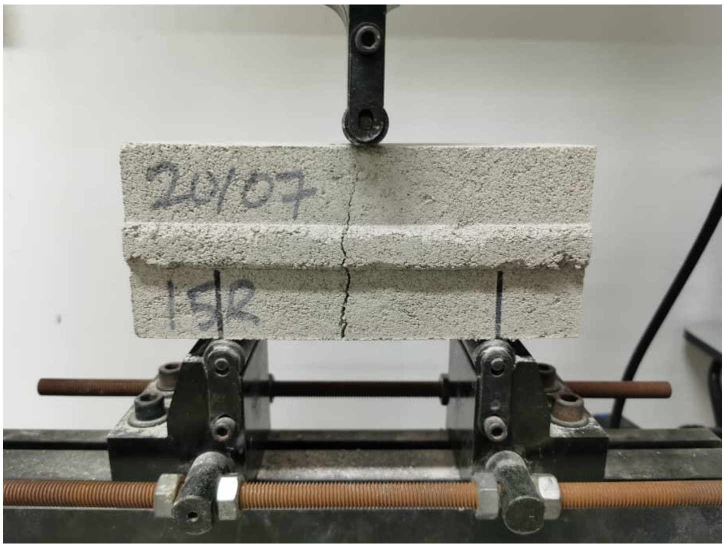

Figure 3.14: Flexural Strength Test Conducted.

3.7.3 Bulk Density Test

The density of the brick specimens was determined by the bulk density test in compliance with the American Society for Testing and Material (ASTM C140/C140M-20). The brick specimens were dried in the oven at a temperature of 100 to 115℃ for 24 hours. After the drying process, the specimens were cool down at room temperature, and the dry weight of each specimen was measured and recorded. Then, the specimens were placed and immersed completely in water to obtain the saturation weight of the specimen. The specimen had to be immersed in water for 24 hours to ensure the specimen was saturated. After 24 hours, the weight of the submerged specimen in water was recorded by buoyancy balance, as shown in Figure 3.15, the specimen was taken out from the water. Any surface water had to be removed to obtain the accurate saturation weight of the specimen. Equation 3.3 was applied to calculate the specimens’ bulk density.

$$D = \frac{w_d}{w_w - w_s} \times 1000 \tag{3.3}$$

Where

D = Bulk Density, kg/m^3

W$_d$ = Weight of dried specimens, g

W$_w$ = Weight of specimens, g

W$_s$= Weight of immersed specimens, g

Figure 3.15: Buoyancy Balance.

3.7.4 Water Absorption Test

The water absorption test determined the water absorption rate of the CSB specimens in compliance with the American Society for Testing and Material (ASTM C140/C140M-20). The specimens were dried in the oven at around 100 to 115 ℃ for 24 hours. After the drying process, the specimens were cool down at room temperature, and each specimen's dry weight was measured and recorded. Then, the specimens were placed and immersed completely in water to obtain the saturation weight of the specimen, as shown in Figure 3.16. The specimen had to be immersed in water for 24 hours to ensure the specimen was saturated. After 24 hours, the specimen was taken out from the water. Any surface water had to be removed so that the accurate saturation weight of the specimen could be obtained. Equation 3.4 was applied to calculate the specimen's water absorption rate.

$$M = \frac{W_w - W_d}{W_d} \times 100 \tag{3.4}$$

where

M = Percentage of water absorption, %

W_d = Weight of dry specimen, g

W_w = Weight of saturated specimen, g

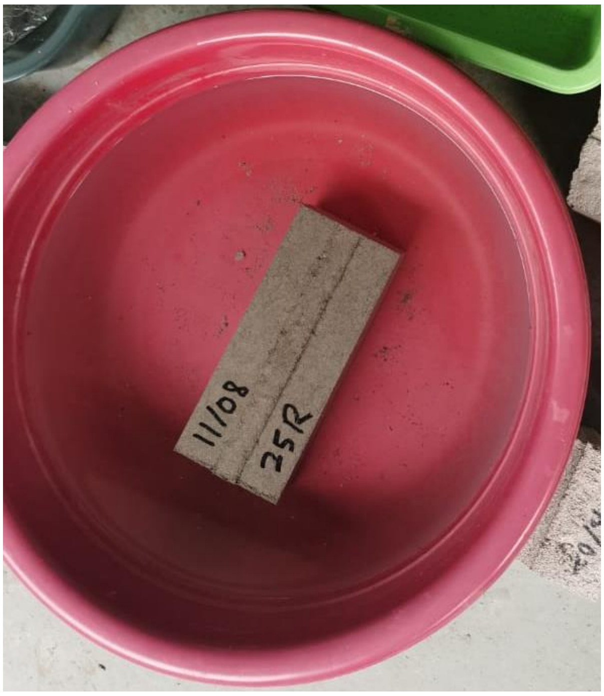

Figure 3.16: Specimen Immersed in Water For 24 hours.

3.7.5 Porosity Test

A porosity test was carried out to calculate the number of void spaces in the CSB. The void space affects the strength and durability of the brick. The higher the porousness of the specimen, the more the negative impact on the durability of CSB. Based on RILEM Recommendations, three specimens of age 7 days, 14 days, and 28 days are needed to evaluate the porousness. The specimens were placed in the oven for the drying process to remove excess moisture content. After 24 hours, the specimens were placed in a vacuum water-saturated desiccator, as shown in Figure 3.17. Water was then filled up to the level 1 cm above the height of the specimen. The duration of the evacuation process is 15 minutes. After that, the specimens were soaked in water for another 3 hours and underwent 15 minutes of evacuation. Once the evacuation was done, the specimens were placed and immersed completely in water for 24 hours. Last, the specimens were removed from the water, wiped, and obtained the immersed and submerged weight. **Equation 3.5** was applied to calculate the porosity of the specimen.

$$n = \frac{W_w - W_d}{W_w - W_s} \times 1000 \tag{3.5}$$

where

n = Porosity, %

W_d = Weight of dry specimen, g

W_w= Weight of the submerged specimen, g

W_s = Weight of immersed specimen, g

Figure 3.17: Vacuum Pump and Desiccator.

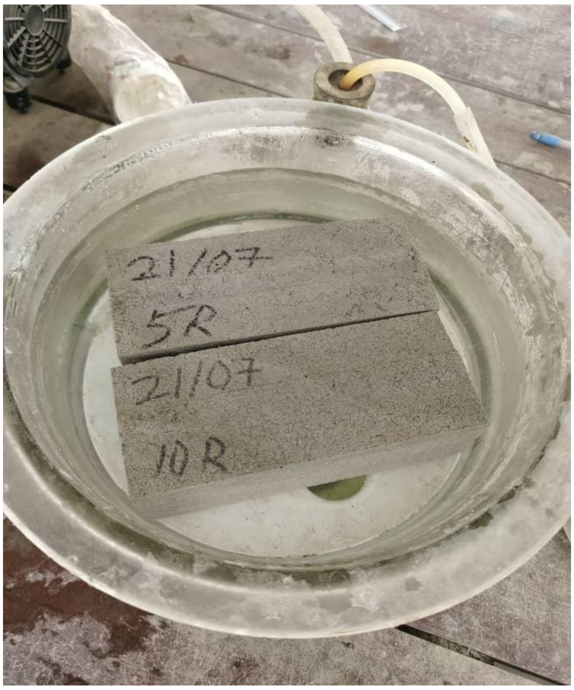

Figure 3.18: Specimen Immersed in The Vacuum Pump and Desiccator.

3.7.6 Microstructure Analysis

Microstructure analysis was adopted to determine the microstructure properties of CSB specimens. Based on the American Society for Testing and Material ASTM C1723-16, a Scanning Electron Microscope (SEM) was used to determine the microstructure properties of the **CSB** specimen on the 28th day of the curing period, as shown in Figure 3.19. The specimen is disintegrated into smaller pieces and crushed into powder form. 15kV of SEM accelerating voltage was adjusted, and 500, 1000, 2000, and 5000x of magnification were set to observe the insight structure of the CSB specimen. Microstructure analysis promoted a detailed view of the material matrix, internal structure, and also the permeability of CSB specimens.

Figure 3.19: Scanning Electron Microscopy Test Machine.

3.7.7 Metal Ions Leaching Test

The leachability of metal ions from the CSB specimen was determined through the Leaching of Trace Elements from Hardened Concrete (JSCE G575-2005). The Japan Society of Civil Engineers proposed this standard method to determine the trace element that leached from the concrete specimen. First, to prepare for leachate, the specimens had to be immersed in distilled water for 24 hours once they had been hardened. The amount of distilled water needed was based on the specimen's surface area of 5mL per 100 mm^2. In this research project, the immersion period was extended to 7 days, as shown in Figure 3.20, although the standard suggested the duration of immersion of specimen in water is only 24 hours. The extension of time is to ensure that more accurate data is obtained. Once the leachate was ready, the leachate had to filter through a 0.45μm syringe filter. After that, metal ions were analyzed in the leachate using ICP-OES in UTAR Sungai Long Campus, as shown in Figure 3.21.

Figure 3.20: Leaching of Metal Ions from The Specimens.

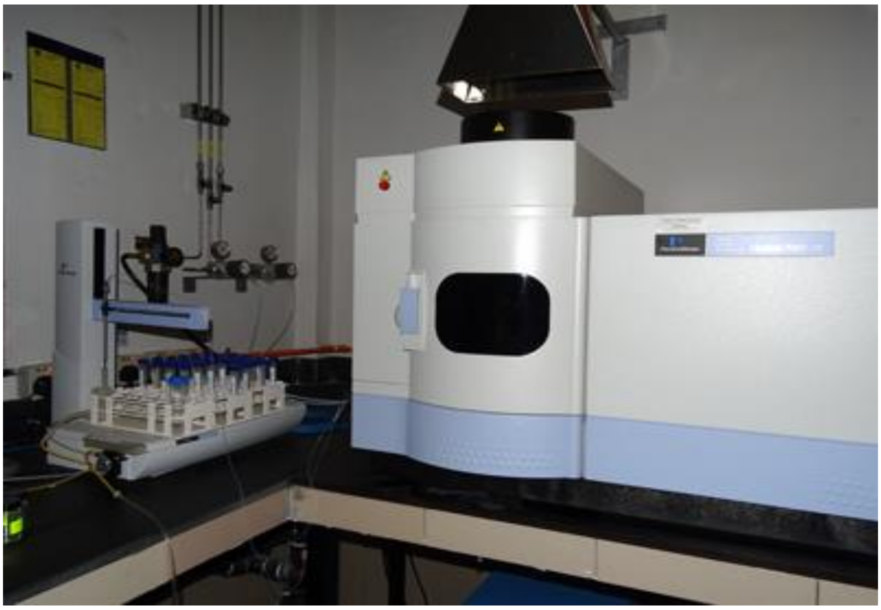

Figure 3.21: The ICP-OES.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter will analyze and discuss the characteristics of AD before and after treatment, engineering properties, durability properties, and metal ions leachability. After various laboratory tests, the results obtained were discussed and compared. The percentage of treated AD replacing sand in fabricating Cement Sand Brick (CSB) specimens are 0, 5, 10, 15, 20, and 25%, respectively.

4.2 Preliminary Analysis of Incorporation of Aluminium Dross in Cement Sand Brick

Figure 4.2 above showed the CSB specimen was substituted with untreated AD crack on Day 3 after being immersed in water for one day. The crack of the specimen is because of the chemical shrinkage caused by the excessive heat released from the hydrolysis of AlN. As it is immersed in water, the water can enter the brick and provide sufficient water for the AlN to react. Since the reaction is exothermic and detrimental to the brick structure, treatment is needed to remove the AlN from the AD.

Figure 4.1: The CSB Specimen Was Substituted with Untreated AD on Day 2.

Figure 4.2: The Immersed CSB Specimen Substituted with Untreated AD in Water on Day 3.

4.3 Characteristics of Untreated Aluminium Dross and Treated Aluminium Dross

Table 4.1: Characteristics of Untreated AD and Treated AD.

	Untreated AD	**Treated AD**
Colour	Dark grey	White Grey
pH	10.215	9.703

Figure 4.3: The Untreated AD (Left) and Treated AD (Right).

The pH of treated AD was lower than untreated AD showing that the corrosive properties of AD can be reduced through treatment. **Table 4.1** and **Figure 4.3** show that the treated AD is white-grey compared to the untreated AD in dark grey. The colour change can be explained as the formation of amorphous aluminium hydroxide (AlOOH), also called pseudoboehmite, which is a white colour produced from the hydrolysis of AlN (Kocjan, Krnel, and Kosmač, 2008). It is insoluble in water and can hinder the AlN from being hydrolysed when contacting water. Later, crystallisation occurs, which converts AlOOH to aluminium hydroxide ($Al(OH)_3$). It emitted lesser ammonia gas, and the concentration of OH^- is low; hence the pH is lower than in untreated AD. The decrease in pH is mainly due to the protective layer, which slows down the AlN hydrolysed process.

Table 4.2: The Composition Present in Untreated and Treated AD.

Composition (wt%)	**Untreated AD**	**Treated AD**
Na_2O	1.79	1.17
MgO	4.71	4.19
Al_2O_3	73.0	81.4
SiO_2	3.13	3.84
P_2O_5	1.23	1.84
AlN	1.59	0.33
SO_3	1.14	0.33
Cl	9.46	1.56
K_2O	2.02	1.27
CaO	1.28	1.43
Fe_2O_3	1.74	2.40
CuO	0.205	0.226
ZnO	0.140	0.171
SrO	0.117	0.0622
NiO	0.0516	-
MnO	-	0.121

As from Table 4.2, the major components present in untreated AD are Al_2O_3 (73.0%), Cl (9.46%), MgO (4.71%), and SiO_2 (3.13%). After treatment, the Al_2O_3 content had increased by 8.40%, from 73.0 % to 81.4%. Cl had reduced to 1.56% and added 0.71% of SiO_2 from 3.13% to 3.84%. Al_2O_3, SiO_2, CaO, and Fe_2O_3 are the major ingredients of cement hydration and the pozzolanic reaction between Al_2O and Fe_2O_3. The treated AD has a higher potential to enhance the strength of CSB as it contains more Al_2O_3, SiO_2, CaO, and Fe_2O_3 than the untreated AD. The abundance of Al_2O_3 can provide the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which retard swelling and shrinkage and hence, improves the strength (Muzenski, Flores-Vivian, and Sobolev, 2019). The composition of AlN in the Untreated AD is 1.59% and reduced to 0.33%, with an efficiency of 79.47 % after the treatment. Cl is detrimental to the strength of concrete as it can corrode the reinforcements. High Cl concentration in water can kill aquatic life and disturb the ecosystem. The low amount of Cl in the treated AD shows that the hydrolysis treatment can remove Cl and is less harmful to the environment.

Table 4.3: Comparison of The Metal Ions Present in One Gram of Untreated AD and Treated AD.

Types of Metal Ions	The Concentration of Untreated AD (mg/L)	The Concentration of Treated AD (mg/L)	Difference (%)
Aluminium, Al	2977.425	2419.225	18.75
Cadmium, Cd	0.177	0.121	31.64
Chromium, Cr	5.163	3.250	37.05
Copper, Cu	8.157	6.466	20.73
Iron, Fe	93.228	58.334	37.43
Lead, Pb	0.292	0.248	15.07
Manganese, Mn	2.731	2.187	19.92
Nickel, Ni	0.063	0.032	49.21
Zinc, Zn	1.313	1.181	10.05

Based on the analysis of the composition of metal ions, it was found that both untreated and treated AD contained many metal ions that exceeded the standard stated in EQA 1974. There were abundant Al, Fe, Cu, Cr, and Mn ions in both AD. These few metal ions are detrimental to humans and aquatic life once the metal ions are leached into the environment. Therefore, the AD is categorised as scheduled waste SW204 in Malaysia based on Environmental Quality (Scheduled Waste) Regulations 2005.

4.4 Compressive Strength

The average compressive strength of CSB specimens with different curing ages is shown in **Table 4.4** and **Figure 4.4**. Moreover, the compressive strength development trends of CSB specimens throughout the 28 days curing period are shown in **Figure 4.3**.

Table 4.4: Compressive Strength of Cement Sand Brick Specimen.

Specimen	**Compressive Strength (N/mm^2)**		
	7 days	14 days	28 days
XR	10.990	13.328	22.078
5R	16.366	19.000	17.796
10R	16.349	17.620	15.738
15R	12.172	13.520	11.130
20R	10.954	11.770	8.913
25R	9.750	10.050	7.018

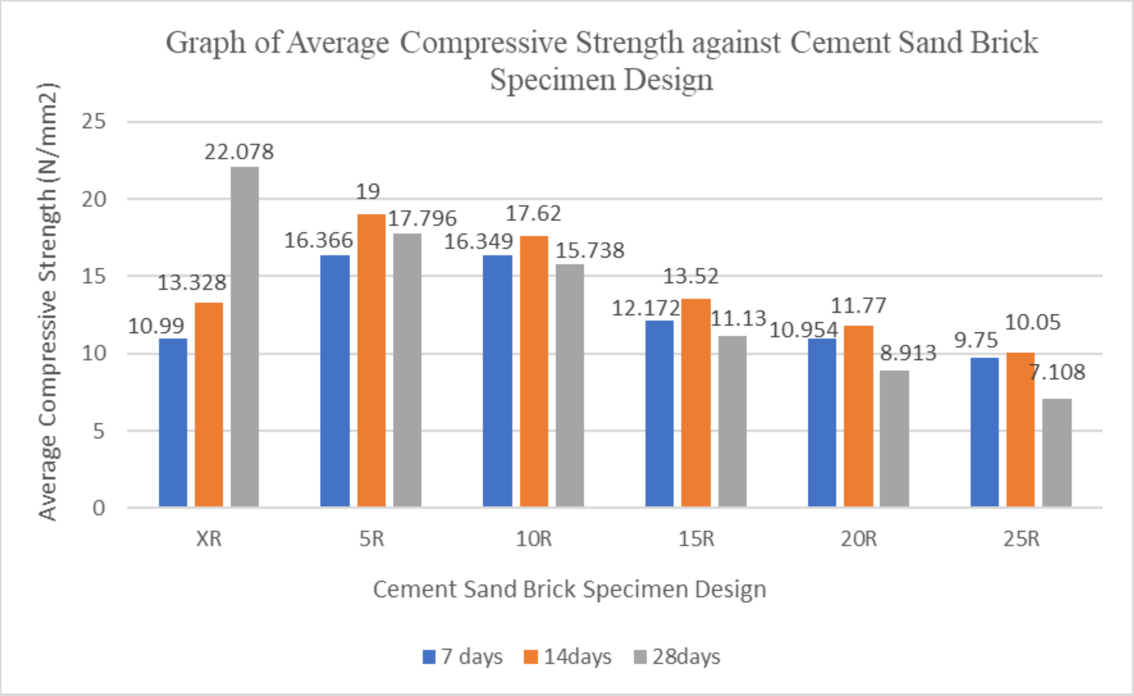

Figure 4.4: Graph of Average Compressive Strength against Cement Sand Brick Specimen Design.

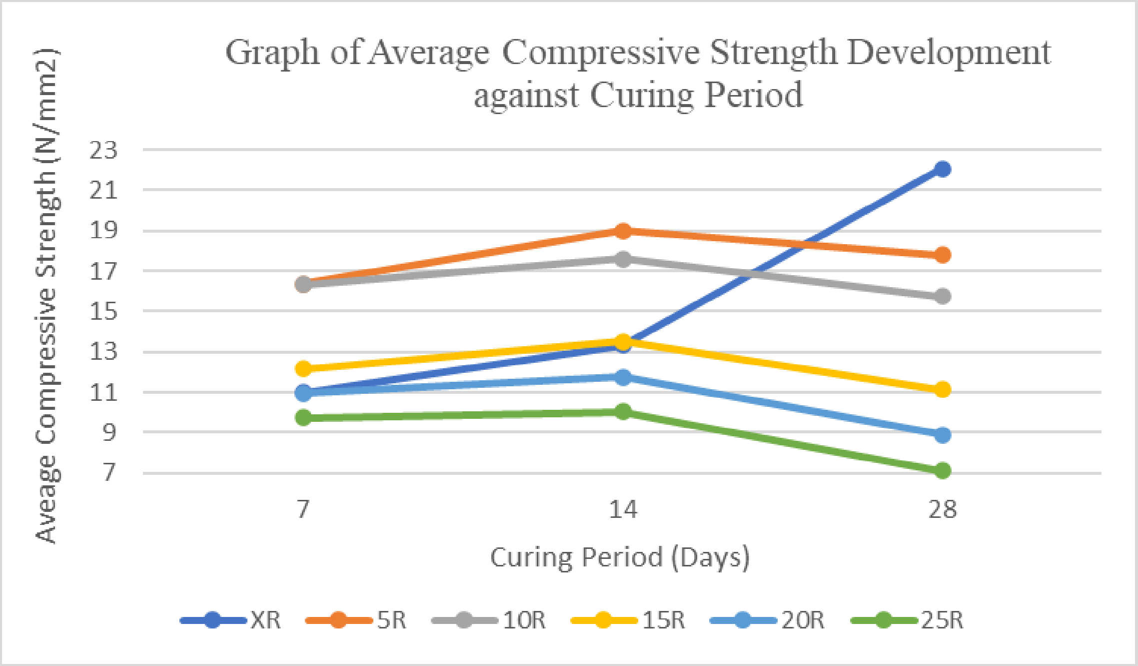

Figure 4.5: Graph of Average Compressive Strength Development Trend.

Compressive strength is the most critical parameter of CSB when used in construction. Table 4.4 and Figure show the compressive strength test result of all the CSB specimens at 7 days, 14 days, and 28 days. The compressive strength development trend is also described in Figure 4.5.

As the AD percentage reached 5%, there is an increment of 42.56% in compressive strength which is 19 N/mm^2 higher than XR, 13.328 N/mm^2 at age 14 days. 10% AD replacement specimen (10R) gained higher strength with 4.292 N/mm^2 different from the specimen without AD replacement (XR) at 14 days of curing. The improvement in strength is due to the fineness of the AD, which can act as a filler to close up the pores in the CSB. Since AD contained a large amount of Al_2O_3, enough alumino-siliceous compound was provided to react with CaO from cement to form C-S-H gel and C-A-H gel (Arthur Michael, 2019).

$$Ca_2SiO_5 + H_2O \rightarrow CaO - SiO_2 - H_2O \tag{4.1}$$

$$C_2S + H \rightarrow C\text{-}S\text{-}H \tag{4.2}$$

AlN hydrolyses to form amorphous aluminium hydroxide (AlOOH), which is insoluble in water and acts as a protective layer to prevent AlN from further reaction. Porosity is the major factor that affects compressive strength. Crystal products known as aluminium hydroxide ($Al(OH)_3$) generated from AlOOH thought crystallisation further reduces the pore size. However, the crystal products are stable at a pH range of 5.5 to 8.0 (Kocjan, Krnel, and Kosmač, 2008).

Once the replacement percentage reaches 15% and further increases to 25%, the compressive strength decreases. The 25R had the largest percentage of decrease in strength, which was 30.17%, while the strength lost by 5R was only 6.33%. The large strength loss implied the more AD substitution, the more strength loss in later time as the AlN hydrolysed to give ammonia gas that created pores. Another probable reason to justify the decrease of strength as the percentage of AD increased was the poor bonding because of insufficient sand in the brick specimen. Sand's rough, irregular shape contributes to the bonding by providing mechanical engagement force. Riza and Rahman (2015) mentioned that addition of sand in brick able to reduce the drying shrinkage and oppose the shrinkage movement. Thus, the lesser the sand, the lower the ability of the brick to resist shrinkage.

At 28 days, the compressive strength development trend in all the bricks with AD replacement declined compared to 14 days except for the control specimen. The main reason for the strength loss is the heat and gas released from the hydrolysis reaction of AlN with water. Since the hydrolysis reaction is exothermic, excessive heat is released to dry up the water available for cement hydration. At the same time, pores are created by the NH_3 gas released by the hydrolysis of AlN. Since ammonia is soluble, it dissolved in water to form NH_4^+ and OH^-. The abundance of OH^- caused an increase in pH that leads to the degradation of hydroxide or oxide protective layer known as $Al(OH)_3$, which is insoluble in water (Milinchuk et al., 2016). The degradation released the unreacted AlN present in AD to continue the hydrolysis reaction and contribute to the pore formation. In addition, the hydrogen gas is emitted from the reaction between the Al ions present in the AD and OH^- in the water (David and Kopac, 2012). The equation of reaction is shown in the Equation 4.3.

$$2Al + 6H_20 \rightarrow 2Al(OH)_3 + H_2 + Heat \qquad (4.3)$$

Eventually, the pores are created as the gas is released, which causes the compressive strength to decrease over time. For the time being, the cement hydration and pozzolanic reaction fill up the pores. However, the compressive strength is still decreased due to the rate of pore filling being much slower than the rate of pore created from the AlN hydrolysis.

According to Malaysia Standard MS 76:1972, the minimum compressive strength for CSB used as construction masonry is 7 N/mm^2. Although incorporating AD in CSB could not enhance the compressive strength, all the specimens at 28 days could achieve the minimum compressive strength required in the standard. Therefore, sand replacement using AD is workable for up to 25% of sand replacement since it can still achieve the minimum strength required.

4.5 Flexural Strength

Table 4.5 and **Figure 4.6** showed the average flexural strength of CSB specimens with different curing ages. The flexural strength development trends of CSB specimens throughout the 28 days curing period are shown in **Figure 4.7**.

Table 4.5: Flexural Strength of Cement Sand Brick Specimen.

Specimen	**Flexural Strength (N/mm^2)**		
	7 days	14 days	28 days
XR	2.510	3.160	4.240
5R	3.520	3.638	2.981
10R	3.240	3.350	2.733
15R	2.000	2.403	1.710
20R	1.356	1.781	0.966
25R	1.267	1.503	0.846

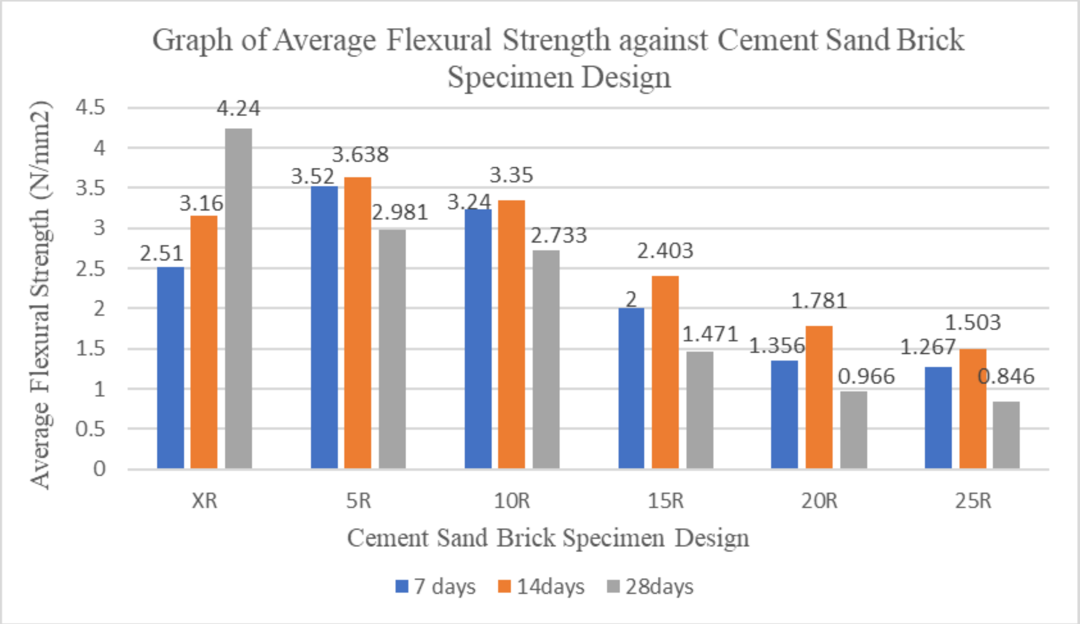

Figure 4.6: Graph of Average Flexural Strength against Cement Sand Brick Specimen Design.

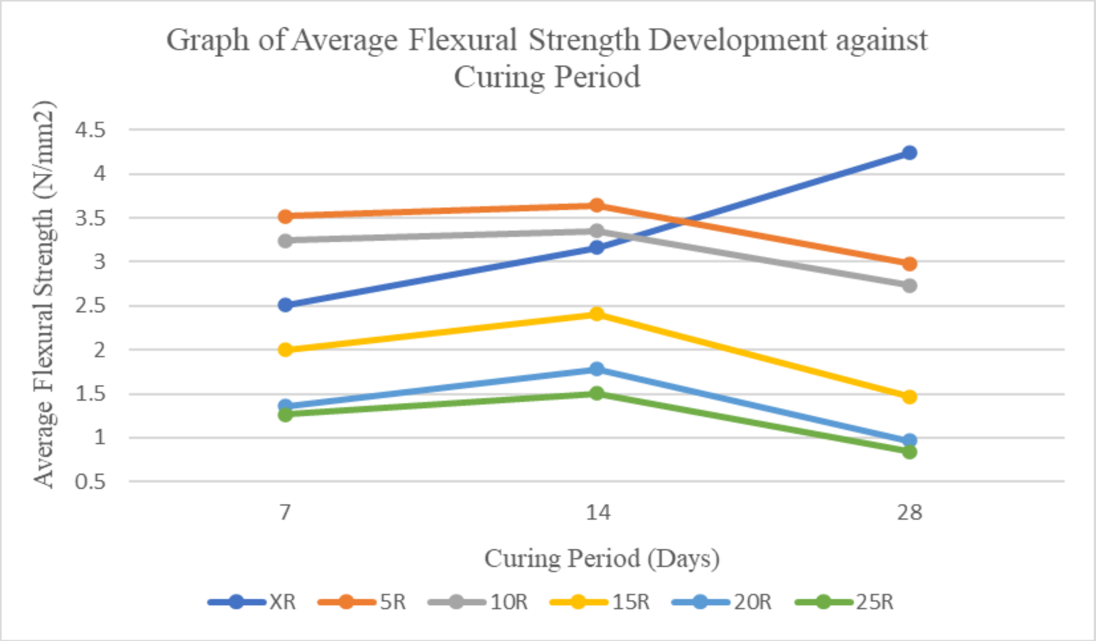

Figure 4.7: Graph of Average Flexural Strength Development Trend.

Figure 4.7 shows two trends in porosity development in CSB specimens as the substitution increases. On day 14 days, from 5R to 25R, there is an inclining trend in flexural strength. The trend then turned into an inclining trend at 28 days. The trend of flexural strength is similar to the trend developed in compressive strength.

The fineness of AD and the formation of C-S-H and C-A-H gel contributed to the declining porosity in 14 days of curing. The improvement in porosity is because of the fineness of the AD, which can act as a filler to close up the pores in the CSB. Since AD contains a large amount of Al_2O_3, enough alumino-siliceous compound is provided to react with CaO from cement to form C-S-H gel and C-A-H gel (Arthur Michael, 2019). As AlN contacts water, amorphous aluminium hydroxide (AlOOH) is formed. It hinders the hydrolysis of AlN by forming a white insoluble layer of film. As it ages, crystallization converts AlOOH into aluminium hydroxide ($Al(OH)_3$). The crystal products generated from hydrolysis of AlN are stable at a pH range of 5.5 to 8.0 (Kocjan, Krnel, and Kosmač, 2008). Consequently, pores are reduced by forming crystal products, enhancing flexural strength.

The flexural strength of 5R to 25R specimens plunged upon reaching the age of 28 days. The decrease in flexural strength can be explained by the ammonia gas produced from the hydrolysis of AlN dissolved in water to form NH_4^+ and OH^- because of its water solubility. As time is prolonged, the pH rises because of OH^- accumulation. Once pH reached 9.5 and 12, the solubility of crystal products, $Al(OH)_3$, improved, leading to the degradation of the barrier layer. The unreacted AlN further undergoes hydrolysis, exposing the pores previously filled by the crystal products and forming more pores. In addition, the hydrogen gas emitted from the reaction between the Al ions present in the AD and OH^- in the water (David and Kopac, 2012) lower the flexural strength by contributing to the formation of pores.

At 14 days, 5R had a 15% higher strength, while 10R achieved 6.01% higher than the XR. The increase in strength indicated the incorporation of AD able to close up the voids between sand particles and enhance the bonding between the particles and cement. This is credited to forming C-S-H and C-A-H gels that bind the particles together to reduce the porosity of brick specimens. Since there is less pore, the specimen can achieve higher flexural strength. The plunge in flexural strength is due to the increase of the AlN contents in AD, corresponding to the generation of the NH_3 gas, which then leads to the formation of the pores.

Meanwhile, there is also hydrogen gas produced that contributes to pores formation. These two reactions are exothermic and release heat. The hydrolysis reaction rate speeds up at high temperatures compared to at room temperature (Lv et al., 2020). Hence, it can be concluded that the pore filling rate from the cement and pozzolanic reaction is much slower than the pore created by the AlN hydrolysis. Another possible reason to justify the decrease of strength as the percentage of AD increased was the poor bonding because of insufficient sand in the brick specimen. Sand's rough, irregular shape contributes to the bonding by providing mechanical engagement force. Riza and Rahman (2015) mentioned that adding sand to brick can reduce the drying shrinkage and oppose the shrinkage movement. Thus, the lesser the sand, the lower the ability of the brick to resist shrinkage, causing the flexural strength to drop.

According to British Standard BS 6073 Part 1:1981, the minimum flexural strength for CSB used as construction masonry is 0.65 N/mm^2. Although incorporating AD in CSB could not enhance the flexure strength, all the specimens at 28 days could achieve the minimum flexural strength required in the standard. Therefore, sand replacement using AD is feasible for up to 25% of sand replacement since it can still achieve the minimum strength required.

4.6 Bulk Density

This research measured the bulk density of CSB specimens on the 28th day of the curing period. The results obtained are summarised in Table 4.6 and Figure 4.8.

Table 4.6: Bulk Density of Cement Sand Brick Specimen.

Specimen	Bulk Density on the 28th day (kg/m^3)
XR	1901.21
5R	1809.12
10R	1786.81
15R	1782.61
20R	1769.12
25R	1750.33

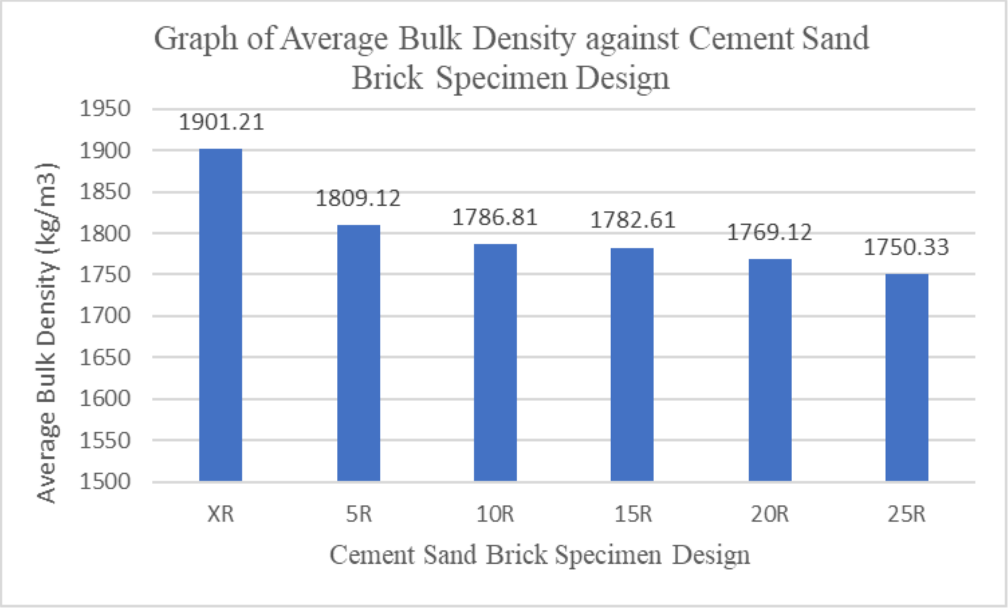

Figure 4.8: Graph of Average Bulk Density against Cement Sand Brick Specimen Design at 28th Day.

All the CSB specimens with AD substitution had a lower bulk density than the XR specimen. The bulk density decreased as the AD replaced more sand. As referred to in Figure, the highest average bulk density for CSB with AD was 5R which achieved a value of 1809.12 kg/m^3, while the lowest average bulk density was 1750.33 kg/m^3 obtained by 25R. The decrease in bulk density was mainly due to the porosity of the specimens. The pores and voids were created by the gas released from AlN hydrolysis and the hydrogen gas from the reaction between Al and OH^-. As the percentage of AD surged, it caused more ammonia and hydrogen gases, further increasing the voids and lowering the bulk density. Another possible reason to explain the reduction in bulk density was the replacement of sand which has a specific density of 1600kg/m^3 (Mahajan, n.d.), by AD, which a specific density range between 828 kg/m^3 to 1180 kg/m^3 (Wibner, Antrekowitsch, and Meisel, 2021). Since AD is less dense than sand, it can reduce the bulk density when incorporated into the CSB specimen. This can justify the drop in bulk density as the increase in the replacement of sand by AD.

Based on Malaysia Standard MS 76: 1972, the bulk density of CSB should be 1300 kg/m^3 to 2200 kg/m^3. All the CSB specimens with AD substitution fell within the range and had met the requirement in the standard. 25R is the optimum CSB specimen since it has the lowest bulk density and is lighter, which is preferred in the construction sector.

4.7 Water Absorption

The average water absorption of CSB specimens with different curing ages is shown in **Table 4.7** and **Figure 4.9**. The average water absorption development trends of CSB specimens throughout the 28 days curing period are shown in **Figure 4.10**.

Table 4.7: Water Absorption Rate of Cement Sand Brick Specimen.

Specimen	**Water Absorption Rate (%)**		
	7 days	14 days	28 days
XR	9.120	8.520	7.920
5R	8.270	8.050	9.420
10R	8.360	8.100	9.580
15R	11.400	11.220	12.680
20R	14.250	13.980	15.110
25R	15.770	15.210	17.560

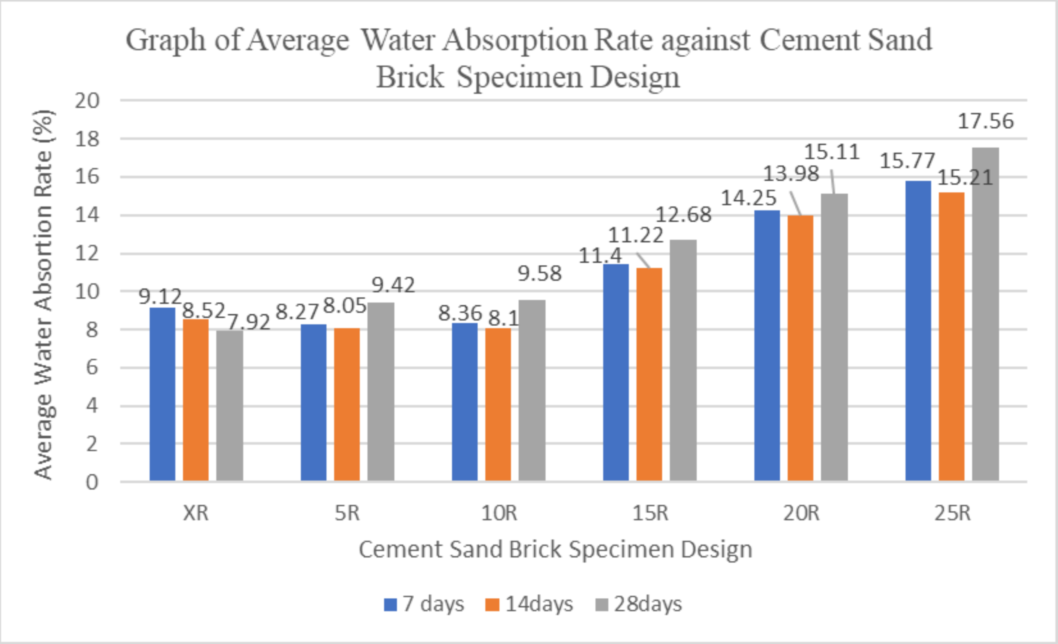

Figure 4.9: Graph of Average Water Absorption Rate against Cement Sand Brick Specimen Design.

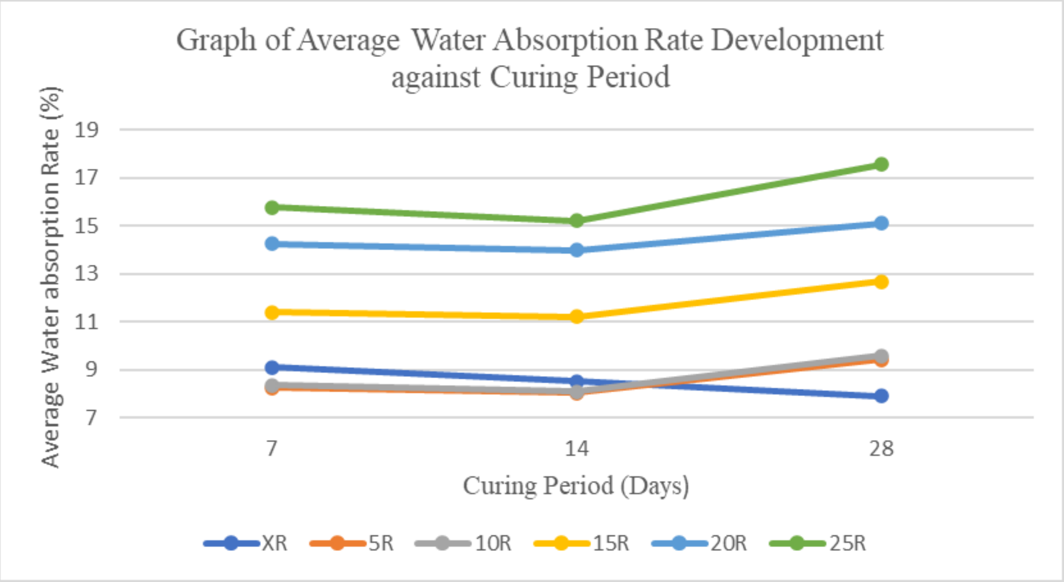

Figure 4.10: Graph of Average Water Absorption Rate Development Trend.

Based on the Figures 4.9 and 4.10, the average water absorption rate for all the specimens with AD substitution decreased at 7 days and 14 days but increased upon reaching the age of 28 days. The decrease in water absorption during the first 14 days was mainly because of the fineness of AD, which can act as a filler to fill the pores. The filling of pores reduces the spaces for the water to keep on the brick structure, thus, lowering the capability to absorb the water. The formation of C-S-H gel and C-A-H gel from the pozzolanic reaction between the alumino-siliceous compound and CaO further enhances the pore filling process. Since AlN is present in AD, it hydrolyses to form amorphous aluminium hydroxide (AlOOH), also called pseudoboehmite, when contacting water (Kocjan, Krnel, and Kosmač, 2008). The AlOOH is insoluble in water and acts as a protective layer to prevent AlN from further reaction. Thus, the hydrolysis rate is slowed down. Later, crystallisation occurs, which converts AlOOH to aluminium hydroxide ($Al(OH)_3$). Kocjan, Krnel, and Kosmač (2008) also mentioned that the crystal product generated from hydrolysis of AlN is stable at a pH range of 5.5 to 8.0. Hence, the crystals formed help reduce the pores and the water absorption rate.

Upon reaching the age of 28 days, the water absorption rate of all specimens with AD substitution increased. The hydrolysis of AlN yields ammonia gas which dissolves in water to form NH_4^+ and OH^-. OH- then increases the water's pH. The solubility of $Al(OH)_3$ increases as the pH reaches 9.5 and 12 (Kocjan, Krnel, and Kosmač, 2008). The dissolution of the barrier layer released unreacted AlN to undergo hydrolysis further. Due to destruction, the pores originally filled up by the $Al(OH)_3$ had been exposed, which further increased the porosity. The NH_3 gas released creates pores that absorb water. In addition, the hydrogen gas emitted from the reaction between the Al ions present in the AD and OH^- in the water (David and Kopac, 2012) also contributed to the formation of pores.

At the age of 14 days, 5R achieved a 5.51% lower water absorption rate while 4.93% lower in 10R as compared to the XR. The low water absorption indicated the incorporation of AD able to fill up the voids between sand particles and enhance the bonding between the particles and cement. This is credited to the formation of C-S-H and C-A-H gels that bind the particles together to reduce the ability of brick specimens to absorb water. As the replacement percentage increased from 15% to 25%, the CSB specimens showed a higher water absorption rate. The increase in water absorption is due to the increase of the AlN contents in AD, corresponding to the generation of the NH_3 gas then leads to the formation of the pores. Meanwhile, there is also hydrogen gas produced that contributes to pores formation. These two reactions are exothermic and release heat. The hydrolysis reaction rate speeds up at high temperatures compared to at room temperature (Lv et al., 2020). Hence, it can be concluded that the pore filling rate from the cement and pozzolanic reaction is much slower than the pore created by the AlN hydrolysis.

As for water absorption rate, no special requirement is found in MS 76:1972 and BS 3961:1976. EN 771-3 stated that the water absorption rate standard only applies to masonry that is not protected by the finishing. Based on India Standard IS-1077:1992, the water absorption rate should be less than 20%. Although incorporating AD in CSB could not enhance the water absorption rate, all the specimens at 28 days were still within the water absorption rate, as required in the standard. 5R specimen is optimum on water absorption among the other specimens with AD replacement. Therefore, sand replacement using AD is feasible for up to 25% of sand replacement since it can still fulfill the standard required.

4.8 Porosity

Table 4.8 and **Figure 4.11** showed the average porosity of CSB specimens with different curing ages. Moreover, the average porosity development trends of CSB specimens throughout the 28 days curing period are shown in **Figure 4.12**.

Table 4.8: Porosity of Cement Sand Brick Specimen.

Specimen	**Porosity (%)**		
	7 days	14 days	28 days
XR	16.69	15.01	14.39
5R	14.92	14.21	16.83
10R	15.81	14.63	17.28
15R	17.10	16.44	20.14
20R	17.80	17.24	21.55
25R	19.25	18.39	22.87

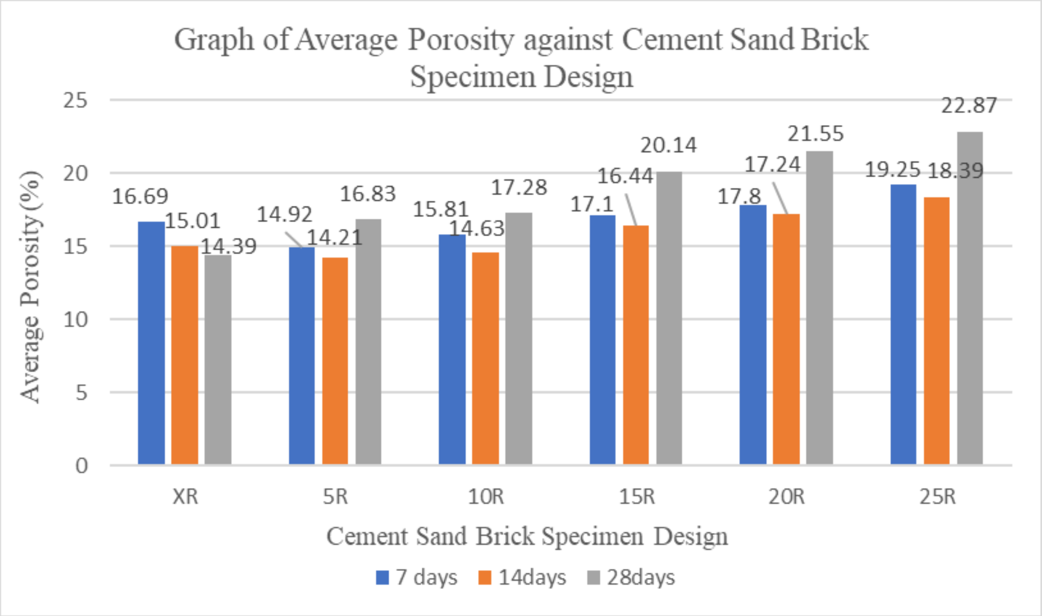

Figure 4.11: Graph of Average Porosity against Cement Sand Brick Specimen Design.

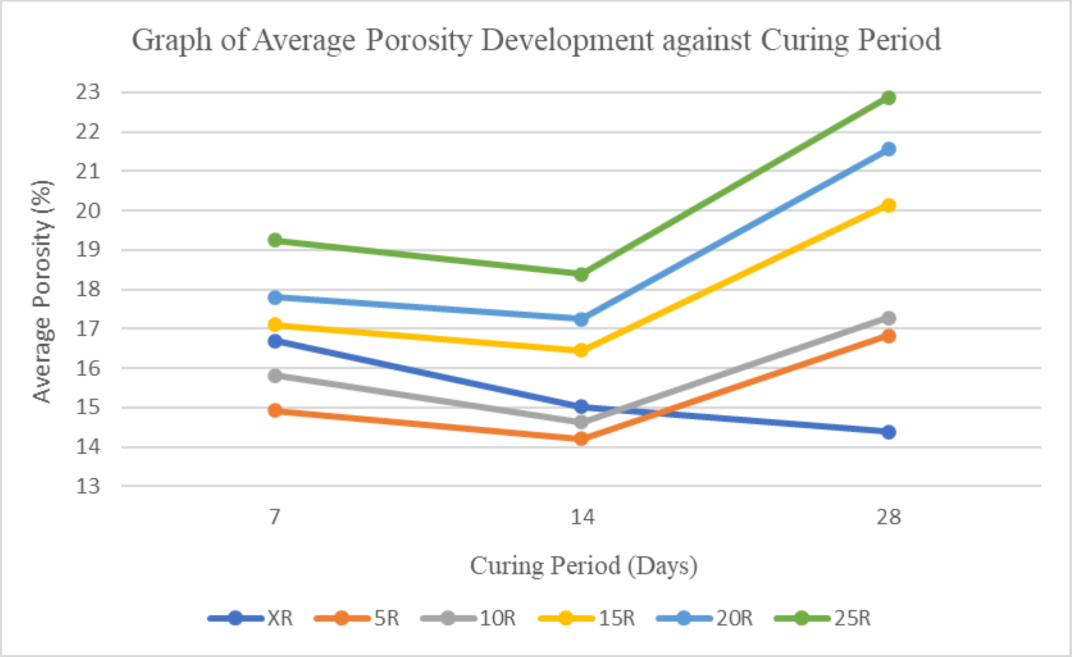

Figure 4.12: Graph of Average Porosity Development Trend.

Figures 4.11 and 4.12 showed two trends in porosity development in CSB specimens as the substitution increases. On day 14 days, from 5R to 25R, there is a declining trend in porosity. The trend then turned into an inclining trend at 28 days. Mailar, G et al. (2016) mentioned that water absorption is governed by porosity, as it provides the pathway for fluid movement in specimens. Therefore, both trend is similar to each other.

The fineness of AD and the formation of C-S-H and C-A-H gel contributed to the declining porosity on 14 days of curing. The improvement in porosity is due to the fineness of the AD, which can act as a filler to close up the pores in the CSB. Since AD contains a large amount of Al_2O_3, enough alumino-siliceous compound is provided to react with CaO from cement to form C-S-H gel and C-A-H gel (Arthur Michael, 2019). As AlN contacts water, amorphous aluminium hydroxide (AlOOH) is formed. It hinders the hydrolysis of AlN by forming a white insoluble layer of film. As it ages, crystallization converts AlOOH into aluminium hydroxide ($Al(OH)_3$). The crystal products generated from hydrolysis of AlN are stable at a pH range of 5.5 to 8.0 (Kocjan, Krnel and Kosmač, 2008). Consequently, pores are reduced with the formation of crystal products.

Ammonia gas is produced from the hydrolysis of AlN and is soluble in water to form NH_4^+ and OH^-. The porosity of 5R to 25R specimens surged upon reaching the age of 28 days. As time is prolonged, the pH rises due to OH^- accumulation. Once pH reached 9.5 and 12, the solubility of crystals products, $Al(OH)_3$, improved, leading to the degradation of the barrier layer. The unreacted AlN further undergoes hydrolysis, exposing the pores previously filled by the crystal products and forming more pores. In addition, the hydrogen gas emitted from the reaction between the Al ions present in the AD and OH^- in the water (David and Kopac, 2012) also contributed to the formation of pores.

As compared to the XR, 5R had a 5.33% lower porosity while 2.53% lower in 10R at 14 days. The low porosity indicated the incorporation of AD able to fill up the voids between sand particles and enhances the bonding between the particles and cement. This is credited to forming C-S-H and C-A-H gels that bind the particles together to reduce the porosity of brick specimens. The increase in water absorption is due to the increase of the AlN contents in AD, corresponding to the generation of the NH_3 gas then leads to the formation of the pores. Meanwhile, there is also hydrogen gas produced that contributes to pores formation. These two reactions are exothermic and release heat. The hydrolysis reaction rate speeds up at high temperatures compared to at room temperature (Lv et al., 2020). Hence, it can be concluded that the pore filling rate from the cement and pozzolanic reaction is much slower than the pore created from the AlN hydrolysis.

No specific value for CSB's porosity is indicated in any of the standards. The water absorption rate standard mentioned by India Standard IS-1077:1992 can be used as a reference value for porosity since porosity governs the water absorption rate. We can conclude that all specimens are within the conventional range of porosity. As mentioned above, incorporating AD did not enhance the porosity of CSB specimens. 5R specimen is optimum on porosity among the other specimens with AD replacement. Therefore, sand replacement using AD is feasible for up to 25% of sand replacement since it is still within the required range.

4.9 Microstructure Analysis

In this research study, Field Emission Scanning Electron Microscopy (FESEM) analysis is conducted to analyse the microstructure of the CSB specimens with different percentages of AD substitution.

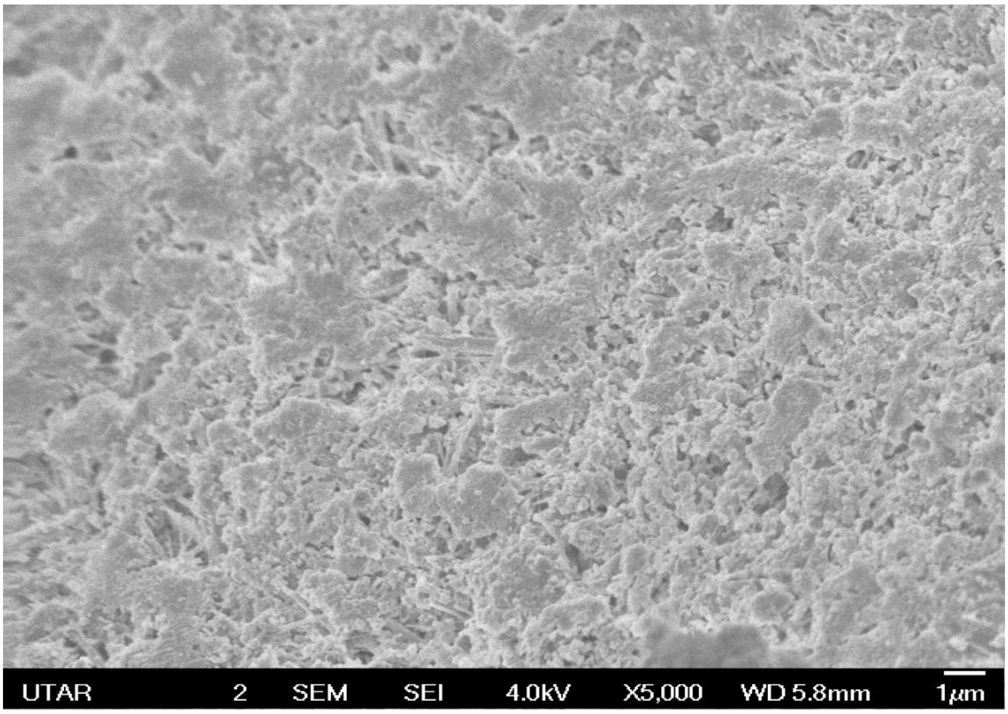

Figure 4.13: FESEM Image of Specimen CS.

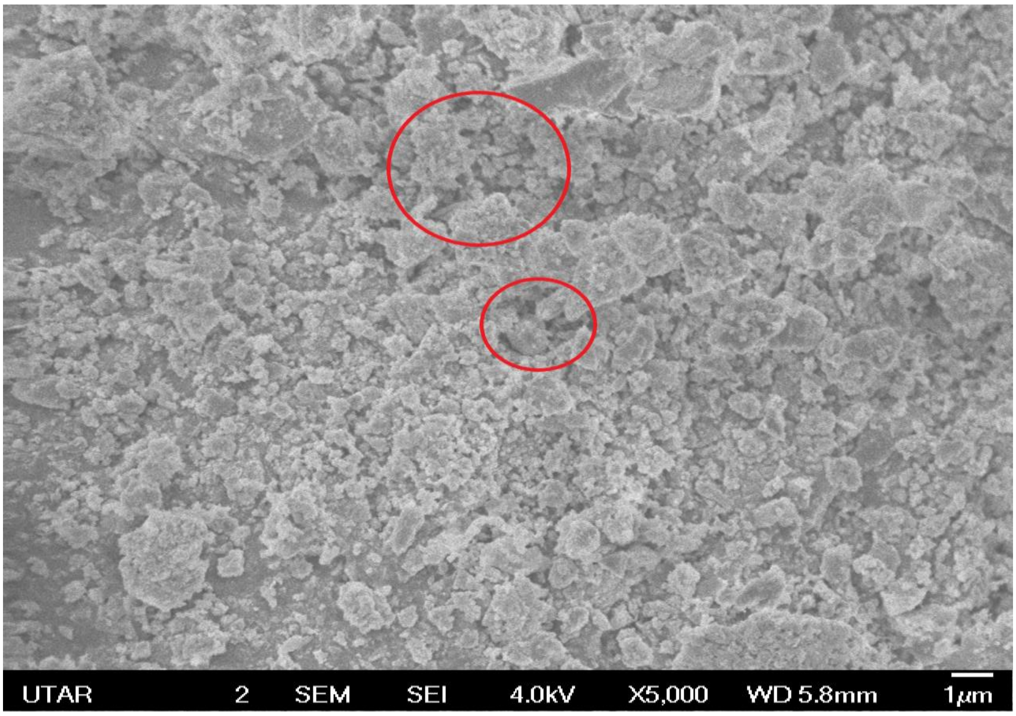

Figure 4.14: FESEM Image of Specimen 5R.

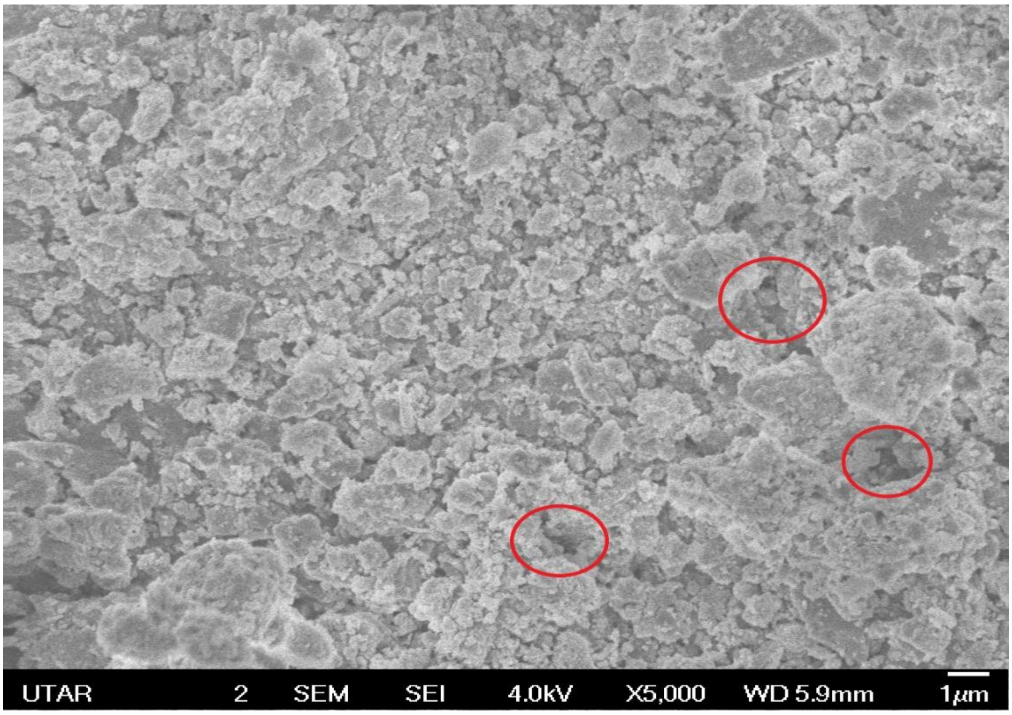

Figure 4.15: FESEM Image of Specimen 10R.

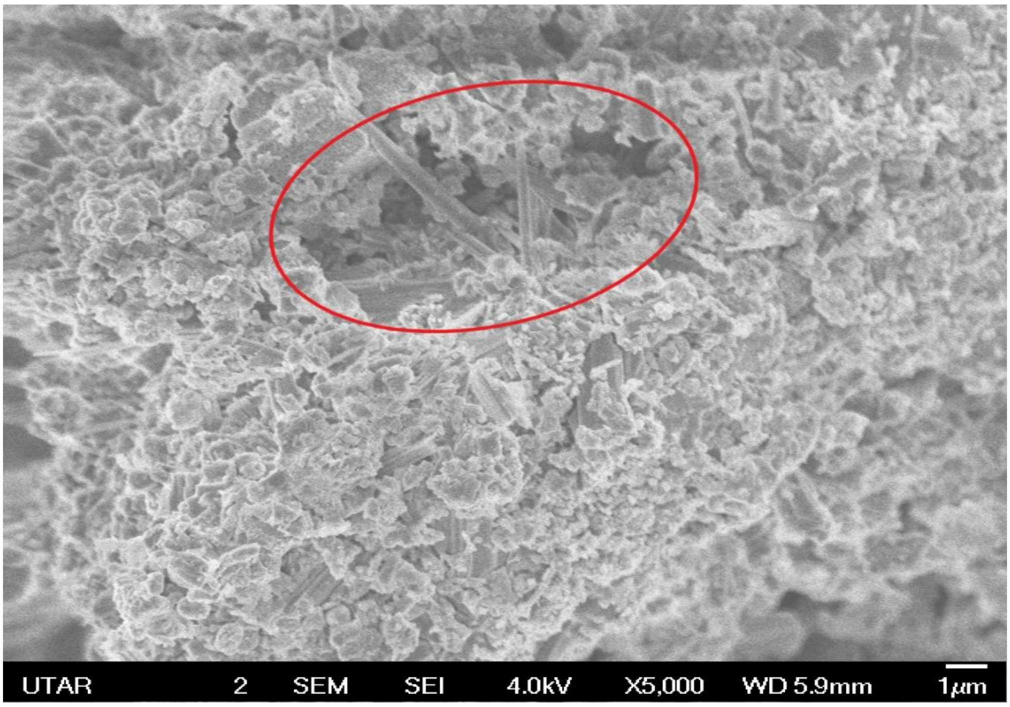

Figure 4.16: FESEM Image of Specimen 15R.

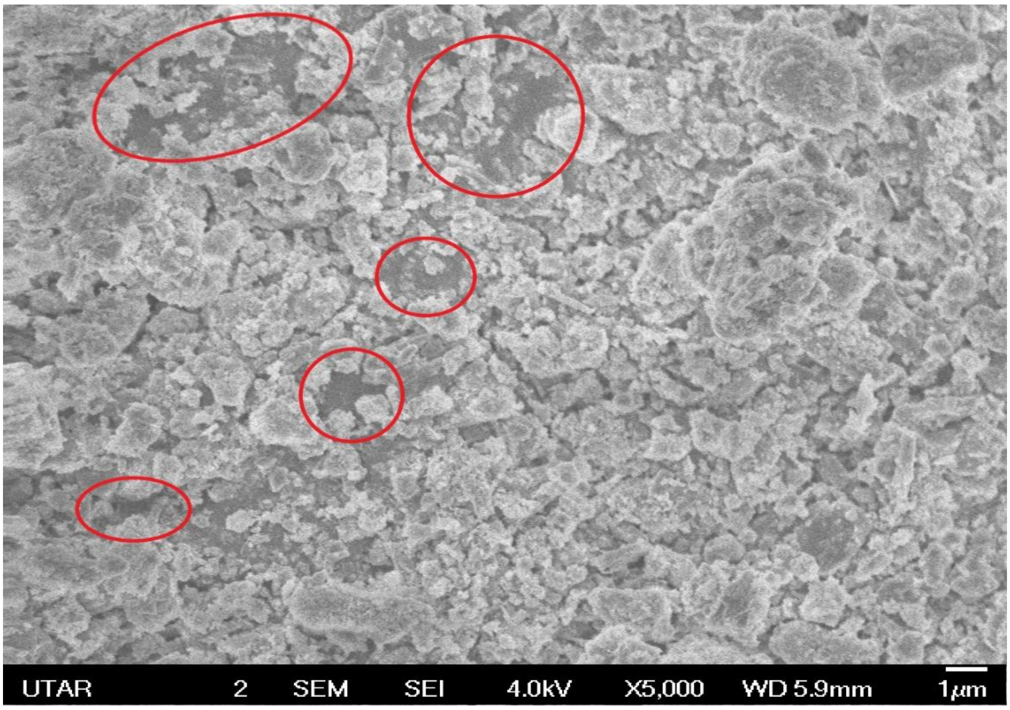

Figure 4.17: FESEM Image of Specimen 20R.

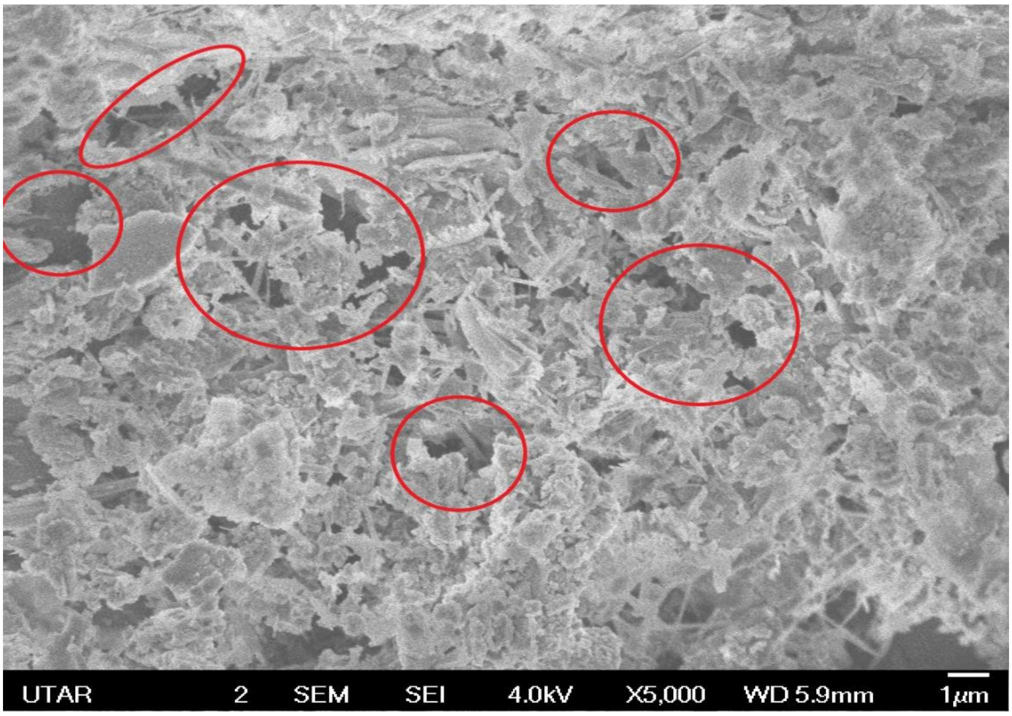

Figure 4.18: FESEM Image of Specimen 25R.

Figures 4.13 showed the SEM image with 5000x magnification for the XR specimen at 28 days without incorporating AD. As can see from the image, a packed and homogeneous microstructure with a few pores and voids was observed. The compact microstructure proved that forming C-S-H or C-A-H gels provides a good bonding between the sand particles.

Pores and voids greatly impact a brick specimen's compressive strength, flexural strength, and water absorption rate. Figures 4.13 to 4.18 showed the SEM image for the age of 28 days of CSB specimens with different AD substitutions from 5% to 25%. From the SEM images, the number of pores and voids increased as more sand was substituted with AD. The compressive and flexural strength decreased while the water absorption rate increased from 5R to 25R as the pores and voids increased. The development trend indicated the pores created by the effect of continuous hydrolysis of AlN released ammonia gas and the hydrogen gas generated from the reaction of Al ions and OH^- in the water.

Among the specimens with AD substitution, 5R is the optimum specimen selected based on the observation of the SEM images due to its denser microstructure and fewer pores and voids than other specimens.

4.10 Leachability of Metal Ions from Cement Sand Brick

In this research study, a metal ions leaching test is conducted to determine the concentration of metal ions that leaked from the brick into the environment. Compliance of the leachate to the Environmental Quality (Industrial Effluent) Regulations 2009 will be checked. Table 4.9 showed the concentration of 9 types of metal ions that leached out.

Based on the table 4.9, the highest concentration of metal ions being leached out was the Aluminium ion (Al), followed by iron (Fe), Chromium (Cr), Zinc (Zn), Manganese (Mn), and Copper (Cu). The other three metal ions that were not detected were Cadmium (Cd), Lead (Pb), and Nickel (Ni). It can be observed from the table that the XR specimen leaked out 3.659 mg/L of Al and 0.058 mg/L of Fe, although there was an absence of AD. The increasing AD substitution led to more metal ions from the brick specimen. All the leachates generated from the specimens that contained AD had met the acceptable discharge of industrial effluents limit in the Standard A requirement except for the Al leached by the 15R and 20R specimens. Although the concentration of Al exceeded the limit in Standard A, the specimens were still within the limit stated by Standard B other than 25R. The concentration of Al in the leachate from the 25R specimen had exceeded both Standard A and Standard B; thus, it is not allowed to be used in the construction field. To conclude, the 10R specimen is the optimum as the leachate produced had met all the limits stated and was not harmful to humans and the environment.

Table 4.9: The concentration of metal ions that leached out from the brick specimens.

Types of metal ions	Concentration (mg/L)							
	Standard A	**Standard B**	XR	5R	10R	15R	20R	25R
Aluminium, Al	**10.00**	**15.00**	3.659	6.884	9.109	12.377	14.099	15.558
Cadmium, Cd	**0.01**	**0.02**	Not Detected					
Chromium, Cr	**0.05**	**0.05**	0.007	0.007	0.010	0.038	0.041	0.052
Copper, Cu	**0.20**	**1.00**	0.0031	0.0064	0.0084	0.010	0.014	0.016
Iron, Fe	**1.00**	**5.00**	0.058	0.283	0.308	0.440	0.615	0.768
Lead, Pb	**0.10**	**0.50**	Not Detected					
Manganese, Mn	**0.20**	**1.00**	0.004	0.0042	0.0051	0.0056	0.006	0.0064
Nickel, Ni	**0.20**	**1.00**	Not Detected					
Zinc, Zn	**2.00**	**2.00**	ND	ND	ND	0.0015	0.0026	0.0038

4.11 Comparative Evaluation of Fabricated Cement Sand Brick

Based on Table 4.10, most of the CSB specimens with AD substitution had passed the standard required for each property, including compressive strength, flexural strength, water absorption rate, bulk density, and metal ions leaching. The leachate produced by the 25R specimen is the only specimen that failed to meet Standard A & B in Environmental Quality (Industrial Effluent) Regulations 2009. In the leachate, the Al ions exceeded the Standard B requirement; hence, it is unsuitable to be marketed, although the other properties had passed the requirements. Among all the specimens with AD substitution, the 20R specimen is the optimum specimen that fulfills all the requirements and achieves the highest replacement of sand. Since 20R has the highest replacement, it is more cost-friendly than other specimens.

Table 4.10: Comparison Between Standard Requirements and Fabricated Cement Sand Brick Specimens.

Properties	**Standard Requirement**	**CSB Specimens**					
		XR	5R	10R	15R	20R	25R
Compressive Strength (N/mm^2)	>7 N/mm^2 (MS 76:1972)	22.078	17.796	15.738	11.130	8.913	7.108
Flexural Strength (N/mm^2)	> 0.65 N/mm^2 (BS 6071 Part 1:1981)	4.24	2.981	2.733	1.471	0.966	0.846
Bulk Density (kg/m^3)	1300 – 2200 kg/m^3 (MS 76:1972)	1901.21	1809.12	1786.81	1782.61	1769.12	1750.33
Water Absorption (%)	<20% (IS-1077:1992)	7.92	9.42	9.58	12.68	15.11	17.56
Leaching of metal ions	Standard A & B in Environmental Quality (Industrial Effluent) Regulations 2009	Passed	Passed	Passed	Passed	Passed	Failed (Al > Standard B)

4.12 Economic Appraisal

Table 4.11: Cost Comparison Between AD Treatment and AD Disposal.

	AD Treatment Cost			**AD Disposal Cost**	**Difference (RM)**	**Difference (%)**
Composition	Price per unit (RM)	Unit	Total (RM)			
NaOH	0.0104	26.4 g	0.2746			
Electricity (Treatment & Drying)	0.0003	660 g	0.1980			
Total Cost			**0.4726**	**0.99**	**0.5174**	**52.26**

* The NaOH cost was from (KS Hardware & Engineering, n.d.).
* The electricity consumption of equipment was from (Electric heating mixing tank, n.d.)
* The electricity cost was from the website of Tenaga Nasional Berhad.
* The disposal cost for AD was from KYH Recycle Industries Sdn Bhd.

Table 4.12: Cost Comparison Between One Unit CSB XR and 20R.

		XR		**20R**		**Difference (%)**
Composition	Price per unit (RM)	Unit	Total (RM)	Unit	Total (RM)	
Sand	0.037	2.244 kg	0.083	1.584 kg	0.0586	**29.40**
Cement	0.33	0.66 kg	0.2178	0.66 kg	0.2178	-
Water	0.0012	0.396 kg	0.00005	0.396 kg	0.00005	-
Electricity (Mixing & Dross Treatment)			0.4730		0.4730	-
Total Cost			**0.7739**		**0.7495**	**3.15**

* The sand cost was from (Building Materials Online, n.d.).
* The cement cost was from (AKTC eWarehouse Home Improvement Store, n.d.).
* The water cost was from the website of Lembaga Air Perak.
* The electricity cost was from the website of Tenaga Nasional Berhad.

Table 4.13: Cost Comparison Between One Unit CSB 20R and CSB In Market.

	20R			**CSB in Market**	**Difference (RM)**	**Difference (%)**
Composition	Price per unit (RM)	Unit	Total (RM)	**Selling Price**		
Sand	0.037	1.584 kg	0.0586			
Cement	0.33	0.66 kg	0.2178			
Water	0.0012	0.396 kg	0.00005			
Electricity (Mixing & Dross Treatment)	-	-	0.4730			
Minus: Cost Saving from AD Disposal			0.5174			
Total Cost			**0.2321**	**0.365**	**0.1329**	**36.41**

* The sand cost was from (Building Materials Online, n.d.).
* The cement cost was from (AKTC eWarehouse Home Improvement Store, n.d.).
* The water cost was from the website of Lembaga Air Perak.
* The electricity cost was from the website of Tenaga Nasional Berhad.

As there is a treatment for AD, the cost comparison between treatment cost and disposal cost of AD is needed and shown in Table 4.11. The disposal cost of AD given by KYH Recycle Industries Sdn Bhd is RM 1500 per ton. The disposal cost for the amount of AD used in the 20R specimen is RM 0.99. Assuming an electric heating mixing tank LH-EMT with a capacity of 500L was used for AD treatment, the electricity cost for fabrication of one 20R specimen is RM 0.4730. The NaOH used costs RM 0.2746. The total treatment cost is RM 0.4726, which saved 52.27% or RM 0.5174 compared to the disposal cost. Hence, the treatment of AD can help in cost savings for the company.

In this economical appraisal, the cost of manufacturing one unit of CSB XR specimen is RM 0.7739, while RM 0.7495 is for a 20R specimen. The replacement of sand using AD can save 28.92% of the sand cost compared to XR, as shown in Table 4.12. However, the selling price of one unit of CSB in the market is RM 0.30 per unit with a dimension of 215mm x 100mm x 65mm quoted by AKTC eWarehouse Home Improvement Store. After interpolation of the dimension to be the same as the 20R specimen, the price for the conventional CSB is RM 0.365 per unit. Compared to the market selling price, the production cost of one unit 20R specimen is RM 0.7495 more than the selling price of conventional CSB. But, the cost was actually reduced to RM 0.2321 after considering the cost saved from the disposal cost. The 20R specimen costs 36.41% cheaper than the conventional CSB in the market. Therefore, the treatment of AD is feasible to produce and can lower the production cost and reduce the hazardous AD going into the landfill.

4.13 Estimation of CO_2 Emission

Table 4.14: CO_2 Emission of One Unit of CSB XR Specimen and 20R Specimen.

CO_2 Emission	**Specimen**		**Difference (%)**
	XR	20R	
Sand (5.51 kg/ton)*	0.01237	0.008728	29.44
Cement (900 kg/ton)*	0.5940	0.5940	-
Total Emission (kg)	0.6064	0.6027	0.610

* The CO_2 emission data of sand was from (National Stone Sand & Gravel Association, 2021).
* The CO_2 emission data of cement was from (Fayomi, Mini, Fayomi, and Ayoola, 2019).

Table 4.14 showed the total carbon dioxide emission from the production of one unit of CSB specimen. 0.6064 kg of CO_2 will be emitted from the production of one unit XR specimen, while 0.6027 kg of CO_2 from 20R specimen. Although there is only a 0.61% reduction in CO_2 emission in 20R as XR, there is a decrease of 29.44 % of CO_2 emission from sand usage contributed by 20R.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this research project, the objectives listed in the beginning were achieved successfully. Most of the cement sand brick (CSB) with and without treated aluminium dross (AD) substitution had achieved the standard and requirement of the brick industry. Several laboratory tests have been conducted to evaluate the CSB mechanical properties, durability, and environmental impact. Thus, the outcome of this research could be summarised as below:

1. Treatment of AD is necessary before incorporating it into the CSB to remove the hazardous compound, AlN, which is reactive and sensitive to moisture and water. Without treatment, the excessive heat released from the AlN hydrolysis will harm the strength of CSB. AD treatment is able to save RM 783.94 or 52.27% of the cost for each ton of AD disposed into the landfill.
2. Substitution of treated AD cannot improve the mechanical properties and durability of CSB since the hydrolysis of AlN emits ammonia gases, creating pores that are detrimental to its strength and durability.
3. 20R specimen has the most optimum sand replacement percentage as it fulfills the compressive strength, flexural strength, water absorption rate, bulk density, and leachability of metal ions stated in the standard.

4. The 20R specimen still costs 36.41% cheaper than the conventional CSB in the market after the additional AD treatment. Thus, the low production cost, makes CSB more competitive in the market.

Since treated AD is less harmful, the presence of AlN is still giving a huge impact on the strength and durability of CSB. This research project proved that AD replacement is detrimental to strength. Although some specimens are still able to achieve the strength required, the long-term strength development of CSB with treated AD is questionable. On the other hand, the fabrication of CSB with AD substitution for sand replacement is an initiative to achieve zero hazardous waste and turn waste into sustainable products that facilitate the circular economy.

5.2 Recommendations

There are several recommendations for the future fabrication of CSB are proposed as stated below:

1. Deeply evaluate the long-term mechanical properties, durability, and environmental impacts of the CSB substituted with treated AD.
2. Deeply investigate the properties and mechanism of AlN in the AD hydrolysed when in contact with water.
3. Determine the mechanical properties and durability of CSB using the natural air curing method.
4. Determine the other possibilities for usage of AD, such as hydrogen gas production, ammonia-based fertilizer, and heat energy harvest other than incorporated in brick.
5. Conduct further research on the feasibility of cement replacement using treated AD.

The abovementioned recommendations are based on the experiences gained from the research study. These suggestions might be helpful for future research relevant to this topic.

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