MANUFACTURING OF COMPRESSED STABILIZED EARTH BRICKS (CSEB) USING ALUMINIUM DROSS

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

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DECLARATION

I hereby declare that project report is based on my original work except for citation and quotation which have been duly acknowledge. 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 **"MANUFACTURING OF COMPRESSED STABILIZED EARTH BRICKS (CSEB) USING ALUMINIUM DROSS."** was prepared by **LOO YI XIN** 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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Supervisor : Ir. Ts. Dr. Leong Kah Hon

Date : 22 April 2022

Specially dedicated to

my beloved grandmother, mother and father

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ABSTRACT

Carbon dioxide (CO_2) is a greenhouse gas whose atmospheric concentration is increased year by year and reflects a significant impact on the global. Compressed stabilized earth block (CSEB) is one of the masonries units, which is energy-efficient, high strength and environmentally friendly as compared to fired brick. Cement is the major stabilizer in casting CSEB, but cement manufacturing factory is one of the major emission sources of CO_2. At the same time, the growth of population all over the world, it indicates the growth of the various type of factories. However, the growth of factories not only brings the growth in the economy but also the challenges disposal of waste generated safely for the ecological balance. In addition, aluminium factories are the major source of aluminium dross (AD) generation. It is a challenge to safely dispose of AD because it is considered a hazardous waste that will reflect a lot of environmental issues and even human health problems. The most common way to dispose of is through landfill, but leachate from the landfill might bring a lot of disadvantages to the environment and affect humans indirectly. Hence, to solve the issues due to cement used in CSEB and AD, AD is suggested to replace the cement used in CSEB fabrication. It can reduce the cement usage and also solve the amount of AD to be disposed of.

The objectives of this research are (i) to fabricate CSEB with partial replacement of cement by aluminium dross powder for sustainable purpose, (ii) to evaluate the engineering properties and durability of the fabricated CSEB and (iii) to elucidate the feasibilities of aluminium dross as part of the cement substitution in CSEB. The cement replacement percentage for this research was ranging from 0 to 35 % of AD. All the CSEB specimens with 28 days of curing process were tested to identify their engineering properties through bulk density test, compressive strength test, water absorption test, porosity test, air permeability test and microstructure analysis. In this research, the most suitable cement replacement percentage is 15 % (CAD-15) at 28 days of curing and indicates a 5.499 N/mm^2 of compressive strength which is most similar to 5.512 N/mm^2 of purely cement-stabilized specimen although the optimum replacement is 10 % of AD. The 28th-day compressive strength and water absorption rate of the CSEB specimen with 5, 10, 15, 20, 25, 30 % replacement are within the recommended limit of 3 N/mm^2 and 15 % respectively except for the CSEB with 35 % of AD substitution (CAD-35).

The main mechanism that influences the mechanical properties is the formation of calcium silicates hydrates (C-S-H) and calcium aluminate hydrates (C-A-H) gel from the reaction between pozzolanic reaction and cement hydration process. Formation of these gels contribute to the bonding between soil matrixes and consequently reduce the pores and capillaries formation. The more the bond formed, the density and strength will be higher. Consequently, the water absorption, porosity and air permeability will be much reduced. Therefore, after the optimum replacement percentage, the bond between soil matrixes started to become weaker and thus showed a lower strength. In addition, for CSEB with 30 % of cement replacement (CAD-30), since its strength and water absorption were within the recommended standard, therefore, it had been used for cost feasibility study. From the analysis, CAD-30 had resulted a higher profit earn as compared to CS.

Hence, based on the results obtained, fabrication of CSEB with the incorporation of AD will promote in reduction of air pollution and mitigate the problem caused during the conventional brick firing process and cement manufacturing process. Furthermore, CSEB also solved the waste management problems and landfill capacity issues, thus promoting a more sustainable environment.

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LIST OF SYMBOLS / ABBREVIATIONS

cm	Centimetre
cm^3/s	Cubic centimetre per second
$^{\circ}C$	Degree Celsius
g	Gram
$>$	Greater than
$\geq$	Greater than or equal to
kg	Kilogram
kg/m^3	Kilogram per cubic metre
kJ	Kilojoule
kN	Kilonewton
kV	Kilovolt
$<$	Less than
$\leq$	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
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
HDPE	High-Density Polyethylene
H_2S	Hydrogen disulfide
Fe_2O_3	Iron oxide
$Al_2Si_2O_5(OH)_4$	Kaolinite
LDPE	Low-Density Polyethylene
MgO	Magnesia
CH_4	Methane
NO_X	Nitrogen oxides
O	Oxygen
PETE or PET	Polyethylene Terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl Chloride
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
CEB	Compressed Earth Brick
CSEB	Compressed Stabilized Earth Brick
EDX	Energy Dispersive X-ray
GGBS	Ground Granulated Blast Furnace Slag
MS	Malaysia Standard
OPC	Ordinary Portland Cement
PM	Particulate Matter
SEM	Scanning Electron Microscopy

CHAPTER 1

INTRODUCTION

1.1 General Background

In this globalization era, there is an increasing trend in population growth all over the world. The rapid growth in population, indicates the growth of various types of factories and sectors like the construction sector. However, a drawback – the increase in the amount of waste generated (Reddy and Neeraja, 2016). The waste will be generated as the factories operate; hence the waste might affect the environment faster. The waste can be classified into two types: biodegradable and non-biodegradable. Non-biodegradable waste always the main challenge in determining the safest disposal method to prevent the rise of significant environmental problem. This is due to the most common way to deal with non-biodegradable waste is landfilled which consequently lead to various destruction to the environment (Panditharadhya, Sampath, Mulangi and Ravi Shankar, 2018).

Based on Liu et al. (2021), besides iron, aluminium is the second most widely used metal in the world due to its physical properties like resistance to corrosion and light in weight. Therefore, it is widely used in aerospace, packaging, etc. However, during the aluminium smelting process, large amount of aluminium dross (AD) is generated as an unavoidable by-product. It is non-biodegradable and considered a hazardous waste that will negatively impact the environment and human being. According to Shi, Li and Shi (2021), if AD comes into contact with humid air or water, it will react vigorously and cause significant environmental issues. Moreover, smelting 1000 kg of aluminium into the molten form will generate about 20 kg of AD, but the dross will usually be treated in rotary kilns before disposal at a landfill. It is to recovery come of the remaining aluminium remains in AD (Dangtungee, Vatcharakajon and Techawinyutham, 2021).

According to Zhu, Jin and Ye (2020), China is the largest aluminium producer in the world. China generated up to 1.29 million tons of AD in 2017. In addition, AD is divided into two types: primary AD and secondary AD. Secondary AD has a lower metal aluminium content than primary AD, which is about 5 to 10 % per unit weight. Based on Shen, Liu, Ekberg and Zhang (2021), the harmful gases emitted into the atmosphere will potentially negatively impact human safety problems. This is because aluminium nitride (AlN) is the major source of harmful gases formed after the reaction between liquid aluminium and nitrogen. Hence, the disposal of AD becomes challenging when the exiting of AlN. On the other hand, after AD is disposed of in a landfill, AD might contact water and thus react with water and generate toxic gases like ammonia (NH_3) and methane gas (CH_4). These hazardous gases will lead to various human health issues. Furthermore, landfill leachate might also affect the underground water quality and destroy the soil quality. Furthermore, the cost of landfills is very high; therefore, recycling AD becomes a more recommended way to deal with AD (Dangtungee, Vatcharakajon and Techawinyutham, 2021).

Compressed Stabilized Earth Brick (CSEB) also known as one of the non-fired bricks which do not require a firing process to gain durability and energy efficiency. Therefore, CSEB is considered a construction material with low carbon emission, energy-efficient, cost-effective and environmentally sustainable brick. This is due to the fire process in conventional brick manufacturing industries, it generates a range of gas emissions into the atmosphere and thus will reflect severe environmental pollution due to the use of coal as a fuel for firing with a temperature of 800℃ to 1100℃. The range of gases such as CO, CO_2, NH_3 and SO_2 will be emitted into the atmosphere, and due to the properties of these gases, some environmental issues will arise, i.e., climate change (Abdul Kadir and Mohajerani, 2015). Thus, compared to fired brick, non-fired brick CSEB will be an alternative environmentally sustainable brick that efficiently enhances the reduction of environmental pollution.

In addition, the limitation of using earth as a masonry unit can be overcome with the effect of stabilizers such as type and amount of stabilizer, moisture content, soil gradation, etc. Nevertheless, cement is the most efficient stabilizer used in fabricating CSEB (Elahi, Shahriar and Islam, 2021). According to Elahi et al. (2020), the use of cement can achieve high durability, lower water absorption, reduce swelling properties of soil and increase the density of CSEB. With the addition of 4 – 10 % of cement, the strength of the block can achieve at 7.42 *MPa*. However, cement is not encouraged in the aspect of an environmental standpoint which will influence environmental sustainability. According to Poudyal and Adhikari (2021), besides power plant industries, cement industries are one of the major contributors of greenhouse gases to the atmosphere, i.e., CO_2. In addition, as the demand for cement increases, the aggregate demand, especially limestone for Portland cement production, rises. Moreover, limestone is one of the non-renewable resources, and it will reflect the exhaustion of the earth's non-renewable resources if the quarrying and mining sector continues to be active. Harvesting for non-renewable resources is exposed to deterioration, i.e., global warming and ecosystem destruction (Mohamad et al., 2021).

Since the cement is the most efficient stabilizer, cement is not eco-friendly, thus, to reduce the usage of cement, incorporating waste is one of the efficient methods. The reduction of cement used will reflect in lowering the CO_2 emission to the atmosphere. This is because the production of cement depends on the demand for cement. Hence, decreasing the usage of cement in the fabrication of CSEB will enhance the reduction of cement demand. Moreover, AD is considered hazardous solid waste will lead to environmental issues and hence needs proper management. Nevertheless, recycling is the most eco-friendly way to deal with the AD. Hence, the fate of waste will change from being landfilled to solving the waste management problem and environmental pollution. Moreover, AD can be considered pozzolanic materials since it contains amorphous silica and a high specific surface. Hence, it is suitable to act as cementitious material at the size below 150 μm to enhance the pozzolanic reactivity for strength gaining (Jochem et al., 2021). With an optimum portion of AD, it can be used to substitute cement, the sustainable development of construction material can be achieved and eventually reduce the CO_2 emission.

1.2 Problem Statements

Nowadays, aluminium is widely used in various sectors due to its good physical properties like light in weight and most important is it is recyclable. However, aluminium manufacturing will generate a lot of aluminium dross (AD), which is considered hazardous solid waste. When AD contacts 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. For example, during mixing stage in CSEB fabrication, the toxic gas will be emitted after AD contacted with water and the gas will irritate eyes and nose. Hence, a proper mask and goggle are needed. In addition, most AD will end up in the landfill and contribute to the formation of hazardous landfill leachate. Landfill leachate will pollute the groundwater, affect soil salinization, and indirectly affect human health. Thus, the recycling of AD has become important for environmental sustainability.

At the same time, in this modern civilization, the economic sector developed rapidly and reflected the increase of population in centers of economic activity. Changes in human population densities have increased the demand for housing. Brick is the most common and cost-effective masonry unit for housing development; therefore, the demand for brick rises dramatically. Moreover, the conventional brick, also known as fired brick which, requires a firing process put at a high temperature to achieve durability. But the firing process involves burning fossil fuel, a non-renewable source and produces various toxic gases and particular matter that will cause harm to human and environmental pollution, i.e., air pollution. Therefore, non-fired brick is more suitable to be used as a masonry unit.

Compressed earth block (CEB) is one of the non-fired bricks, but it is low durability as compared to fired brick, hence, the stabilizer is added to overcome the weakness and become CSEB. Since there is demand for CSEB, the cement production line increases rapidly. However, cement production industries are one of the major CO_2 contributors to the environment. In addition, cement is made of limestone, a non-renewable source that will run off in future if excessive mining. Therefore, without firing process, the strength gaining for CSEB will almost similar as fired brick.

In the nutshell, aluminium dross is being chosen as the waste to partially replace the amount of cement used in CSEB fabrication to achieve the objective in reduce environmental problem and eventually bring benefits to the waste management.

1.3 Objectives of Study

This research is to determine the performance of aluminium dross (AD) incorporate with compressed stabilized earth brick (CSEB) to reduce the usage of cement. Hence, the optimum portion of AD as partial replacement for cement is obtained and evaluated. The main goals in this research study are stated as follow:

i. To manufacture CSEB with partial replacement of cement by aluminium dross powder for sustainable purpose.
ii. To analyze the engineering properties of the fabricated CSEB.
iii. To determine the feasibilities of aluminium dross as part of the cement substitution in CSEB.

1.4 Outline of Study

This research is focusing on the feasibility of aluminium dross (AD) in fabrication of CSEB. Efficiency of CSEB with the incorporation of aluminium dross at different percentage of cement replacement will be examined in lab. The various percentage of cement replacement are 10, 15, 20, 25, 30 and 35 %. In addition, CSEB will be casted into two different shape which are 50 x 50 x 50 mm of cube specimen and cylinder specimen with 40 mm high and diameter of 45mm. After curing process for 7,14 and 28 days respectively, all specimens will undergo mechanical properties and compressive strength analysis through some laboratory tests. A control specimen will be used for comparison purpose which helps in determining the efficiency of CSEB with different cement substitution portions through the analysis of properties.

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 the influence toward ecology. ▪ Introduction on Compressed Stabilized Earth Brick (CSEB) as a non-fired brick. ▪ Introduction of cement production and its consequences. ▪ Introduction of aluminium dross. ▪ Introduction of aluminium dross as partial cement replacement in CSEB. ▪ Outline the aim, objective and scope of study in this research study.

Table 1.1: Research Thesis Framework (continued)

2	Literature Review	▪ General background of aluminium dross. ▪ Properties of aluminium dross. ▪ Drawback of aluminium dross. ▪ General background of conventional brick. ▪ Properties of conventional brick. ▪ Effect of conventional brick. ▪ General background of CSEB. ▪ Properties of CSEB. ▪ Drawback of CSEB. ▪ Relevant past research on CSEB fabrication.
3	Research Methodology	▪ General background of research methodology. ▪ Preparation of research material such as cement, soil, sand, aluminium dross. ▪ Mix proportion for CSEB fabrication. ▪ Moulding of specimen. ▪ Curing of specimen. ▪ Laboratory test for CSEB specimen.

Table 1.1: Research Thesis Framework (continued)

4	Results and Discussion	▪ Preliminary analysis of aluminium dross ▪ Present the data obtained for the mechanical properties analysis. ▪ Deeply discuss the results obtained from the CSEB fabrication. ▪ Evaluate the mechanical properties of fabricated CSEB. ▪ Comparative evaluation of fabricated CSEB. ▪ Feasibility analysis of CSEB with partial cement replacement.
5	Conclusion and Recommendation	▪ Overall summary on the research study. ▪ Recommendation suggested for future relevant research study on CSEB to improve the outcome.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The source and consequences of plastic waste and glass waste are justified in detail together with their properties in this chapter. Moreover, the differences between conventional brick and compressed stabilized block e.g., advantages and disadvantages, concern to the environment are elaborated. Lastly, the previous research reviews on the incorporating of different types of waste into CSEB fabrication are listed out.

2.2 Aluminium Dross (AD)

Nowadays, there is an increasing trend in population of the world which directly influence the growth of various type of industries, factories and construction sector. As the growth of industries, the amount of waste generates in a rapid rate into the environment in term of biodegradable and non-biodegradable. The non-biodegradable waste has result in challenge in disposal and also ecological imbalance for a maximum period. Therefore, sustainability of the waste generated become one of the challenges for industries to reduce the significant impact on environment (Panditharadhya, Sampath, Mulangi and Ravi Shankar, 2018).

Aluminium dross (AD) is one of the hazardous wastes produced by the metal manufacturing industries and it is the major challenge of industries to safely dispose the waste (Verma, Dwivedi and Dwivedi, 2021). This is due to during the aluminium manufacturing process, AD will be generated and result in significant environmental issues due to its hazardous properties when exposed to humid air or water. According to Li et al. (2021), in 2019, global had generated around 63.70 million tons of primary aluminium while in 2020, about 97 million of primary aluminium had been generated. This is due to its physical properties ease for the application in construction, automotive industries and even in aerospace. For example, light in weight, easy alloying, ductility and resist to corrosion.

All around the world, most of the AD is generated in the aluminium smelter plants (Meshram, Jha and Varghese, 2021). Currently, there are two pathways for manufacturing metallic aluminium which are extraction of alumina from bauxite ore through industrial electrolytic process and secondary aluminium production from used aluminium products like extrusion, foils and other or aluminium scrap. During smelting one ton of metallic aluminium, around 80 to 150 *kg* of AD will be produced (Li et al., 2021). Hence, aluminium dross considered as an unavoidable by product from aluminium smelting process which involves 60 to 75 % of metallic aluminium, 20 to 30 % of oxides and 5 to 10 % of salts (Dangtungee, Vatcharakajon and Techawinyutham, 2021).

2.2.1 Properties of Aluminium Dross

AD is also known as heterogeneous material which consist of aluminum (Al), alumina (Al_2O_3) and salt flux. Based on Wu et al. (2021), AD can perform in different form and there are three dominant form which are Al, aluminium nitride (AlN) and Al_2O_3. Moreover, AD can be divided into two types based on the metal content and hazardous which are primary aluminium dross (PAD) and secondary aluminium dross (SAD). The most common PAD is white dross while for SAD is black dross. PAD generated as the by-product of electrolytic production consists of 15 to 80 wt% of metal content which is considered high, less than 6 wt% of fluorine salt and chlorine salt and has slightly hazardous properties. Due to these properties, it is valorised in secondary steel industry or aluminium production. In addition, SAD is considered as residue since it is generated after recycling of primary aluminium dross, scrap or even used beverage cans through some pyrometallurgical process in secondary aluminium industries (Li et al., 2021). On the other hand, SAD consists of 5 to 20 wt% of alumina which is considered low, metal oxides and some salts. Hence, its composition is usually more complex as compared to PAD since it extracts from PAD.

Al	Al_2O_3	SiO_2	MgO	CaO	AlN	K	Na	Cl
8.5	76.9	7.84	6.24	0.18	0.12	0.03	0.04	0.12

Figure 2.1: Chemical Composition of SAD (wt%) (Shi, Li and Shi, 2021).

According to Meshram, Jha and Varghese (2021), recycling of AD is more conventional and applicable. For example, direct consumption for cement clinker production or even use as reinforcement for composite production like CSEB. Based on Panditharadhya, Sampath, Mulangi and Ravi Shankar (2018), AD has the good effect in replacing the cement used in brick fabrication but not exceed 15 % of cement replacement by AD. As refer to **Figure 2.2**, we can observe that AD contains higher alumina ion but lower silica ion which are used to enhance the pozzolanic activity with the cement.

Chemical composition	OPC	Aluminium dross
Al_2O_3 (%)	4 - 8	60 - 80
SiO_2 (%)	17 - 25	4 - 6
P_2O_5 (%)	-	0.57
SO_3 (%)	4.3	1.37
Cl^- (%)	0.1	2.2
CaO (%)	1.3 - 3.0	4 - 20
TiO_2 (%)	0.5	2.0

Figure 2.2: Composition of AD and Ordinary Portland Cement (Panditharadhya, Sampath, Mulangi and Ravi Shankar, 2018).

2.2.2 Drawback of Aluminium Dross

Significant environmental effects had been found along fulfilling the needs for market and industry as large amount of AD being generate as the by-product. Carbon dioxide (CO_2), Sulphur dioxide (SO_2), fluoronium (H_2F), liquid alumina and molten mixture dross had been produced along the alumunium primary and secondary extraction process. These gases will reflect in greenhouse effect and even depletion of the ozone layer. Both negative effects will cause a long chain of consequences. Furthermore, according to Shen, Liu, Ekberg and Zhang (2021), the harmful gases emitted to the atmosphere will bring potential negative impact to human safety problem. This is due to AlN is the major source of harmful gases which formed after the reaction between liquid aluminium and nitrogen.

Moreover, a negative outcome which known as salt cakes will be produced as the PAD being recycle back to reverberatory heater together with salt transition to prompt more extraction of aluminium. The fate of the salt cakes is ended in landfill; hence it consequently rises the landfill issues (Verma, Dwivedi and Dwivedi, 2021).

Moreover, dumping of AD will lead to several adverse ecological issues. SAD consists of some active phases, for example, metal aluminum, aluminum carbide and aluminum nitride which will easily react with water especially during humid climate. As the result, the explosive hydrogen (H_2), methane (CH_4) which has flammable properties, stinky ammonia (NH_3), hydrogen disulfide (H_2S) which is toxic gas will be generated to the ambient air. These gases not only cause pollution to the atmosphere but also rise security risks due to the gases are highly susceptible to explode. Furthermore, ammonia gas emitted will result in poisoning of aquatic animal due to the ammonia-nitrogen ($N\text{-}NH_3$) agglomeration phenomenon in water (Li et al., 2021).

In addition, the leachate from landfill might consist of SAD which contain large amount of toxic ions, for example heavy metal and even fluorine. The leachate might pollute the underground water and result in surface water pollution and also soil salinization. Soil salinization will affect the crop yield and destruct the nutrient level of crop. In addition, the heavy metal accumulated in plant and soil have potential risk in affecting human health. Hence, it is classified as a hazardous solid waste in some countries. However, due to 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).

2.3 Conventional Brick

Conventional brick also known as fired brick, it has been widely used in construction sector such as constructing building and structure. Brick has played an important role in many countries especially in most developing countries such as Thailand (Chindaprasirt et al., 2021). According to Bhairappanavar, Liu and Shakoor (2021), around 1.83 trillion of brick had been produced annually and it might increase to 2.76 trillion in the future in 2027 due to the rapid growth in construction sector. However, manufacturing brick required huge amount of nature resources and hence rising concern about the over mining for the natural resources and environmental issue. Furthermore, they also stated that construction sector that involved building sector had generated about 40 % of greenhouse gases through consuming world primary energy, mineral resources and water resources due to the rise in global population especially in urban area. The common fired brick has the composition of 48.7 % of silica (SiO_2), 13.7 % of alumina (Al_2O_3) and 37.6 % of remaining ingredient such as calcium oxide (CaO) and iron oxide (Fe_2O_3) (Sveda, Sokolar, Janik and Stefunkova, 2017).

Chemical composition	%
SiO_2	48.7
Al_2O_3	13.7
Fe_2O_3	5.67
CaO	9.99
MgO	3.74
Na_2O	0.50
K_2O	2.51
MnO	0.35
TiO_2	0,69
P_2O_5	0.16
SO_3	0.21
Loss on ignition	13.4

Figure 2.3: Chemical Composition of Fired Brick (ŠVEDA, SOKOLÁŘ, JANÍK and ŠTEFUNKOVÁ, 2017).

Manufacturing of fired brick involved six process which are mining and storge of raw materials, manage the raw materials, forming the basic shape of the brick, drying, firing and cooling process and lastly packing and shipping. Excavator and dump trucks are common mining methods to remove the clay from the pit and convey it by dump truck to storage place. The technique is known as open-cast "bench-mining" which ensure a good blending of clays. Before proceeding to forming process, the management on the mined raw material should be done. A size reduction equipment is needed to reduce the size of the clay lumps and stones and thus undergoes screening process to separate other impurities. Moreover, after screening process, it will undergo weathering process for few months. Then, the clay will be used to form brick through three process which are extrusion, pressing and hand thrown. For extrusion, around 10 to 15 % of water is used to mixed with clay to produce plasticity and followed by the de-airing process which remove the air holes and bubbles in a vacuum of 375 to 725 *mm* of mercury de-airing chamber. De-airing chamber promote the workability, plasticity and strength of the clay. The clay is then extruded to form a column of clay through a die so that the texture or surface coating been applied.

Furthermore, for pressing process, more than 10 % of water will be added to form a low plasticity and been pressed into a steel mold through 3.4 to 10.3 *MPa* of pressure by hydraulic air rams while for hand thrown, around 20 to 30 % of water will be added and pressed into the brick molds that lubricated with sand or water to prevent sticking. It is formed by hand or machine. Next, the brick will been cut to size through reel cutter or push through cutter. For reel cutter, the clay column will be cut into brick units and leaves the extruder while another method is sent the clay column into cutter by conveyor. The wet brick after cutting process will contain 7 to 30 % of moisture depend on the forming process. Before firing process, the wet brick will undergo drying process at 38 to 240 ℃ drier chamber for 24 to 48 hours to evaporate the excess water content. However, the heat should be proper managed to prevent brick cracking and affect the strength. Then, the brick will be proceeded to firing process. There are three types of common firing methods which are clamp kiln, transverse arch kiln and tunnel kiln. For clamp kiln, the brick will be arranged in the form of block together with the coal which will be used to assist the firing process; for transverse arch kiln, the brick will be placed at various chamber which the heat input through the exhaust fan and the coal will be burnt on the top of the chamber; for tunnel kiln, it operates continuously from the dryer into the kiln through the kiln cars. After firing process, the brick will enter cooling zone and proceed to packing stage.

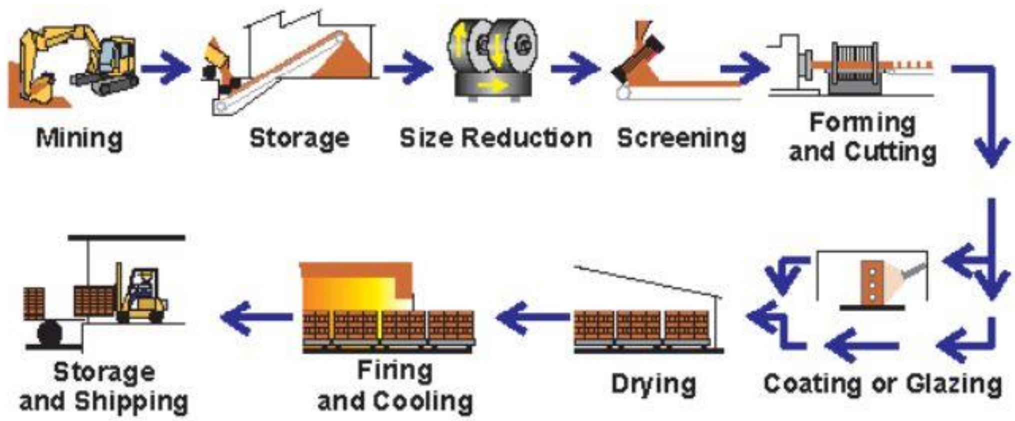

Figure 2.4: Manufacturing of Fired Brick (N.S. TWALA., 2008).

2.3.1 Properties of Conventional Brick

Conventional brick is widely used in construction sector is due to its low water absorption, high density, strength can withstand in different weather and required little maintenance (Chindaprasirt et al., 2021). Durability is one of the important clay brick properties which depends on the firing process. The firing temperature will affect the compressive strength, adsorption rate and saturation coefficient because these properties are the predictors of the brick durability. Moreover, the firing temperature will result in various colour of fired brick together with the various chemical composition. As increase in firing temperature, the darker the colour of clay brick. Not only in colour but also low absorption values and higher compressive strength. In addition, the common clay brick having a sand-finished textures or smooth surface after manufactured by molds. The formed of smooth texture is due to the pressure exerted during the extrusion process by the steel die. Furthermore, an antique appearance will be achieved before or after the firing process through the tumbling action.

Apart from this, slurries of finely ground clay will be applied to the column by the manufacturing plants to develop hardness and create interesting patterns on the brick but it might affect the moisture content of the brick. However, the size of the brick is based on the shrinkage process happened during the drying and firing process. As the increase in firing temperature, the more the shrinkage process and darker shades. During drying process, around 2 to 4 % of shrinkage happened while during firing process, around 2.5 to 4 % of shrinkage happened in brick. Besides that, clay brick considered as weatherproof brick because there are fine capillaries that allow the absorption and release of water after the rain (Overview of South Africa's Clay Brick Industry, 2008). With the firing process, conventional brick having a higher thermal conductivity because a glassy product will be formed by the partially combination of clay (Riza, Ahmad Zaidi and Rahman, 2010).

2.3.2 Effect of Conventional Brick

According to Paul Levi and Raut (2021), fired brick will reflect significant effects to the environment, wildlife and also environment during manufacturing in industry. According to Elahi, T., Shahriar, A. and Islam, M. (2021), fired brick has contribute to the carbon footing and result in series of human, wildlife and environmental problems along the consumption of the raw materials. Moreover, fired brick had been reported that as a non-ecofriendly which generate 143 *kg/ton* of CO_2 to the ambient air (Elahi, T., Shahriar, A. and Islam, M., 2021). The most non-ecofriendly process is during firing process which released CO_2, CO, SO_2, NO_x and PM (size that less than 10*μm*) from the kiln. Based on Kumar, Kumar, Kumar and Srivastava (2021), brick kiln will generate around 70 to 282 *g* of CO_2, 0.001 to 0.29 *g* of C, 0.29 to 5.78 *g* of CO and 0.15 to 1.56 *g* of PM per kg of fired brick and it is depending on the type of fuel and kiln during the firing process. Moreover, after the pulverizing process of raw clay, mill residues will be generated and residues content PM 10 and PM 2.5. Based on Zhang, Wong and Arulrajah (2021), PM 10 is those particular matters smaller than 10 *μm* while PM2.5 is those particular matters smaller than 2.5 *μm*.

CO_2 is considered as a greenhouse gas that will cause global warming to the atmosphere. Global warming means the temperature of the earth keep on increasing and lead to climate change. As the increase in temperature, melt of glazier will happen and result on rise of ocean water level. Moreover, as the ocean temperature rises, aquatic animal and plants will be affected and even distinction. When the CO_2 increase, the respiration rate of plant will increase but it will lower down the nitrogen concentration that contribute to protein concentration and hence affect species at higher trophic level (Difference Between Global Warming & the Greenhouse Effect, 2021). Based on Mathur (2018), different CO_2 concentration will lead to different effect on human. The most dangerous concentration is exposed to more than 30 % which human will experience unconsciousness in 24 second.

% 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

Figure 2.5: Physiological Effects of Different Concentration of Carbon Dioxide (Mathur,2018).

Therefore, all the gases generated by manufacturing of fired brick will affect environment, wildlife and human especially the residents nearby the industry area. However, the impacts have two categories which are direct impact and indirect impact. The direct impacts are ecological damage such as inhibit the plant growth; in environmental damage such as air pollution and even soil degradation; in human impacts such as health problems. Moreover, it required huge number of non-renewable resources, coal for firing process in kiln and generate electricity for the power plant. In addition, there are several indirect impacts from the brick industries. For example, most of the brick kiln used topsoil which around 1 *m* depth from the fertile agricultural land for brick production and hence lead to the soil degradation and ecological damage such as affect the habitats of the underground animal and insects.

2.4 Compressed Stabilized Earth Brick (CSEB)

CSEB is also known as a non-fired brick which means that firing process is not required to achieve the minimum strength according to the standard. Hence, many researchers stated that CSEB is a sustainable and eco-friendly brick as compared to conventional brick and reduce the carbon emission to the ambient air. Since it does not require firing process, the usage of non-renewable source, fuel will be avoided and reflect a low energy consumption (Elahi, T., Shahriar, A. and Islam, M., 2021). The main property of CSEB is widely utilize the earth as construction material which low carbon emission and thermal conductivity, good in hydroscopic, affordable for rural people and hence enhance the local economy. In this era of globalization, sustainable development become more priority in construction sector to reduce the serious environmental problem rise such as global warming, therefore, earthen construction become a preferable method. As refer to Jannat, Hussien, Abdullah and Cotgrave (2020), fired brick will generate around 0.15 *tons* of CO_2 and consume 706 *kWh* of mean energy, hence CSEB is a suitable alternative brick for construction sector. In addition, manufacturing step for CSEB is much easier than fired brick which CSEB only required three main stages process which are CSEB ingredient preparation, mixing, compression and curing process for respective curing period (Dmdok, 2021). Therefore, fabrication of CSEB could be the ideal alternative to address the drawbacks of conventional bricks.

However, earth building material has some drawback and leads to being ignored by modern construction sector. Earth is reported having a low compressive strength, wet compressive strength, durability and shrinkage. Therefore, a suitable stabilizer will be added to overcome all the limitation rise. For example, cement and lime. Stabilizer said that will be affected by the soil gradation, amount of stabilizer added, moisture content, compaction energy etc. Coarse grained soil is suggested by researchers as the most suitable soil type used in fabrication of CSEB. With around 4 to 10 % of cement, the strength of CSEB can achieve a strength of 2.48 to 7.42 *MPa*. Based on Elahi, T et al. (2020), the suggested composition in fabrication of CSEB are 15 % of gravel, 50 % of sand, 15 % of slit and 20 % of clay. Cement is the most important stabilizer in enhancing the strength gaining in CSEB. Most of the cement has the composition such as tricalcium aluminate ($Ca_3Al_2O_6$), tricalcium silicate (Ca_3SiO_5), tetracalcium aluminoferrite ($Ca_4Al_2Fe_2O_{10}$), dicalcium silicate (Ca_2SiO_4) and gypsum. During the cement and soil mixed together with optimum water content, Ca_3SiO_5 and Ca_2SiO_4 will react with water and form a calcium silicate hydrate (C-H-S) gel.

$$Ca_3SiO_5 \text{ or } Ca_2SiO_4 + H_2O \rightarrow C\text{-}S\text{-}H + Ca(OH)_2 \quad (2.1)$$

C-S-H gel will bind up the pores generated and hence increase the strength of CSEB. Moreover, to form a strong interconnecting bond and improve the rigidity of the soil mixture, the cement will adhere to the surface of soil particles and hydration products that found in mixture of CSEB. Hence, it concludes that, the higher the amount of cement added, the higher the strength generated to CSEB (Elahi, T et al., 2020).

2.4.1 Properties of CSEB

To identify the quality of CSEB, compression strength is the most common acceptable value. During saturation condition, the pore water pressure will develop and result a low compressive strength in brick. Hence, cement-content is main factor that affects the stability of the CSEB. With an efficient stabilization, the plasticity index will have a lower value. However, if the plasticity index more than 20, it become not suitable for manual compaction process to gain the strength. Moreover, with the present of iron in clay soil, it will reflect a low compressive strength during soil stabilization process. In addition, in-situ test such as flexural test is suggested to be carried for determination of CSEB strength. According to Elahi, T et al. (2020), compaction strength will increase the strength of

CSEB but if over compact, the soil and bond will be further break down and lead to decease in strength. In addition, density of CSBE is around 1500 to 2000 kg/m^3 which affected by the compaction force applied during manufacturing and compressive strength obtained. There are three type of compaction methods that affect the density of CSEB which are dynamic, static and vibro (Riza, Ahmad Zaidi and Rahman, 2010).

Furthermore, water absorption rate reported will affect the strength and durability of CSEB. As the higher the age of earth brick, the water absorption will reduce and prevent the swelling of CSEB that will lead to lose in strength. The water absorption happened through the capillary absorption and total absorption. Hence, moisture content will influence the strength development in CSEB. With an optimum moisture content, good adhesion and hydration will be promoted. However, it also affected by the compaction force (Riza, Ahmad Zaidi and Rahman, 2010). The higher the compaction force, the lower the water content. If it undergoes dynamic compaction, the strength will increase by 50 % with the reduction from 12 % of moisture content to 10 %., while for static compaction, the optimum moisture range is around 10 to 30 % (Bahar, Benazzoug and Kenai, 2004). Besides that, plasticity index obtained, amount of cement added and water loss event will directly influence the drying shrinkage of CSEB. If the plasticity index below 20 %, the drying shrinkage occur steadily, while for plasticity index from 25 to 30 %, the drying shrinkage occur rapidly together with the increase of clay content. To achieve a good cement stabilization, the soil plasticity index should less than 20 % together with 10 % of cement content and with a shrinkage limit from 0.008 % to 0.1 %.

Moreover, the shrinkage of the brick will be affected by the sand content that will not influence the compressive strength significantly. When the sand content increase, the shrinkage of brick will reduce because the sand particles oppose the shrinkage movement. Not only sand content, but addition cement content will also enhance in the shrinkage reduction about 44 % if 10 % of cement added to the mixture. The cement added for stabilization purpose will enhance in water attacks prevention and achieve a high mechanical strength in saturation condition such as raining day. The most suitable wet to dry ratio is 33 % which result in high durability especially suitable for the brick that experience various climatic condition. In addition, thermal performance of CSEB become one of the important aspects since the rise of ecological awareness and concern of energy conscious. Thermal conductivity performance is influenced by the density and moisture content. A cement based CSEB has a thermal conductivity of 0.2612 ± 0.0350 $W\,m^{-1}\,K^{-1}$ while for fired clay bricks, the thermal conductivity is 0.4007 ± 0.0350 $W\,m^{-1}\,K^{-1}$, hence, the thermal conductivity of CSEB considered lower as compared to fired clay brick. According to Bahar, Benazzoug and Kenai (2004), conductivity of CSEB can be reduced when there is addition of cement and sand content. With a low thermal conductivity brick, it will result in an environmentally friendly and energy efficiency building (Riza, Ahmad Zaidi and Rahman, 2010).

2.4.2 Drawbacks of CSEB

According to Cai et al. (2021), rapid development of economy has led to the increase of human's demand especially on infrastructure such as building, road, etc. The cement used to stabilize the CSEB is considered as a non-environmentally friendly material since the cement manufacturing will cause a lot of significant effect the human, wildlife and environment. This is due to the high carbon emissions from the cement manufacturing industries which cause anthropogenic emission of CO_2 to the ambient air such as carbonate decomposition and oxidation of fossil fuels (Sousa and Bogas, 2021). According to Poudyal, L. and Adhikari, K. (2021), besides power plant, cement manufacturing industry is one of the contributors to carbon footprint and lead to greenhouse effect. The CO_2 emission from the industry considered as anthropogenic emission which contributed 8 to 10 % of CO2 to the ambient air. In future, CO_2 expected will increase dramatically and lead to even more serious problems. Based on Mohamad, N., et al. (2021), CO_2 released together with water vapour during the formation of CaO at high temperature. CO_2 generated from the cement industry contributed 65 % of greenhouse gases to the atmosphere and cement manufacturing industries reported generated 4.1 *Gt* of CO_2 globally in 2017. Cai et al. (2021) stated that the pollution generated by cement production will affect the neighboring areas, hence, it will cause significant effects to nearby human, wildlife and environment.

Not only CO_2, but also particular matter such as PM10 and PM2.5, NOx, SO_2, VOCs, toxic dioxins, furans and mercury. In 2010, during the production, about 136 *tons* of NOx, 4,833 *tons* of SO_2, 183 *tons* of VOCs and 320 *kg* of mercury will be emitted to the ambient air by cement manufacturing industries. During the combustion process that involve fossil fuel, NOx will be released and it considered as one of the greenhouse gases that will lead to global warming. Moreover, PM generated will affect the healthy lifestyle of human and even affect human respiratory system and increase the likelihood of chronic obstructive pulmonary disease (COPD) if exposed to various of PM sizes for long time. This is due to PM size smaller than 10 μm is easily to penetrate respiratory track. In addition, VOCs generated will lead to soil contamination and groundwater contamination. The soil contamination will affect the plant growth and also contribute to the likelihood of chlorosis and necrosis in large-leaved plants. Besides that, VOCs will influence human health issue such as eye, nose and skin irritation, liver function failure, destruction on central nervous system, etc. (Mohamad, N., et al., 2021).

Dust pollution is also one of the problems rise by the cement manufacturing industries. Dust pollution will lower down the air quality and visibility. With a poor air quality, human health will be affected and even reflect chronic diseases. Moreover, if the dust falls into water resources, it will contaminate the water supplies and result in harming human and wildlife health. The dust will also influence the growth of the plant through blocking the stomata of the leaves and retard the respiration process of plants. In addition, cement manufacturing industries generate noise pollution by the heavy machine used. The noise can be classified into three types which are overall gas noise, electrical magnetic noise and mechanical noise that due to vibration. Human hearing ability, human lifestyle, wildlife habitat and even plant growth will be influenced by the noise pollution generated. If exposed to noise for long period, it will affect the anatomy and physiology of human such as nervous system, digestive system and cardiovascular system. Noise pollution will also cause wildlife to move their habitat to a more comfort location for reproduction purpose (Mohamad, N., et al., 2021). Therefore, cement production industries will cause a lot of problem to human, wildlife and environment.

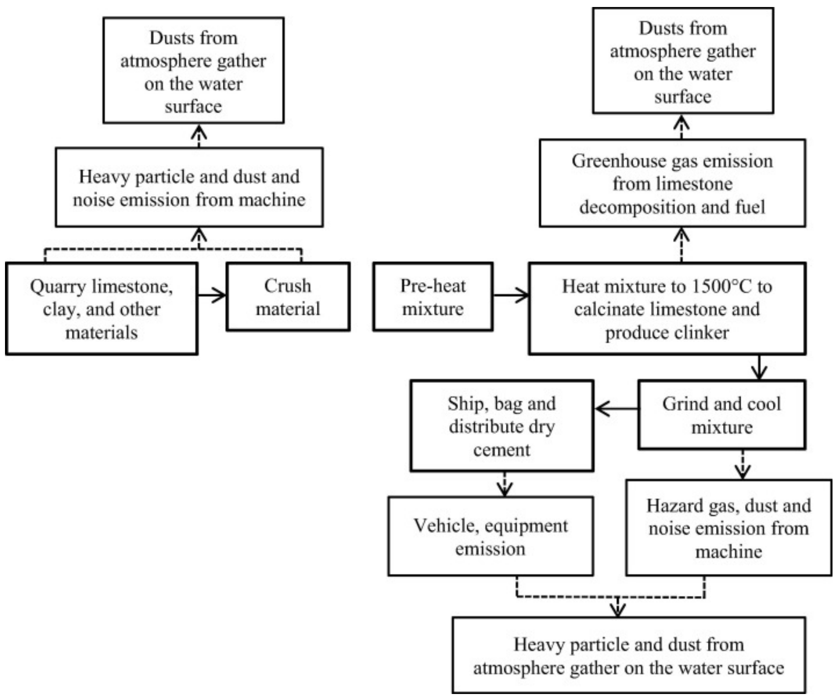

Figure 2.6: Summary of Impacts on Cement Production Industries (Mohamad, N., et al., 2021).

2.5 Relevant Past Research

Sustainable development concept has been promoted and suggested as the environmental pollution keep on increasing over these past few years. Low production cost, ease for transportation and eco-friendly properties of CSEB allow it becomes a more preferable construction material nowadays. However, cement used as stabilizer in CSEB is considered as a non-ecofriendly material that will result in air pollution during manufacturing industries. Hence, there are many researchers had carried out investigation on substituting partial cement portion with waste materials in CSEB fabrication. Although there is lack of studies in incorporation of plastic waste and glass waste in fabrication of CSEB, but there is few research that emphasize on using other waste materials in CSEB fabrication such as fly ash (FA). The relevant past research on incorporating of various waste materials in CSEB fabrication to increase the strength and durability are illustrated as following table:

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication

Type of waste	Method	Review	Reference
Granulated blast furnace slag (GBFS)	GBFS is used to replace portion of lithomargic clay and lateritic soil while cement is added to increase the strength. - For lithomargic clay: [75 % of lithomargic clay + 25 % of GBFS] + [6, 8, 10, 12 % of cement] - For lateritic soil: [80 % of lateritic soil + 20 % of GBSF] + [2, 4, 6, 8 % of cement]	- From unconfined compressive strength (UCS) test, the optimum lithomargic clay replacement obtained is at 25 % of GBFS while lateritic soil is at 20 % of GBFS to involve in pozzolanic reaction. - For lithomargic clay CSEB, with 25 % of GBSF replacement, the dry compressive strength on 28th day increased from 1.05 *MPa* to 1.6 *MPa*. - For lateritic soil CSEB, with 20 % of GBSF replacement, the dry compressive strength on 28th day increased from 1.52 *MPa* to 2.13 *MPa*. - For both types of CSEB, addition of cement showed a continuous increase in strength and reduction in water absorption percentage. - . [75 % of lithomargic clay + 25 % of GBFS + 10 % of cement] and [80 % of lateritic soil + 20 % of GBSF + 6 % of cement] suitable for load bearing wall construction.	C. Sekhar and Nayak (2018)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Fly ash (FA)	Incorporating FA and cement in CSEB fabrication with the mix portion of 10-30 % of FA with 401 m^2/kg in surface area and 3 – 10 % of cement with 331 m^2/kg in surface area. i. [10% of FA] + [3, 5, 7, 10 % of cement] ii. [20% of FA] + [3, 5, 7, 10 % of cement] iii. [30% of FA] + [3, 5, 7, 10 % of cement]	- Maximum CSEB strength for 28 day of curing is achieved by adding 10% of cement which due to the increase in inter-particle connection. - Increase of cement used had led to a higher optimum FA amount. - The range for wet compressive strength is between 0.55 *MPa* and 4.36 *MPa* while the wet-to-dry strength ratio is between 0.26 to 0.65. - CSEB that contained 5 % of cement incorporate different FA amount can achieve a wet strength more than 0.7 *MPa* and wet-to-dry ratio more than 0.33 so it can be used for construction purpose. - For tensile strength, the optimum FA content increase together with the increase of cement percentage and hence reflect a rise in tensile strength.	Elahi, Shahriar and Islam (2021)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Fly ash (FA)	FA act as a supplementary material in CSEB fabrication at the following portion: i. [0 % of FA] + [4, 6, 8, 10 % of cement] ii. [10 % of FA] + [4, 6, 8, 10 % of cement] iii. [20 % of FA] + [4, 6, 8, 10 % of cement] iv. [30 % of FA] + [4, 6, 8, 10 % of cement]	- CSEB incorporate with cement only achieved a maximum strength of 5.13% which 10 % of cement is added. - Increase in cement amount indicated the rise of the strength dramatically due to the increase of interconnecting bond between cement and soil. - The optimum portion of FA for cooperation with 4 % and 6 % of cement is 10 %. - With 8 % of cement, 20 % of FA added had achieved 5.14 *MPa* of optimum strength, however, for adding 10 % of cement, the strength increased continuously with different portion of FA. - The higher the amount of cement, the lower the water absorption and hence indicate the rise of wet strength.	Elahi et al. (2020)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Glass waste (GW) and fly ash (FA)	[50 % of FA + 50% of GW] are acted as precursor added into CSEB fabrication together with portion of alkaline activated cement (AAC). - There are 3 different activators to precursor wt. ratio which are 0.50, 0.57 and 0.75.	- For precursor/soil wt. ratio 30/70, the optimum moisture content is 17 % and achieved 1.77 gcm^3 of dry unit weight. - The optimum precursor wt. ratio is 0.50 which reflected a 11.4 *MPa* compressive strength. - The higher the precursor wt. ratio, the lower the compressive strength. - The average compressive strength obtained for dry CSEB is 17.23 *MPa* while for saturated CSEB is 7.45 *MPa*.	Rivera et al. (2021)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Saw dust ash (SDA)	Combination of 1 % to 10 % of SDA and 4 % to 10 % of cement in fabrication of CSEB. The combinations are as below: i. [4 % of cement] + [2, 4, 6, 8, 10 % of SDA] ii. [6 % of cement] + [2, 4, 6, 8, 10 % of SDA] iii. [8 % of cement] + [2, 4, 6, 8, 10 % of SDA] iv. [10 % of cement] + [2, 4, 6, 8, 10 % of SDA]	- For 4 % of cement, the optimum SDA substitution is 4 % and reflected 1253 *KPa* strength. - For 6 and 8 % of cement, the optimum SDA substitution is 6 % and reflected 1708 and 1871 *KPa* strength respectively. - For 10 % of cement, the optimum SDA is 8 % and reflected 2001 *KPa* strength. - For 0 % of cement, the strength is much lower than those with cement. - Increase of cement added, the overall compressive strength increases due to the formation of C-S-H gel that enhance the chemical reaction between cement and soil. - As the amount of SDA increases, the water absorption decreases due to the reduce of porosity.	Elahi, Shahriar, Alam and Abedin (2020)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Sugarcane bagasse ash (SBA)	Incorporation of 6 % and 12 % of cement and 2 % to 8 % of SBA in CSEB fabrication. i. [6 % of cement] + [2, 4, 8 % of SBA] ii. [12 % of cement] + [2, 4, 8 % of SBA]	- For 6 % of cement, the increase of SBA amount in CSEB fabrication indicated the rise of mean compression strength but not exceed 1.54 *MPa* while for 12 % of cement, the mean compression strength reached 2.00 *MPa* after 28 days curing period. - The larger the amount of cement dispersed in CSEB mixture, the higher the mean compression strength. - Without SBA, the deformation of CSEB is not consistent as compared to 8 % of SBA.	Lima, Varum, Sales and Neto (2012)
Biomass bottom ash waste (BBA) and geosilex (G)	Different portion of BBA and G had been added together with cement in fabrication of CSEB. - For BBA: [100 – 20 wt. %] - For G: [0 – 80 wt. %]	- For the brick with BBA and cement only, the compression strength reached 30 *MPa*. - An increase in strength indicated when the portion [BBA:G] are [70:30] and [60:40] and achieved 52 *MPa* which is an optimum portion.	Eliche-Quesada, Felipe-Sesé and Fuentes-Sánchez (2021)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Glass power waste (GPW)	Different sizes of GPW had been used to partially replace the portion of cement. - For 150 μm of GPW: [20, 40, 60 %] of cement replacement. - For 75 μm of GPW: [5, 10, 15, 20, 25, 30 %] of cement replacement. - 7, 14 and 28 days of curing period.	- The increase of GPW did not reflect an increase of compressive strength but reduce the compressive strength. - 28 days is the suitable curing period to achieve a compressive strength more than 3 N/mm^2. - For 20 % of cement replacement, GPW less than 150 μm is the most suitable particle size.	Aluko et al. (2015)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Iron Mine spoil waste (MSW) and quarry dust (QD)	Two different amounts of cement are incorporate with three different amount portions of MSW and QD. i. [6 % of cement + 2 % of lime] + [30, 40, 50 % of MSW] + [62, 52, 42 % of QD] ii. [8 % of cement + 2 % of lime] + [30, 40, 50 % of MSW] + [60, 50, 40 % of QD] - Ageing period: 7, 15, 30, 60 days and 6 months.	- As the ageing period increase, the wet compression strength (*MPa*) rises dramatically especially for 6 months. - [8 % of cement + 2 % of lime] + [30 % of MSW] + [60 % of QD] achieved the highest wet compressive strength as compared to other. - The water absorption decreases together with the ageing days but the difference between 60 days and 6 months of ageing did show much different.	Nagaraj and Shreyasvi (2017)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Plastic waste	Four different portion of shredded waste plastic are added into CEB fabrication. There are two different size of plastic which are less than 6.3 *mm* and more than 9.6 *mm*. i. 0% of shredded waste plastic ii. 1% of shredded waste plastic iii. 3% of shredded waste plastic iv. 7% of shredded waste plastic	- The optimum portion of shredded plastic waste is 1 % with particle size of less than 6.3 *mm*. - As the increase in shredded plastic waste content after the optimum portion, the compressive strength started to reduce. - With 1 % of shredded plastic waste less than 6.3 *mm*, the erosion rate is low. - The higher the shredded plastic waste content, the larger the erosion rate.	Akinwumi, Domo-Spiff and Salami, (2019)

Table 2.1: Overview of Previous Research Literature on CSEB Fabrication (Continued)

Polypropylene (PP) fiber	There are four different combinations of two sizes of PP fiber content and 8 % of OPC cement. i. [8 % of OPC] + [0.2 % of 54 *mm* PP fiber] ii. [8 % of OPC] + [0.2 % of 27 *mm* PP fiber] iii. [8 % of OPC] + [0.14 % of 54 *mm* PP fiber] + [0.06 % of 27 *mm* PP fiber] iv. [8 % of OPC] + [0.06 % of 54 *mm* PP fiber] + [0.14 % of 27 *mm* PP fiber]	- [8 % of OPC] + [0.2 % of 54 *mm* PP fiber] is the optimum ratio and result in 2.37 *kN* of peak load and deflection at peak load is 0.2 *mm*. -[8 % of OPC] + [0.14 % of 54 *mm* PP fiber] + [0.06 % of 27 *mm* PP fiber] shows the least peak load and easy to deflect.	Donkor and Obonyo (2014)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In this chapter, the detailed methodology design of this research study will be shown, which includes the apparatus and material required, CSEB fabrication procedures and laboratory test applied to determine the engineering properties of CSEB. Various percentages of plastic waste and glass waste will be used to partially replace the cement usage in determining the optimum substitution portion to stabilize and increase the strength of CSEB. However, all laboratory work is conducted according to the ASTM and BS EN standard requirements. The flow of the research methodology is shown in **Figure 3.1**.

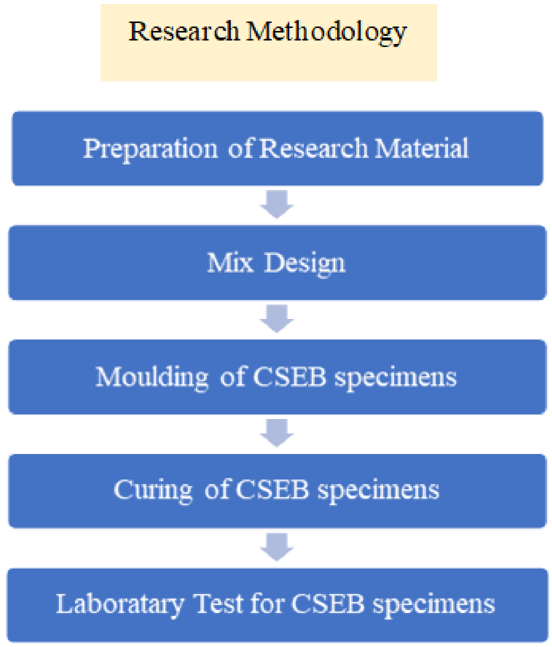

Figure 3.1: Methodology Flow of Research Study.

3.2 Preparation of Materials

Materials required for research study were kept and stored properly. To prevent the materials being affected by external environment especially absorption of excess moisture, airtight containers were used for material storage purpose. Before the fabrication work, the materials were labelled and characterized in Environmental Engineering Workshop of Universiti Tunku Abdul Rahman (UTAR).

3.2.1 Cement

In this research, cement is the stabilizer used to enhance the bonding between elements during CSEB fabrication. As referred to **Figure 3.2**, the cement used in this research study for CSEB fabrication was Ordinary Portland Cement (OPC) which YTL Cement Bhd manufactures. and complied with the standard, BS EN 197-1:2011 that is suitable for construction sector activities such as plastering work, concreting and bricklaying. Pre-hydrated cement clumps were obtained through a sieving process that used No.200 sieve. Hence, the size of pre-hydrated cement was larger than 0.074 *mm*, which resulted in a desirable hydration rate. In addition, an airtight container will be used to keep the sieved OPC properly to inhibit the hydration process that happens when in contact with the external environment.

Figure 3.2: Ordinary Portland Cement (OPC).

3.2.2 Aluminium dross (AD)

Aluminium dross used in this research were collected from Press Metal Aluminium Holdings Bhd. and it is in dry powder form. It is white dross and having pungent smell. As shown in **Figure 3.3**, AD was sieved through 100 μm opening sieve plate to collect the desired particles size.

Figure 3.3: Aluminium Dross in Powder Form (AD).

3.2.3 Soil

In this research study, the soil used for fabrication process was obtained from the ground land behind Construction Management Workshop of UTAR through digging around 0.5 *m* deep soil to prevent the collect of topsoil because topsoil consists of various types of organic materials that will reflect a low CSEB compressive strength. The organic materials found in excavated soil were removed also. The excavated soil was then undergone evaporation process in oven at temperature around 110 ℃ to remove excessive moisture in the soil. Furthermore, the dry soil was breaking into smaller size by using blender. To determine the suitability of soil in CSEB manufacturing, ASTM D2487-17 was used to evaluate the plastic limit, liquid limit and plasticity index of soil. According to the result obtained, the liquid limit and plastic limit of the soil was 58.42% and 36.07% respectively. Moreover, the plasticity index of soil was 22.98% therefore, the excavated soil was categorized as inorganic clay with high degree of plasticity. The plasticity of soil is depended on the types and amount of mineral content which indicates the suitability in CSEB fabrication. High plasticity soil will not indicate a high strength CSEB, therefore, to achieve a high strength CSEB, the clay mineral in the soil should be reduced through diluting it with sand.

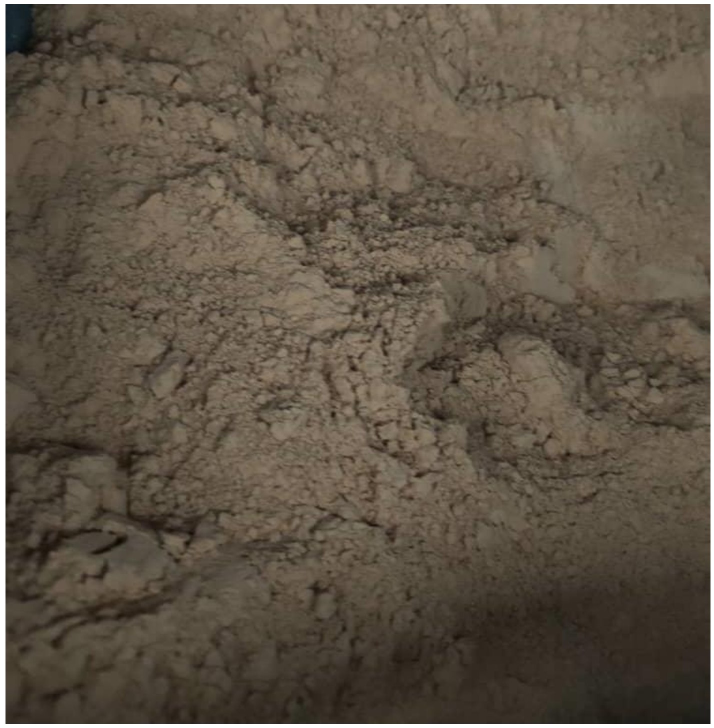

Figure 3.4: Inorganic Clay Soil.

3.2.4 Sand

The sand required for this research study was collected from the aggregates reserve at UTAR Construction Management Workshop. As refer to **Figure 3.5**, the sand was went through evaporation process in oven to remove excessive moisture and sieve through 600 μm sieve plate to obtain a fine aggregate sized sand.

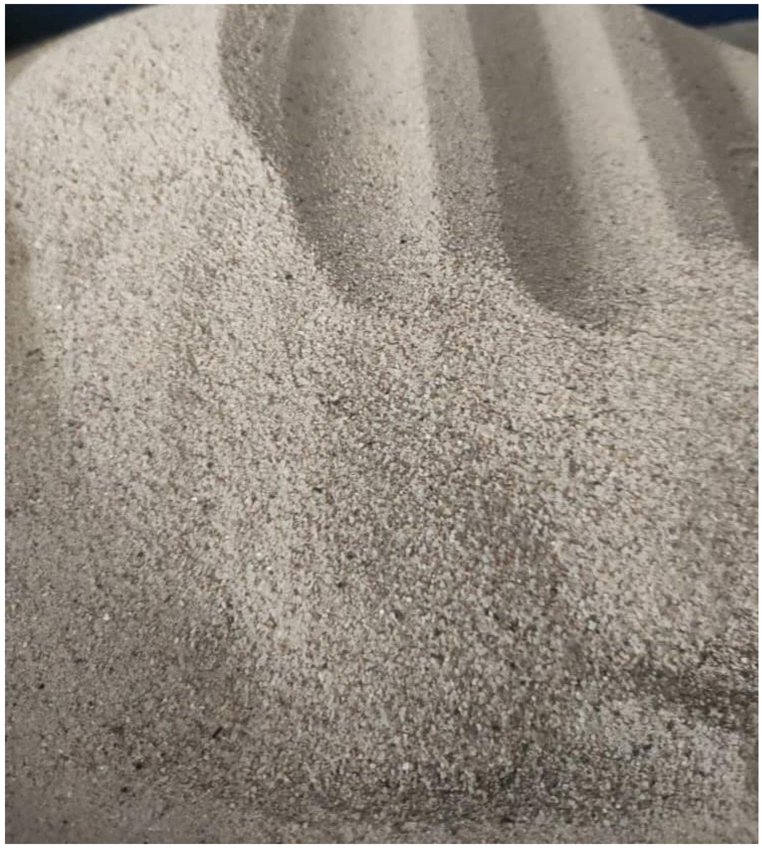

Figure 3.5: 600 μm Sand.

3.3 Mixing of Materials

Based on past relevant research study and trial mixes, various mix portion ratio for CSEB fabrication with or without waste materials were designed. The mix portion ratio by weight for stabilizer to earth was [9:1] while for sand to clay was [7:3] with a fixed water content at 1.50. The amount of cement used was reduced through substituting 0 to 35 % of AD. **Table 3.1** and **Table 3.2** show the respective proportion by weight design.

Table 3.1: Mix Proportion Ratio for CSEB Fabrication

Specimen	Proportion				
	Earth			Stabilizer	
	Water	Sand	Clay	Cement	AD
CS	1.5	5.3	2.2	1.00	0.00
CAD-5	1.5	5.3	2.2	0.95	0.05
CAD-10	1.5	5.3	2.2	0.90	0.10
CAD -15	1.5	5.3	2.2	0.85	0.15
CAD -20	1.5	5.3	2.2	0.80	0.20
CAD -25	1.5	5.3	2.2	0.75	0.25
CAD -30	1.5	5.3	2.2	0.70	0.30
CAD -35	1.5	5.3	2.2	0.65	0.35

Table 3.2: Mix Proportion for CSEB Fabrication in Term of Gram per Cube

Specimen	Proportion				
	Earth			Stabilizer	
	Water	Sand	Clay	Cement	AD
CS	46.88	165.63	68.75	31.25	0.00
CAD-5	46.88	165.63	68.75	29.70	1.55
CAD-10	46.88	165.63	68.75	28.13	3.13
CAD -15	46.88	165.63	68.75	26.58	4.68
CAD -20	46.88	165.63	68.75	25.00	6.25
CAD -25	46.88	165.63	68.75	23.45	7.80
CAD -30	46.88	165.63	68.75	21.88	9.38
CAD -35	46.88	165.63	68.75	20.33	10.93

Notes:

CS – Controlled CSEB specimen sorely stabilized with cement

CAD-*5 – CSEB specimen with 5 % AD substitution for cement replacement*

CAD-*10 – CSEB specimen with 10 % AD substitution for cement replacement*

CAD-*15 – CSEB specimen with 15 % AD substitution for cement replacement*

CAD-*20 – CSEB specimen with 20 % AD substitution for cement replacement*

CAD-*25 – CSEB specimen with 25 % AD substitution for cement replacement*

CAD-*30 – CSEB specimen with 30 % AD substitution for cement replacement*

CAD-*35 – CSEB specimen with 35 % AD substitution for cement replacement*

Figure 3.6: Mixture of CSEB.

3.4 Moulding of Specimens

Every specimen was cast into two different forms to evaluate its engineering properties through various laboratory tests. The two specimen forms were 50×50×50 *mm* cube specimen and 45 *mm* in diameter and 40 *mm* in height of cylinder specimen. First, the moulds were filled with CSEB mixture and manually compacted well through a hydraulic jack to achieve maximum compaction and thus reduce the void space. A consistence compressive force was exerted to every specimen and removed from the mould after completing the compression. Every specimen was properly labelled and characterized.

Figure 3.7: Moulding Set Up.

3.5 Curing of Specimens

The labelled specimens were placed at an ambient environment condition to complete the formation of specimens' rigid bodies. Curing process was carried out by spraying appropriate amount of water on specimens for 7, 14 and 28 days respectively to promote the hydration process in CSEB specimen for strength gaining purpose.

Figure 3.8: Curing Process by Spraying Water on CSEB Specimens.

3.6 Laboratory Tests

As refer to **Figure 3.10**, two forms of CSEB specimens were undergone various laboratory tests to evaluate the engineering properties and performance. Laboratory tests used to evaluate fired brick were applied to evaluate CSEB since that CSEB does not have specific standard testing method for CSEB performance evaluation (Fetra, Ismail, 2010). There are three specimens been fabricated for each test and 3 different curing period. Hence, there are total around 250 specimens had been fabricated for this research.

Table 3.3: Laboratory Test for Two Different Specimens

Cube (50×50×50 mm)	**Cylinder (45 mm diameter × 40 mm height)**
- Compressive strength test	- Porosity test
- Bulk density test	- Air permeability test
- Water absorption test	
- Microstructure analysis	

3.6.1 Bulk Density Test

ASTM C140/C140M-20 was complied to evaluate the density of CSEB specimens. First, the cube specimens were dried in an oven at around 100 to 115 °C to obtain the dry weight of cube specimens over 24 hours. After drying process, the specimens were placed at room temperature to cool down and obtain the dry weight of cube specimens. Then, the cube specimens were immersed completely in water. After this saturation process was undergone for 24 hours, the submerged weight of specimens were obtained. The surface water was removed to obtain the accurate saturation weight of cube specimens. After the saturation period, the submerged specimen weights in water were recorded as well. To obtain the bulk density of cube specimens, **Equation 3.1** was applied.

$$D = \frac{M_d}{M_w - M_s} \times 1000 \tag{3.1}$$

Where

D = Bulk Density, kg/m^3

M_d = Weight of dried specimens, g

M_w = Weight of submerged specimens, g

M_s= Weight of immersed specimens, g

3.6.2 Compressive Strength Test

A compressive strength test was carried out with the compliance of ASTM C140/C140M-20 to evaluate the cube specimens' compressive strength. Digicon-X1 compressive strength test machine was used to carry out the compressive strength test. However, before the strength test, the cube specimen dimension was measured using Vernier calliper. After that, the centroid of the cube specimen was measured and marked to ensure that the centroid of loading plates was aligned with centroid of cube specimen. The specimen was compressed by the machine until the specimen failed to resist the compressive force and the maximum load reading was recorded. The test was repeated for another two same variable specimens to obtain average compressive strength. The cube specimen's compressive strength was calculated by applying **Equation 3.2** as shown below.

$$S = \frac{P}{A} \tag{3.2}$$

Where

S = Compressive strength, N/mm^2

P = Maximum compressive load at failure of cube specimen, N

A = Surface area of cube specimen, mm^2

3.6.3 Water Absorption Test

ASTM C140/C140M-20 was accordance to evaluate the weathering resistant of CSEB cube specimens through water absorption test. First, the cube specimens were placed in oven for drying process for 24 hours to remove the excessive moisture content. After that, the cube specimens were taken out from the oven and placed at room temperature external environment to cool down. The weight of cube specimens was weighted and recorded. The cube specimens were then placed into water and submerged completely for 24 hours. After 24 hours, the saturated cube specimens were taken out, wiped to remove surface moisture and then weighted. **Equation 3.3** was used to calculate the water absorption percentage.

$$W = \frac{M_w - M_d}{M_d} \times 100 \tag{3.3}$$

Where

W = Water absorption percentage, %

M_d = Weight of dry cube specimens, g

M_w = Weight of submerged cube specimens, g

3.6.4 Porosity Test

To determine the amount of void spaces that existed in CSEB, porosity test was carried out to evaluate the impact of void space on the strength of CSEB. The higher the porousness of the specimen, the more the negative impact on the strength gaining of CSEB. Based on RILEM Recommendations, cylinder specimens were adopted to evaluate the porousness. The cylinder specimens were placed in an oven for drying process to remove excess moisture content. After 24 hours, the dry cylinder specimens were evacuated in a vacuum water-saturated desiccator for 15 minutes. Next, the cylinder specimens were soaked in water for another 3 hours and then repeated evacuation for 15 minutes. After evacuation, the cylinder specimens were placed and submerged completely in water for 24 hours. Lastly, the cylinder specimens were taken out from water, wiped and obtained the immersed and submerged weight. **Equation 3.4** was applied to calculate the porosity of the cylinder.

$$P = \frac{M_w - M_d}{M_w - M_s} \times 100 \tag{3.4}$$

Where

P = Porosity, %

M_d = Weight of dry cylinder specimens, g

M_w= Weight of submerged cylinder specimens, g

M_s = Weight of immersed cylinder specimens, g

3.6.5 Air Permeability Test

Building ventilation rate is depends on the air permeability of masonry unit, hence air permeability test was carried out to evaluate the air permeability of CSEB specimens. However, the higher the air permeability in CSEB, the durability of specimens will become weak. British Standard EN 196-6:2018 was complied to evaluate the air permeability of CSEB cylinder specimens. The cylinder specimens were placed in oven for drying purpose and after that proceed to place in airtight vessel. But before proceeding to airtight vessel, the dry cylinder specimens were weighted. In airtight vessel, the gas pressure was inserted into the vessel and pass through the pores and voids of CSEB and then the time taken for the air bubble to travel from one position to another position was observed and recorded. **Equation 3.5, 3.6 and 3.7** were used to calculate the air permeability.

$$K = \frac{2P_2\left(1.76 \times 10^{-16}\right)VL}{A(P_1^2 - P_2^2)} \qquad (3.5)$$

Where

K = Intrinsic permeability, m^2

P_1 = Absolute applied pressure bars (atmosphere pressure), usually 2 bars

P_2 = Pressure at which the flow rate is measured (atmosphere pressure), usually 1 bar

A = Cross sectional areas of specimens, m^2

L = Length of specimen, m

V = Flow rate, cm^3/s

$$V = \frac{\frac{D^2 \pi h}{4}}{T} \qquad (3.6)$$

Where

V = Flow rate, cm^3/s

D = Flowmeter diameter, cm

h = Length read on flowmeter, cm

T = Average time, s

$$A = \left(\frac{D^2}{4}\right)\pi \tag{3.6}$$

where

A = Cross sectional area of specimen, m^2

D = Diameter of specimen, m

3.6.6 Microstructure Analysis

Microstructure analysis was adopted to determine the microstructure properties of CSEB specimens. Microstructure analysis promoted a detailed view of the material matrix, internal structure, and permeability of CSEB specimens. Based on ASTM C1723-16, Field Emission Scanning Electron Microscope (FESEM) was used to determine the CSEB specimens' microstructure properties at 28^{th} day of curing period. The specimens were disintegrated into smaller pieces. 15 *kV* of SEM accelerating voltage was adjusted and 500, 1000, 2000 and 5000 x of magnification were set to observe the insight structure of CSEB. Moreover, Energy Dispersive X-ray Spectroscopy (EDX) was also adopted to observe AD powder.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this research, the percentage for AD to replace cement in fabrication of CSEB specimens are 0, 5, 10, 15, 20, 25, 30, 35 % respectively. After various laboratory tests, the results obtained were being discussed and compared.

4.2 Preliminary Analysis of Aluminium Dross

Energy Dispersive X-Ray Spectroscopy (EDX) was conducted to enhance the evaluation on the elemental characterization of AD. In this research, the basic elements of AD were identified. In addition, as shown in **Table 4.1**, three separate EDX spectra were used to calculate the average weightage of basic chemical elements in AD.

Table 4.1: Weightage of Basic Chemical Elements Composition in AD

Element	Weightage (%)
O	60.55
Na	5.36
Mg	5.87
Al	22.50
Cl	5.73
Total	100.00

The major element found in AD is O which used silica dioxide (SiO_2) as standard to determine present of O element. The high percentage of O was obtained because aluminium has high affinity towards oxygen after exposed to the air (Wibner, Antrekowitsch and Meisel, 2021). Beside O, there is abundant of Al and Mg which use alumina (Al_2O_3) and magnesium (MgO) as standard to determine them accordingly. According to Murayama et al. (2006), Al and Mg are main elements in AD while Na is considered as impurity exist in AD that originally exist in Al scrap. In addition, Cl is obtained from potassium chloride (KCl). As the Al has higher weightage, it reflects a higher amount of Al_2O_3 exist in AD. It is beneficial for soil stabilization in CSEB. Thus, it improves the possibility for AD to replace the usage of cement in CSEB fabrication.

Based on **Table 4.1**, it shows that AD has the potential in replacing the amount of cement used in CSEB fabrication. This is due to the cement hydration process will promote the generation of calcium hydroxide ($CaOH_2$) and react with Al and Si to form cementitious properties. For example, calcium silicate hydrate (C-S-H) gel and calcium aluminate hydrate (C-A-H) gel (Elahi et al., 2020). Hence, it is considered to have high similarity of chemical composition as compared with OPC.

4.3 Bulk Density

In this research, the bulk density of CSEB specimens at 28th days of curing period were measured, obtained average result and summarized in **Table 4.2** and **Figure 4.1**.

Table 4.2: Bulk Density of CSEB Specimens

Specimen	Bulk density at 28th day (kg/m^3)
CS	1933.75
CAD-5	1898.51
CAD-10	1884.39
CAD-15	1875.26
CAD-20	1861.17
CAD-25	1859.32
CAD-30	1841.97
CAD-35	-

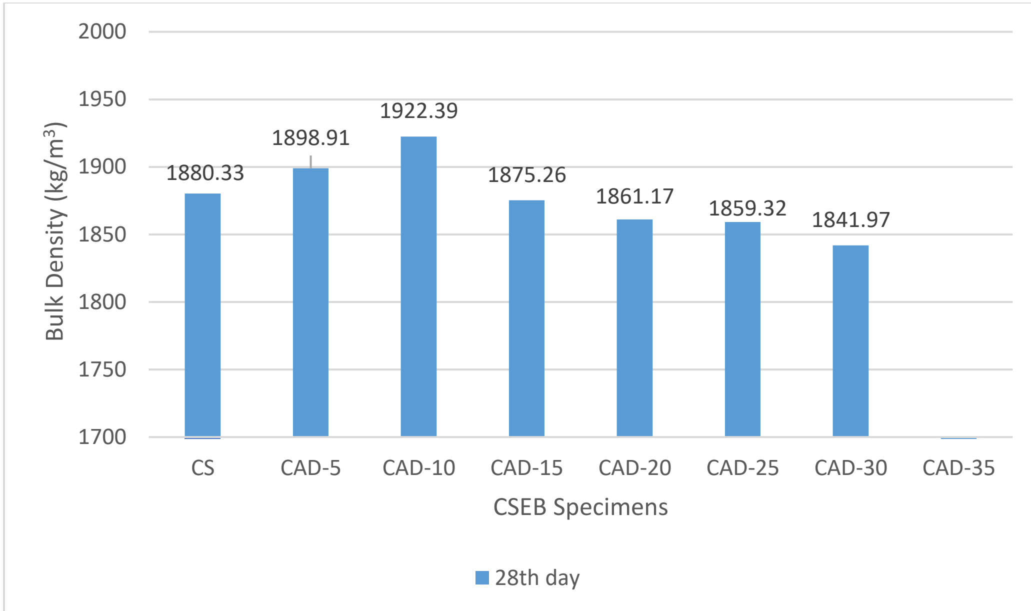

Figure 4.1: Graph of Bulk Density for CSEB Specimens at 28th Day.

Based on **Figure 4.1**, the highest dry bulk density for CSEB specimens with AD replacement was CAD-10 which reflect 1922.39 *kg/m*^{3} and increase the bulk density by 2.24% as compared with CS. It shows that the replacement of cement with AD had led to the reduction in density of CSEB specimen after the optimum AD substitution. According to Poorveekan, K.et al. (2021), the replacement of cement with waste will result in lower density brick as the density of waste is lower than cement. Hence, it can conclude that the density of CSEB is depends on constituent material's characteristic (Riza et al., 2010).

Furthermore, the cement's density will affect the density of the CSEB specimen due to the formation of C-S-H gel. The formation of C-S-H gel is depended on the reaction between cement, soil and water to fill up the gaps and hence densify the CSEB specimen. The reduction in cement percentage results in lesser cementitious material to perform the cement hydration process. Thus, the increase in AD substitution means a lower cement content. The density of CSEB specimens decreases since there are limited cementitious materials to form C-S-H gel between cement and soil (Elahi et al., 2020). As the AD replacement was above 10%, the density started to decrease, thus 10% of AD can be considered as an optimum replacement for CSEB specimens to react with calcium oxide (CaO) which is the product of crystallization of cement to form C-S-H gel and densify the specimens. However, when AD replacement is above 10%, there is not enough cementitious gel formed in the CSEB specimen due to lesser available CaO to be reacted and hence reduce density (Elahi et al., 2020).

For CAD- 35, the dry bulk density cannot be determined since it showed serious crack during immerse in water to determine the immersed weight and also saturation weight. This is due to insufficient C-S-H and C-A-H gels form between soil matrixes. Insufficient of cement will lead to lesser CaO generation and hence affect the formation of bonds that contribute to strength gaining. Moreover, the excess AD contributed to the formation of pores and void that will consequently generate capillaries for water to pass through easily.

In addition, based on ASTM Specification, the bulk density for brick at the range of 1680 to 2000 kg/m^3 is considered as medium weight brick while less than 1680 kg/m^3 is considered as light weight brick. Thus, all the specimens in this research considered as medium weight CSEB since all specimens fall between range. Moreover, according to past relevant research, bulk density with sawdust and wood ash replacement is at the range between 1380 to 2080 kg/m^3 while replace with palm oil fly ash, the bulk density ranged between 1339 to 1628 kg/m^3.

4.4 Compressive Strength

The average compressive strength of CSEB specimens with different curing ages are shown in **Table 4.3** and **Figure 4.2**. Moreover, the compressive strength development trends of CSEB specimens are shown in **Figure 4.3**.

Table 4.3: Compressive Strength of CSEB Specimen

Specimen	Compressive strength (N/mm^2)		
	7 days	14 days	28 days
CS	4.156	4.983	5.512
CAD-5	4.547	5.361	6.248
CAD-10	5.174	5.846	6.336
CAD-15	4.214	5.103	5.499
CAD-20	4.132	4.825	5.200
CAD-25	3.862	4.262	5.076
CAD-30	2.764	3.549	3.948
CAD-35	0.879	0.968	1.085

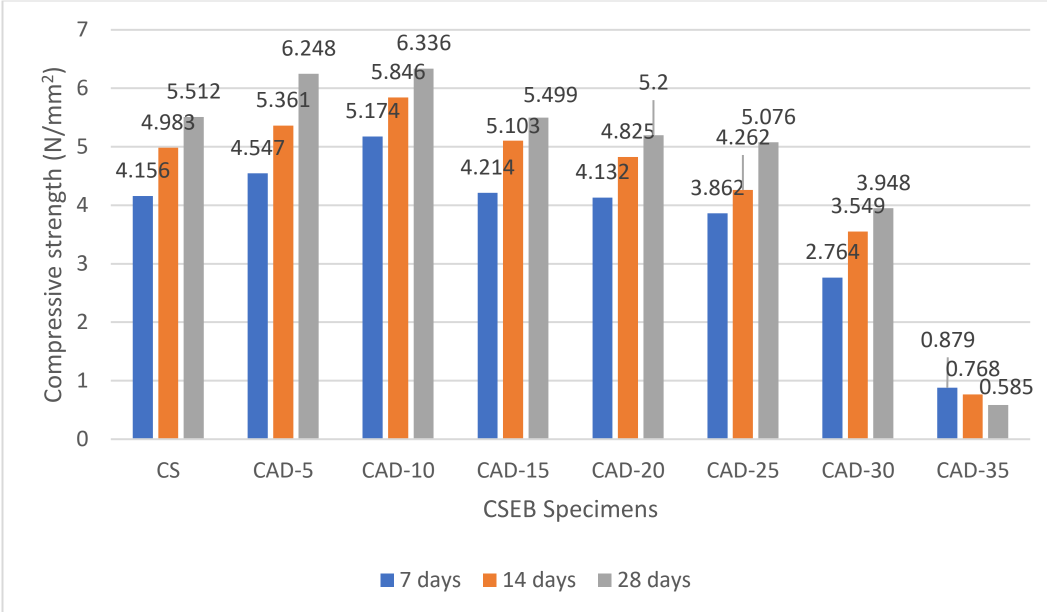

Figure 4.2: Graph of Average Compressive Strength against CSEB Specimen Design.

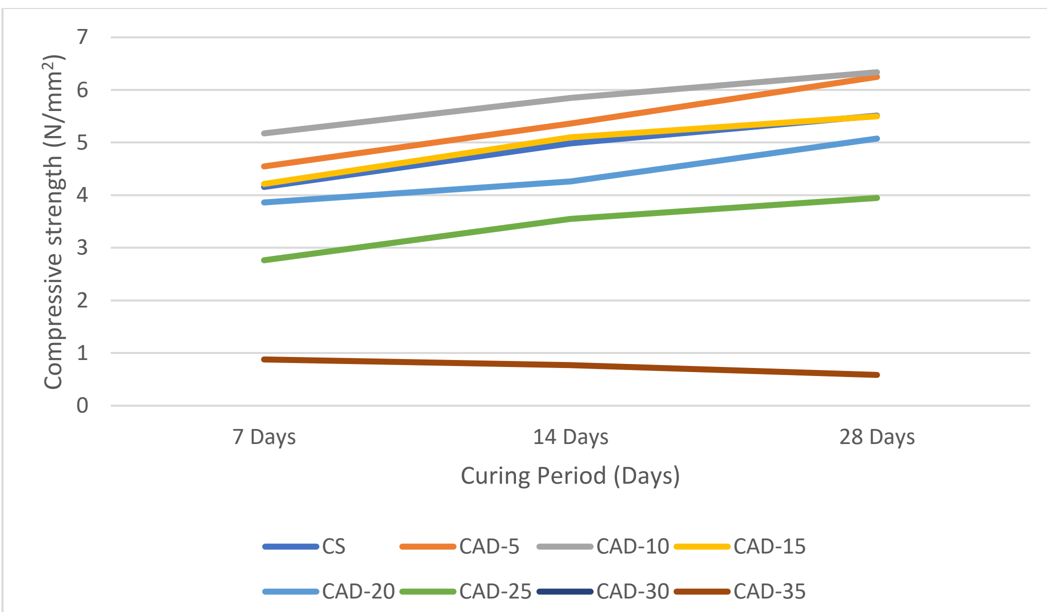

Figure 4.3: Graph of Compressive Strength Development Trend.

As refer to **Figure 4.2**, all the CSEB specimens after 28 days of curing period showed a higher compressive strength as compared to the specimens with 7 and 14 days of curing period. Moreover, as shown in **Figure 4.3**, there are increasing trend in strength gain which means that the increase in curing period ease for the strength gaining in specimens (Panditharadhya, B. et al., 2018). The compressive strength development is relied on the cement hydration process that produces the CaO in specimens. During cement hydration process, the cement will start to harden and gain up to 90% of ultimate strength after 28 days of curing period (C. Sekhar, D. and Nayak, S., 2018). Hence, it can conclude that the longer the curing age, it provides more sufficient time for CSEB specimen to gain strength through formation of C-S-H gel. However, for CAD- 35, it shows a decline trend as the increase in curing period.

Furthermore, as the AD percentage increased up to 10 %, it showed a higher strength gaining, resulting in 14.95 % increment and 6.336 *N/mm2* of compressive strength compared to the specimen without AD substitution (CS). However, after the substitution above 10 %, the strength gained started to decrease and resulted in a lower strength as compared to control specimens. Thus, it can conclude that the optimum cement replacement is 10 % of AD to achieve the highest compressive strength in CSEB specimens. This is because there is enough alumino-siliceous compound from SiO_2 and Al_2O_3 to react with CaO attribute from the cement hydration process and form C-S-H gel and C-A-H gel (Arthur Michael, 2019). Therefore, the pozzolanic reaction equation is shown as follow:

$$Ca_2SiO_5 + H_2O > CaO - SiO_2 - H_2O \qquad (4.1)$$

$$C_2S + H > C\text{-}S\text{-}H \qquad (4.2)$$

Moreover, as the substitution above 10 %, there is no sufficient SiO_2 and Al_2O_3 to form cementitious material for pozzolanic reaction and also less cement to fill the gap between the soil matrix which help in enhancing the strength development through bond connection between soil matrixes. Thus, the strength gained for CAD-15 after 28 days of curing period was even lower than CS since there is less C-S-H gel for strength enhancement. In addition, CaO is major product of cement after hydration process that contribute Ca. Therefore, it can conclude that sufficient SiO_2, Al_2O_3 and Ca is important for strength gaining (C. Sekhar, D. and Nayak, S., 2018). The optimum amount of SiO_2 and Al_2O_3 is achieved in CAD-10.

Besides that, as shown in **Figure 4.3**, there is a decreasing trend in strength development for the specimen with 35 % AD substitution. The decreasing trend is due to the dilution effect due to the AD substitution that causes adverse effects to the strength development at early ages (Aqel and Panesar, 2020). Less C-S-H gel can be formed due to less available cement to undergo the hydration process and produce CaO. Although AD is considered fine powder since the particle size is less than 100 μm and is beneficial for filling up the pores for strength gaining, the cementitious effect between soil matrixes is weaker than cement (Riaz et al., 2019). On the other hand, the "excess" AD will weaken the bonding between cement and soil matrixed and thus influence the strength development (Mailar et al., 2016).

According to Malaysia Standard MS 7.6:1972, the minimum strength for non-load bearing brick in construction masonry is 2.8 N/mm^2. To achieve the standard, minimum recommended compressive strength for specimen at 28^{th} day is 3 N/mm^2. As refer to **Figure 4.2**, CAD-5 to CAD-10 achieve above 3 N/mm^2, only CAD- 35 below the recommended strength. Hence, the replacement is feasible to take up to 30% of cement replacement since it still achieves more than 3 N/mm^2.

4.5 Water Absorption

The average water absorption results for different substitution percentage of CSEB specimens with 3 different curing ages are as shown in **Table 4.4** and **Figure 4.4**. Moreover, **Figure 4.5** shows the growth trend throughout the curing period.

Table 4.4: Water Absorption Rate of CSEB Specimen

Specimen	Water Absorption Rate (%)		
	7 days	14 days	28 days
CS	14.63	14.5	14.16
CAD-5	14.41	14.24	14.01
CAD-10	14.32	14.2	13.96
CAD-15	14.69	14.54	14.34
CAD-20	14.88	14.76	14.42
CAD-25	15.07	14.83	14.64
CAD-30	15.35	14.91	14.74
CAD-35	15.72	-	-

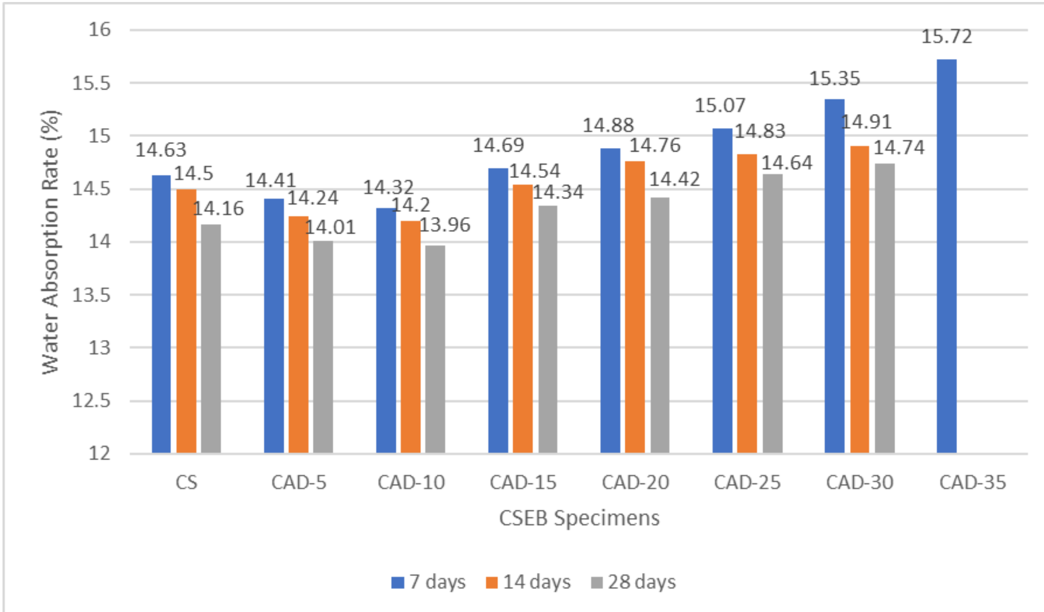

Figure 4.4: Graph of Water Absorption Rate against CSEB Specimen Design.

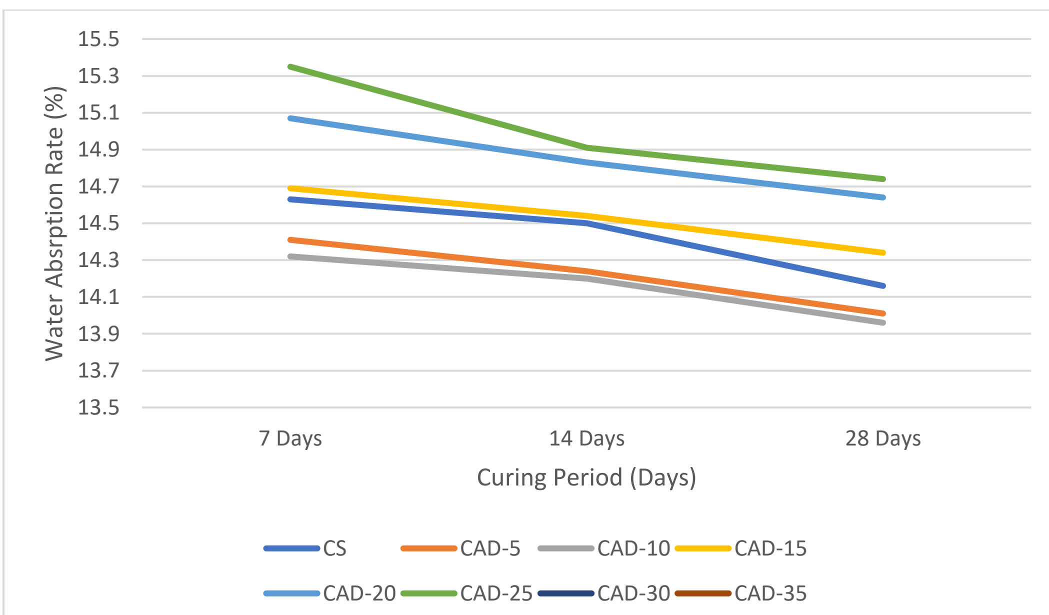

Figure 4.5: Graph of Water Absorption Rate Development Trend.

As refer to **Figure 4.5**, the water absorption rate for all the specimens showed a decline development trend as the increase in curing ages. According to Abdullah et al. (2017), as the curing ages increase, it provides sufficient time for CSEB specimens to form C-S-H gel. As there is sufficient time for cement to undergo hydration process, sufficient Ca will be produced for pozzolanic reaction with SiO_2 and Al_2O_3 to occur and hence promote the formation of C-S-H gel in soil matrixes. Formation of C-S-H gel will enhance in filling up the pores exist between the particles in specimens and make the specimen impervious in nature (Abdullah et al., 2017). Hence, it can conclude that, as the increase in curing ages, the lower the water absorption rate due to more complete curing process.

Based on **Figure 4.4**, there are two trends. First, there is decline trend from CS to CAD-10 and then an increment trend from CAD-15 to CAD-35. These variations are due to the characteristics of AD and result from cementitious and pozzolanic reaction that influence the porosity in specimens (Hany, Fouad, Abdel-Wahab and Sadek, 2021). Based on Mailar, G et al. (2016), the porosity governing the water absorption rate because it provides the pathway for fluids movement in specimens. Thus, it can say that CAD-10 has the least pores for fluids to pass through.

In addition, CAD-10 results the lowest water absorption rate which result 1.41 % of reduction as compared to other specimen and even CS which means that it has the least voids. This is credited to CAD-10 generated more C-S-H gel in soil matrixes to fill up the pores and contribute to improvement of bonding between soil and binding materials. Furthermore, CAD-10 considered can generate optimum amount of cementitious materials and result in lower dilution effect to the CSEB specimens. It has the sufficient cementitious materials to react with CaO which product of cement hydration and thus improve pozzolanic reaction to generate C-S-H gel.

However, as the replacement was more than 10 %, the water absorption rate rose due to more pores showing up in specimens. According to Hany, Fouad, Abdel-Wahab and Sadek (2021), the water ability of AD will affect the formation of pores by reducing the available water for cement to undergo the hydration process and eventually affect the of C-S-H gel that governs the formation of the pores. Therefore, as the AD amount increases, the more the water is absorbed and consequently increases the formation of the pores. Therefore, the more the pores formed in specimens, the higher the water absorption rate.

Besides that, CSEB does not have a specific standard for water absorption rate, but according to the Malaysia construction industry, recommended water absorption rate must less than 15 %. The lower the water absorption rate, the better the CSEB quality to resist weather effects like exposure to rain and sunlight. After 28 days of the curing period, all the specimens had achieved a water absorption rate less than 15 % except CAD-35. CAD-35 after 14 and 28 days of the curing period, specimens found serious crack during the test. Therefore, there is no result obtained. This is credit to not having enough bond to find the soil matrix and form a rigid specimen. As the increase in AD used over the optimum amount for cement replacement, less C-S-H and C-A-H gel were formed due to insufficient Si from cement and excessive Al will contribute to the pore’s formation. Consequently, as the specimens are placed into water, the water passes through the capillaries formed by the pores and voids rapidly and destroys the specimens. Therefore, the amount of AD substitution is very crucial.

4.6 Porosity

The average porosity results for different substitution percentage of CSEB specimens with 3 different curing ages are as shown in **Table 4.5** and **Figure 4.6**. Moreover, **Figure 4.7** shows the growth trend throughout the curing period.

Table 4.5: Porosity of CSEB Specimens

Specimen	Porosity Rate (%)		
	7 days	14 days	28 days
CS	26.72	26.41	26.02
CAD-5	26.43	26.19	25.78
CAD-10	26.18	26.03	25.43
CAD-15	27.27	26.58	26.12
CAD-20	27.5	26.79	26.32
CAD-25	27.74	27.19	26.85
CAD-30	28.19	27.79	27.35
CAD-35	29.32	-	-

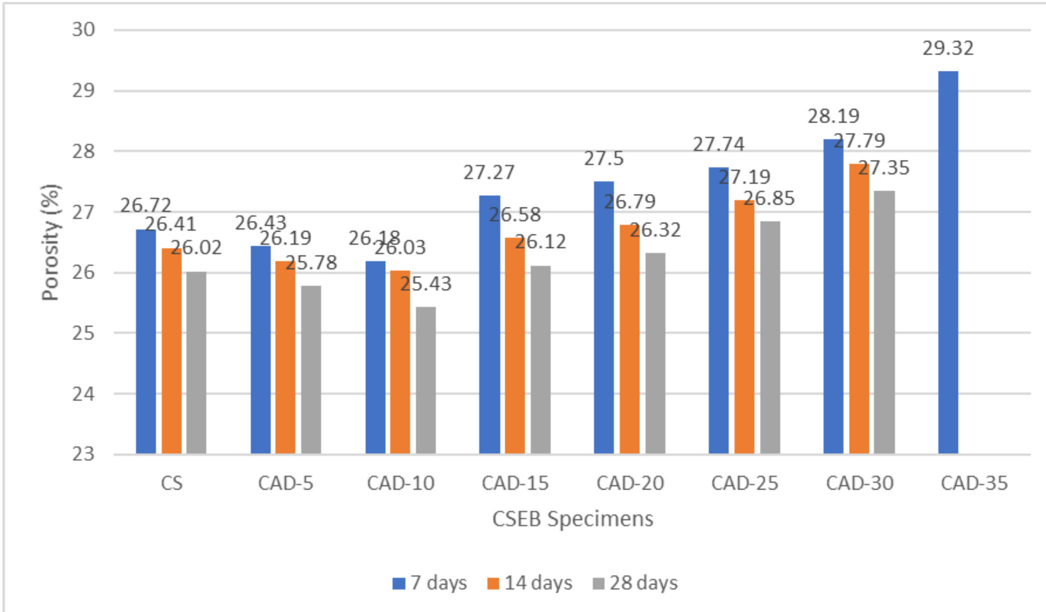

Figure 4.6: Graph of Porosity against CSEB Specimen Design.

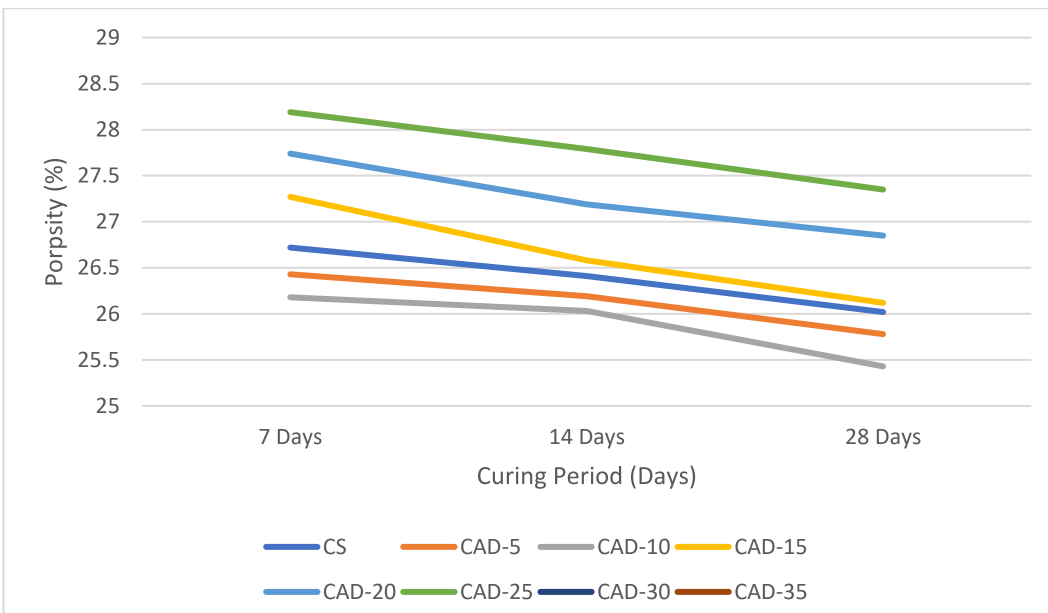

Figure 4.7: Graph of Porosity Development Trend.

Based on **Figure 4.7**, as the curing age increase, the porosity pf CSEB specimen showed a decline trend which prove that there is sufficient time for the formation of C-S-H and C-A-H gel through cement hydration process and pozzolanic reaction in specimens. The voids and pores in specimens being filled up by the gels and consequently improve the specimens become more impervious (Abdullah et al., 2017). Therefore, it can conclude that curing age is the one of the factors that influence the porosity of CSEB specimens.

As referred to **Figure 4.6**, there are two trends in porosity development in CSEB specimens as the substitution percentage increases. From CS to CAD-10, there is a declining trend, while from CAD-15 onward, it shows an inclining trend. According to Elahi et al., (2020), as the waste substitution is up to the optimum percentage, the pozzolanic reaction of waste will generate more cementitious materials between Ca from cement hydration. Therefore, the pores and voids will be filled up and reduce the porosity. However, as the substitution over the optimum percentage, AD will start to inhibit the bonding between soil matrixes and cementitious materials and increase the pores and voids in CSEB specimens. Thus, 10 % is the optimum percentage for cement replacement to reduce the porosity and shows 25.43 % of porosity percentage. In a nutshell, it can conclude that the AD substitution will affect the porosity in CSEB specimens.

In addition, as the optimum AD substitution, there are sufficient Si and Al from AD in CSEB specimen and hence react with the Ca from cement hydration process and form C-S-H and C-A-H gel during pozzolanic reaction. These gels will bind the pores and voids exist in specimens and thus reduce the porosity. Thus, CAD-10 has the most gels in specimens and result least pores as compared to CS. Moreover, in CAD-10, it shows the smallest dilution effect that affect the formation of cementitious materials.

Furthermore, there is a clear correlation between the porosity, density, compressive strength and water absorption. The lower porosity shows a higher density, compressive strength, and lower water absorption rate. These are closely based on the pores and voids that exist in CSEB specimens. The more the C-S-H and C-A-H gels formed, the less pores and voids formed. Hence, from the above mentioned, CAD-10 is the optimum substitution percentage. Last but not least, porosity is one of the important CSEB's parameters because it will directly affect thermal performance. The lesser the pores, the stronger the resistant effect inhibiting the heat transfer across the brick. (Singh et al., 2018).

However, as mentioned above, the water absorption and porosity having a positive correlation, for CAD-35 with 14 and 28 days of curing period found serious crack and lead to null result due to the insufficient bond form between soil matrix to form rigid specimen. In CAD-35, the cement amount is reduced until less amount C-S-H and C-A-H gel formation which highly influence by the amount of Si from cement and Al from both cement and AD. Consequently, as the specimens placed into water, the water pass through the capillaries form by the pores and voids at a rapid speed and destruct the specimens which lead to no result obtained for porosity determination.

4.7 Air Permeability

The average air permeability results for different substitution percentage of CSEB specimens with 3 different curing ages are as shown in **Table 4.6** and **Figure 4.8**. Moreover, **Figure 4.9** shows the growth trend throughout the curing period.

Table 4.6: Air Permeability of CSEB Specimens

Specimen	Air Permeability Rate ($\times 10^{-13}\, m^2$)		
	7 days	14 days	28 days
CS	8.68	8.03	7.89
CAD-5	8.16	7.82	7.57
CAD-10	7.28	7.17	6.9
CAD-15	8.91	8.39	8.22
CAD-20	9.32	8.83	8.59
CAD-25	9.58	9.39	9.06
CAD-30	11.31	10.61	9.79
CAD-35	12.35	-	-

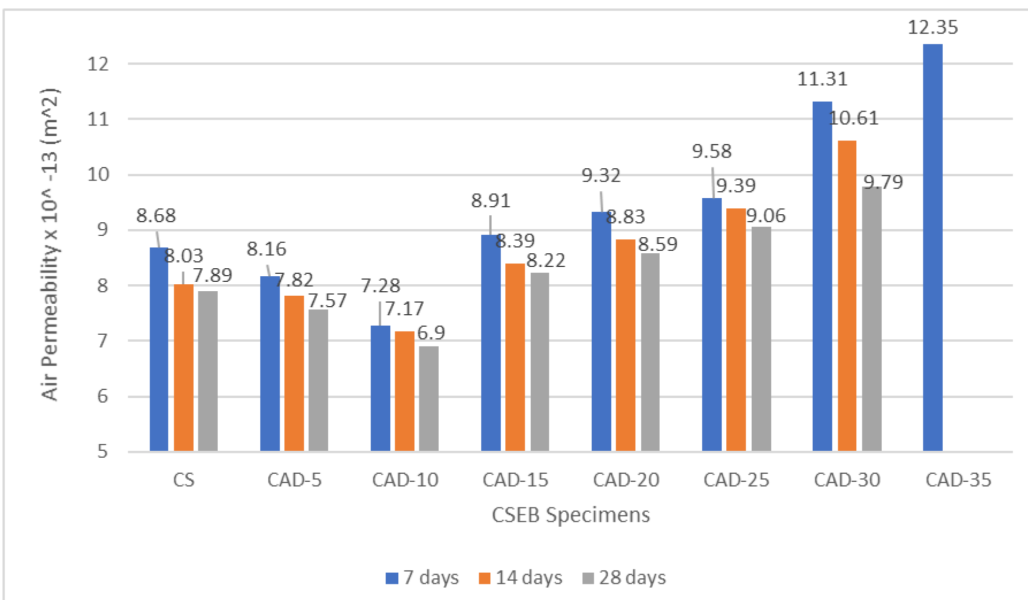

Figure 4.8: Graph of Air Permeability Against CSEB Specimen Design.

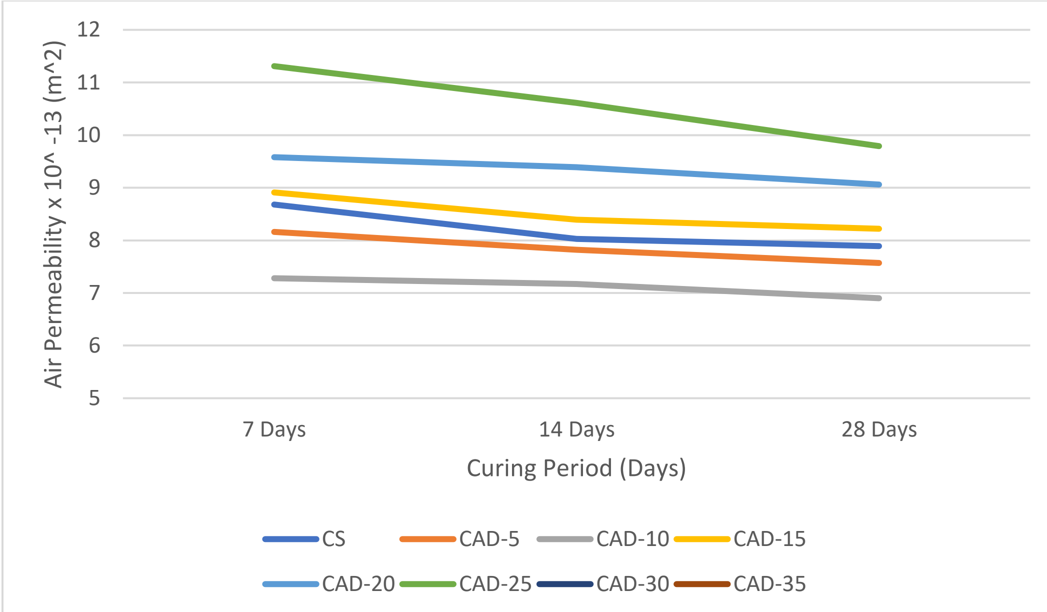

Figure 4.9: Graph of Air Permeability Development Trend.

As shown in **Figure 4.9**, all the CSEB specimens reflected a declining trend in air permeability development, which is considered a good scenario as the curing period increases. The formation of declining trend is due to the formation of C-S-H and C-A-H gel in specimens that will fill up the pores and voids and hence decrease the air permeability. Moreover, as the curing age increases, cement has sufficient time to undergo the hydration process to generate CaO contributing to pozzolanic reaction. Si in cement and Al in both cement and AD will react with Ca from CaO and consequently form the gel. It can be concluded that pores and voids in CSEB specimens that affect air permeability will become lesser as the curing age increases.

Moreover, based on **Figure 4.8**, it can observe that the air permeability shows decline trend from CS to CAD-10 and incline trend after CAD-10 which can conclude that the optimum AD substitution is 10 % and result a reduction in air permeability by 12.55 % after 28 days of curing period. Hence, the lowest air permeability result is 6.9×10^{-13} m^2. In addition, the correlation shown between air permeability and AD substitution in CSEB specimen is same as the porosity of CSEB specimen. As mentioned above, the pores and voids that form the capillaries in CSEB specimen will enhance the air to pass through. Thus, the air permeability of CSEB specimen is highly affected by macrostructure pattern. The more the capillaries form in CSEB specimen, the higher the air permeability result will be obtained. It can conclude that CAD-10 has the least microporosities present in CSEB specimen and contribute to lowest air permeability among others.

The increase in AD substitution until the optimum amount increases the cementitious material to bind with soil matrixes and hence reduces the formation of pores, voids, and capillaries that enhance the air to pass through. Therefore, CAD-10 can be concluded as the optimum substitute percentage since CAD-15 and above show higher air permeability results. The optimum substitution of AD consists of sufficient C-S-H and C-A-H gel to fill up the gaps in the CSEB specimen through the pozzolanic reaction with CaO from the cement hydration process. Furthermore, as the AD substitution over the optimum amount, the unreacted AD will contribute to the formation of porosity that influences the air permeability of the CSEB specimen.

On the other hand, there is inversely proportional relationship between air permeability and compressive strength in CSEB specimens. As the decrease in air permeability, compressive strength increases together with density. Both tests shown that the optimum substitution of AD is 10%. In a nutshell, it can conclude that both tests in this research study are valid. However, for CAD-35, air permeability test had the same result observed during the test which is the serious crack found on the specimen. The reason is same as stated for water absorption and porosity test.

4.8 Microstructure Analysis

In this research study, the microstructure of AD and CSEB specimens were analyzed through Field Emission Scanning Electron Microscopy (FESEM) analysis. This analysis is to observe and analyze the internal structure of AD and CSEB specimens.

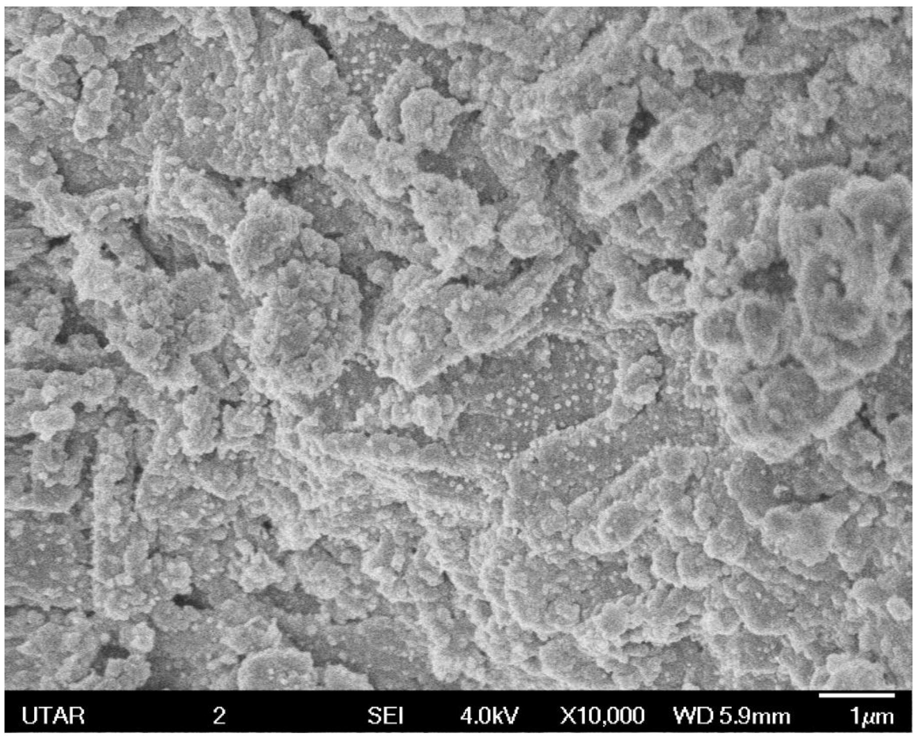

Figure 4.10: FESEM Image of AD.

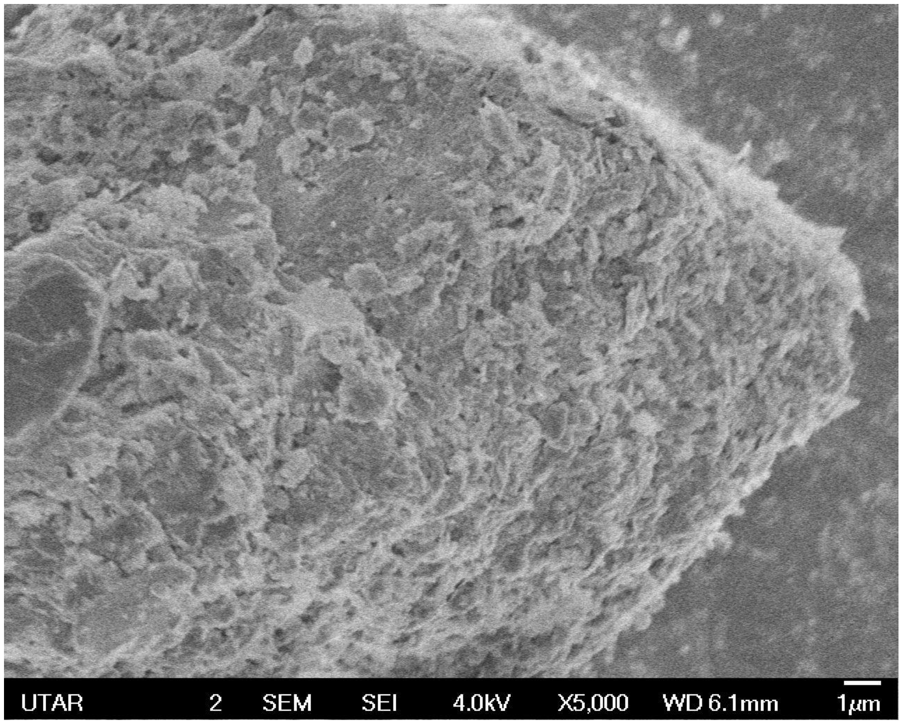

Figure 4.11: FESEM Image of Specimen CS.

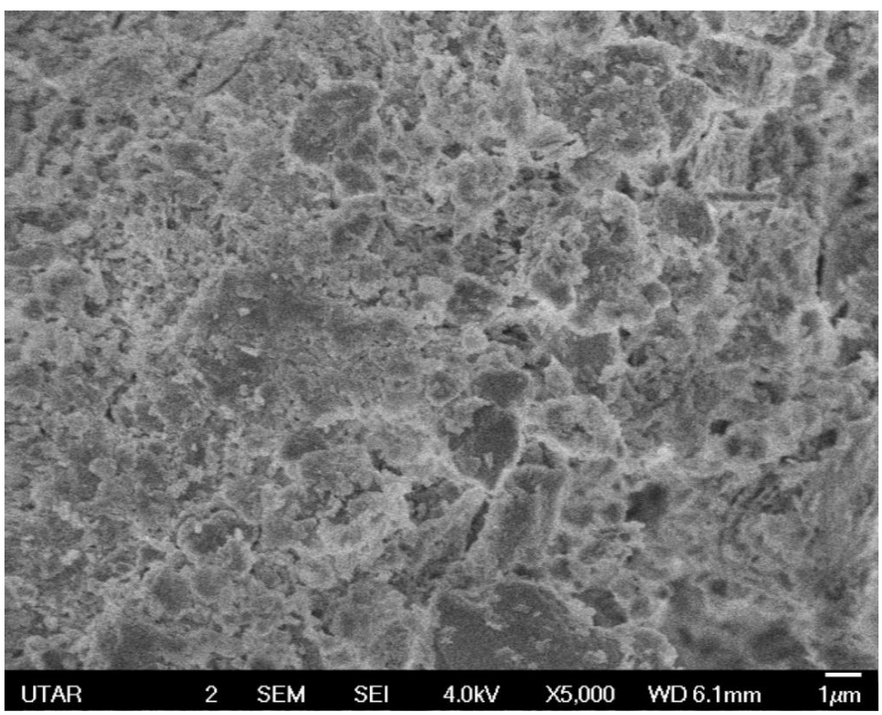

Figure 4.12: FESEM Image of Specimen CAD-5.

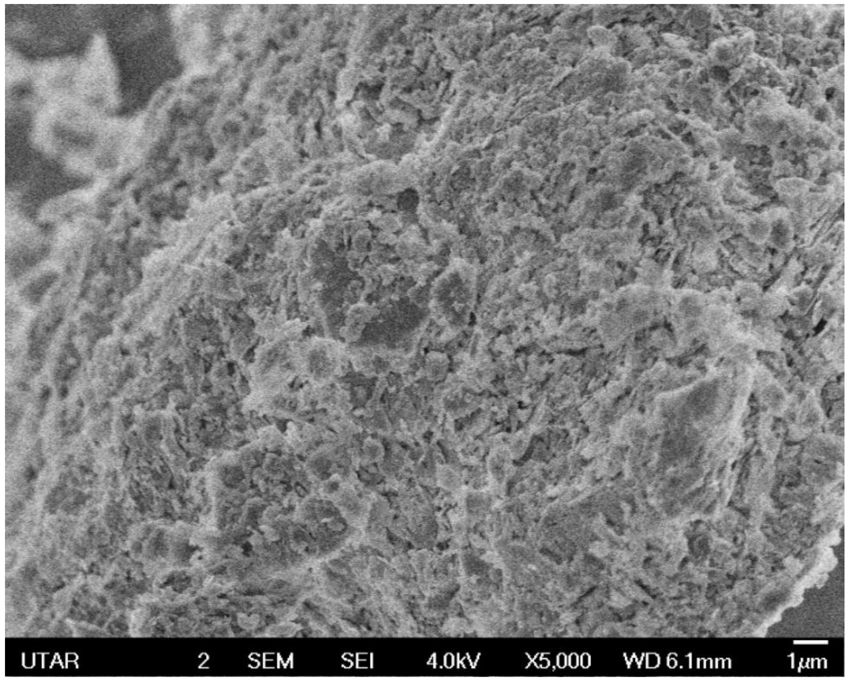

Figure 4.13: FESEM Image of Specimen CAD-10.

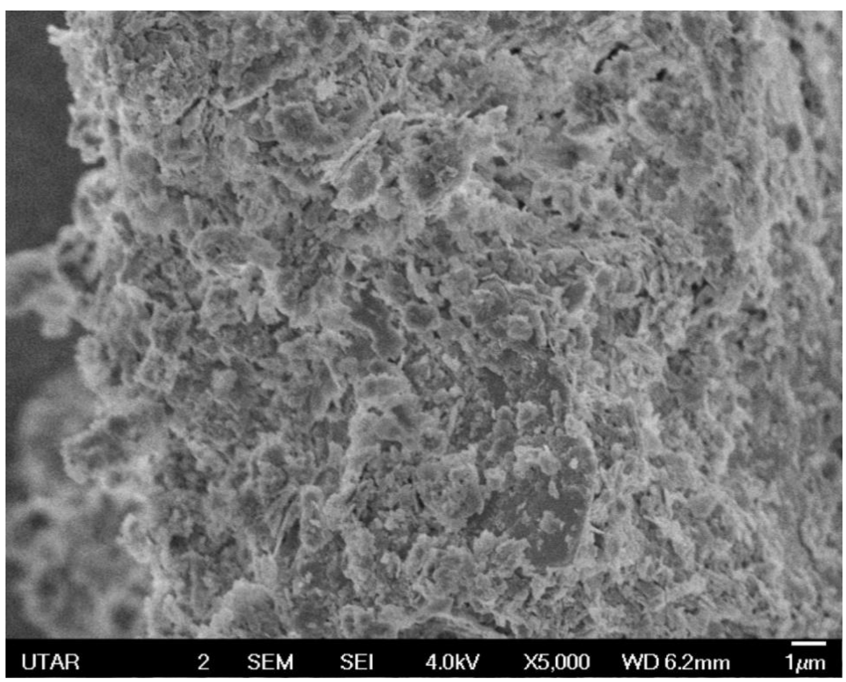

Figure 4.14: FESEM Image of Specimen CAD-15.

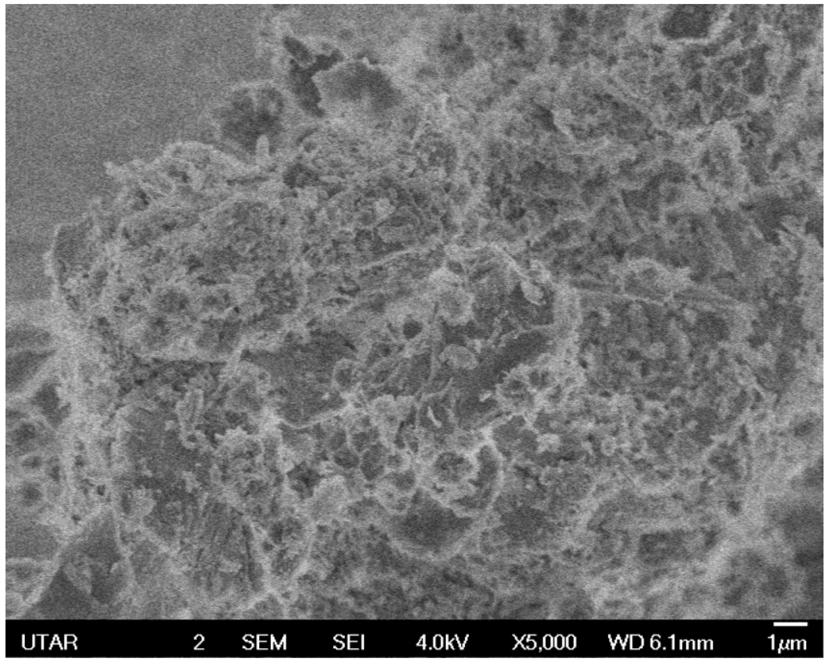

Figure 4.15: FESEM Image of Specimen CAD-20.

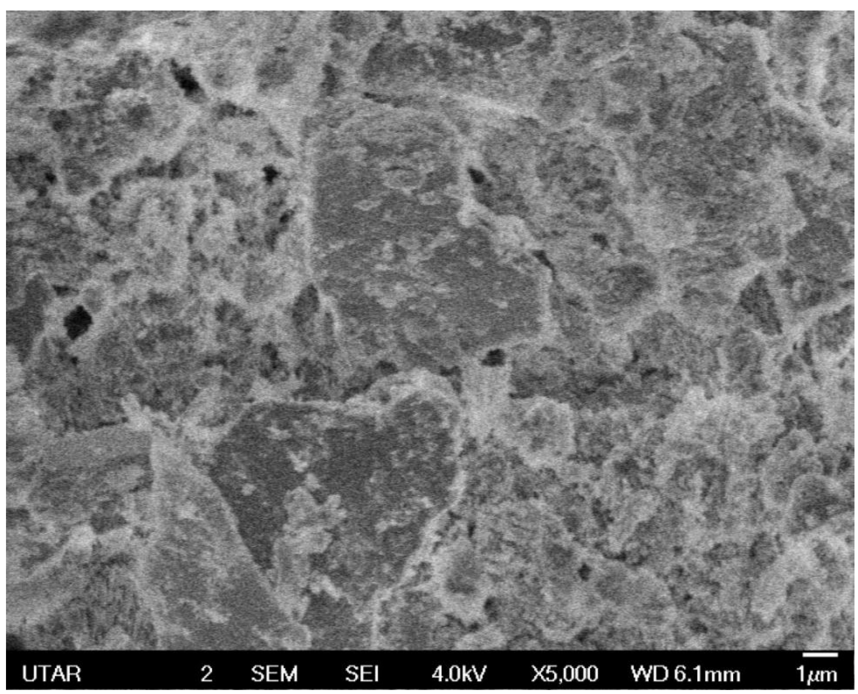

Figure 4.16: FESEM Image of Specimen CAD-25.

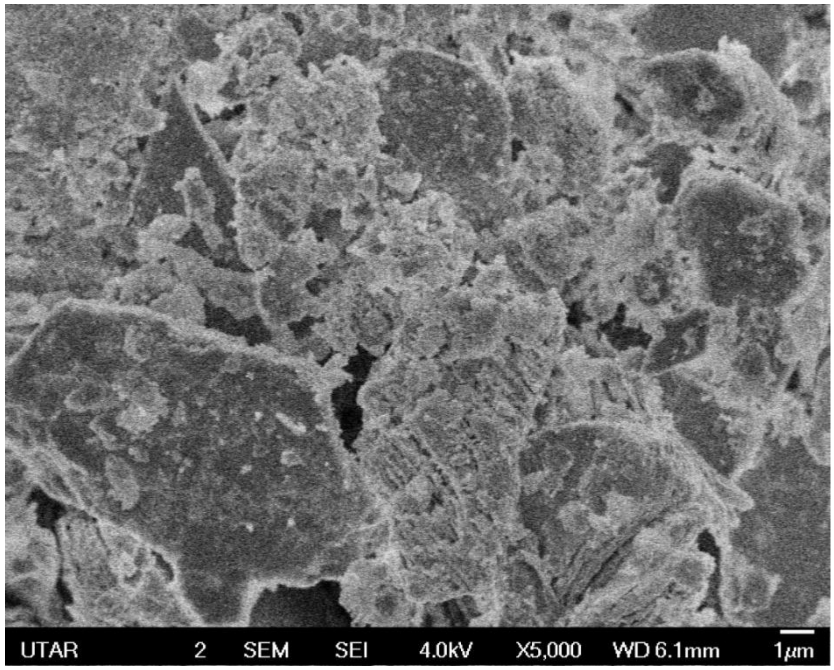

Figure 4.17: FESEM Image of Specimen CAD-30.

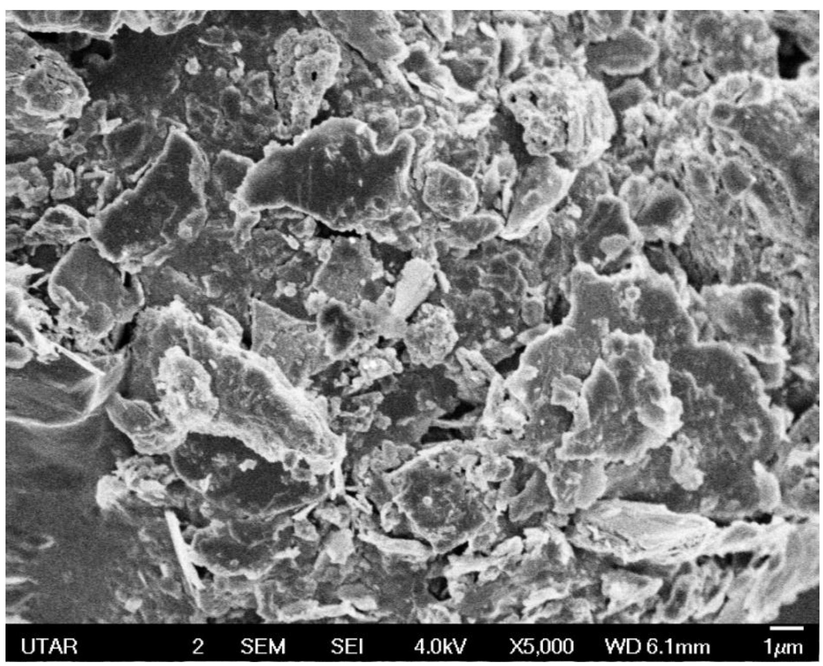

Figure 4.18: FESEM Image of Specimen CAD-35.

As refer to **Figure 4.11**, SEM image for control specimen which stabilized by cement only is shown. From the image, a homogenous and dense microstructure can be observed. However, few tiny pores and voids are spotted also. To prove the occurrence of cement hydration process, C-S-H or C-A-H gels that bind the soil matrixes are found from the image.

In addition, the SEM images with 5000x magnification of CSEB specimens with different AD substitution percentages are as shown in **Figure 4.12** to **Figure 4.18**. As the AD substitution increases from 15 to 35 %, lesser C-S-H or C-A-H gels can be found in CSEB specimens, while 10% of AD substitution has the most C-S-H or C-A-H gels. It is credit to the dilution effect as mentioned above, and lesser cement amount indicates lesser C-S-H or C-A-H gels formation in specimens due to less cement hydration process. However, for CAD-10, although the cement amount is reduced, the optimum amount of Al from AD can react with CaO from cement hydration. Hence, more C-S-H or C-A-H gels can be formed through pozzolanic reaction and eventually densify the specimen, although there are still some tiny pores and voids.

On the other hand, as the AD substitution over the optimum amount, more pores and voids are found which can be observed from **Figure 4.14** to **4.18**. This credit to the excessive AD substitution that promotes the formation of pores and voids. The more the pore formation, the weaker the compressive strength. Moreover, from the images, the microstructure is looser, indicating the pores and voids formation. The pores and voids' formation proves the weak bond between soil matrixes. However, for CAD-35 as shown in **Figure 4.18**, it shows the loosest soil matrixes due to insufficient Al and Si from cement although AD consists of sufficient of Al, the binding effect is still much weaker than cement.

In a nutshell, CAD-10 has the denser microstructure and lesser pores and voids formation due to the optimum Al from AD and promote the formation of bond to bind between soil matrixes. AD can promote the binding effect and also lead to formation of pores and voids based on the amount of substitution. Therefore, as shown in **Figure 4.14** to **Figure 4.18**, it also indicates the increase in water absorption rate, porosity and air permeability as higher percentage of AD substitution.

4.9 Comparative Evaluation of Fabricated CSEB

In this analysis, control set (CS) which fully stabilized by cement only was used to act as baseline for comparison purpose with standard of CSEB. The suitability of CSEB specimen with 5, 10, 15, 20, 25, 30 and 35 % of AD substitution. The recommended criteria from Auroville Earth Institution are used to analyze the CSEB specimen. In **Table 4.7**, it shows the comparison between the fabricated CSEB after 28 days of curing period and standard.

Table 4.7: Comparison Between Auroville Earth Institute Standard and Fabricated CSEB

Properties	Auroville Earth Institute	Fabricated Control Specimen (CS)	Fabricated Specimen (CAD-5)	Fabricated Specimen (CAD-10)
Density (*kg/m³*)	1700 - 2000	1880.33	1898.91	1922.39
Compressive Strength (*N/mm²*)	3 - 7	5.512	6.248	6.336
Water Absorption (%)	8 - 15	14.16	14.01	13.96

Table 4.7: Comparison Between Auroville Earth Institute Standard and Fabricated CSEB (Continued)

Properties	Fabricated Specimen (CAD-15)	Fabricated Specimen (CAD-20)	Fabricated Specimen (CAD-25)	Fabricated Specimen (CAD-30)
Density (*kg/m³*)	1875.26	1861.17	1859.32	1841.97
Compressive Strength (*N/mm²*)	6.016	5.200	5.076	3.948
Water Absorption (%)	14.34	14.42	14.64	14.74

Table 4.7: Comparison Between Auroville Earth Institute Standard and Fabricated CSEB (Continued)

Properties	Fabricated Specimen (CAD-35)
Density (*kg/m³*)	-
Compressive Strength (*N/mm²*)	0.585
Water Absorption (%)	-

As refer to **Table 4.7**, the control specimen (CS) which only stabilized by cement without AD substitution result its density, compressive strength and water absorption within the recommended CSEB standard stated by Auroville Earth Institution. It concludes that the fabricated control specimen in this research was almost consistence with the regular CSEB that fabricated in instutute and suitable for masonry construction purpose.

As the AD added into CSEB to replace the cement from 5 % to 10 %, the density, compressive strength and water absorption started to show an incline trend within the recommended standard. CSEB with 10 % of AD substitution (CAD-10) shows the highest density (1922.39 kg/m^3), compressive strength (6.336 N/mm^2) and lowest water absorption (13.96 %) among the CSEB specimens with different percentage of substitution. Therefore, it can conclude that CAD-10 is the optimum substitution percentage that result in positive strength gaining and still fulfill the required standard. However, as AD substitution increased to 15% (CAD-15), it reflects the mechanical properties lower than control specimen but it still within the standard.

Besides that, CAD-20, CAD-25, CAD-30 show the mechanical properties which lower as compared to CS but still achieved the minimum requirement for a masonry brick. However, for CAD-35, the compressive strength (0.585 N/mm^2) is much lower than the minimum strength required for a brick. Not only compressive strength did not achieve the standard, the density and water absorption obtained a null result due to the cracking of the brick during the test. Hence, CAD-35 is concluded as not feasible for a masonry brick.

According to the result obtained from the comparison evaluation, almost all the CSEB specimens in this research had met the standard for CSEB except CAD-35. CAD-10 had reflected a higher result in strength gaining while reducing 10 % of the cement as compared to others. Although CAD-15 obtained a lower mechanical strength as compared to CAD-10, but it still remains within the standard and similar to the mechanical properties obtained for CS. However, CAD-30 is still considered feasible since the mechanical properties obtained do not compromise the CSEB standard. In the conclusion, three different AD substitutions influence the mechanical properties development, balance state of mechanical properties and cement replacement: 10% of AD substitution reflected the optimum CSEB strength, 15% of AD substitution reflected a balanced state of mechanical properties; CAD-30 indicated the maximum percentage of cement with AD substitution.

4.10 Feasibility Analysis of Fabricated CSEB

This analysis was performed to study the feasibility of incorporation of AD in CSEB fabrication for partial cement replacement purpose through adopting different indicators: carbon dioxide (CO_2) emission, total energy consumption and total cost consumption. Total energy consumption is attributed by cement energy and electrical energy consumption while total cost consumption is attributed by cement and electric cost. Moreover, CO_2 is said to be indicated potential global warming while total energy consumption will indicate the substantial economic growth during the extraction of raw material and manufacturing process. According to Abdullah et al. (2017), one ton of CSEB specimens will emit around 22 kg of CO_2 as compared to fired clay brick which generate 200 kg of CO_2 per ton of brick. Hence, it can be concluded that it is environmentally friendly and sustainable brick which contribute to pollution reduction, energy consumption and eventually biomass fuel.

Based on Rescic, Mattone, Fratini and Luvidi (2021) stated, around 0.894 *kg* of CO_2 will be generated per kg of cement during the raw material extraction phase in CSEB's life cycle. Furthermore, CSEB requires around 4464 *kJ* of energy consumption from 1 *kg* of cement during the raw material extraction phase. Besides, as per the latest market price, 1 *kg* of Portland cement costs RM 0.36. On the other hand, according to Tenaga Nasional Berhad (TNB), the low voltage general industrial tariff rate is RM 0.38 per kilowatt-hour for the first 200 kWh per month. Therefore, this analysis aims to determine the feasibility between CSEB that is solely stabilized by cement (CS) and CSEB with 15% of AD for cement replacement (CAD-15) since it reflects almost similar mechanical properties to CS. It is shown in **Figure 4.3** on the compressive strength gained by the CSEB.

Table 4.8: Feasibility Analysis for CSEB Fabrication

Indicators	Fabricated CSEB		
	CS	CAD-15	Difference (%)
CO_2 Emission (*kg* CO_2)	0.028	0.024	14.29
Energy Consumption (*kJ*)	139.50	118.63	14.96
Cement Cost (RM)	0.0113	0.0096	15.04

Based on **Table 4.8**, it shows a reduction in CO_2 emission by 14.29 % when 15 % of AD had been used for cement replacement in CSEB fabrication. Besides CO_2 emission, the energy consumption was also reduced by 14.96 % from 139.50 *kJ* to 118.63 *kJ* in CAD-15 since it has lesser cement composition and eventually leads to lesser cement production. As a look into cost-effective, CAD-15 had reduced the total cost by 15.04 % to RM 0.0096 from RM 0.0113. This is an attribute to the cement used reduced in CAD-15; hence, the cement cost is directly proportional to the amount of cement used. In conclusion, AD substitution for partial cement replacement is feasible as it positively affects the environmental sector and the production price.

4.11 Cost of Real Size CSEB Fabrication

This study is to determine the cost to fabricate a real size CSEB that feasible to be marketed and increase the overall profit earning. Based on Brick Industry Association stated the size of brick is range between 88.9 *mm* x 57.15 *mm* x 193.68 *mm* and 92.08 *mm* x 92.08 *mm* x 295.23 *mm* (depth x height x length). Moreover, in this research, there is addition research work on fabricating CAD-30 in the size of 20.8 *mm* x 90 *mm* x 90 *mm* which within the range stated by Brick Industry Association since CAD-30 achieved above 3 N/mm^2 as a masonry brick. Based on **Table 4.9**, the mix proportion of CAD-30 for real size brick fabrication had been shown and **Table 4.10** shows the cost comparison between CS and CAD-30.

Table 4.9: Mix Proportion for CSEB Fabrication in Term of kg per Brick

Specimen	**Proportion**				
	Earth			**Stabilizer**	
	Water	**Sand**	**Clay**	**Cement**	**AD**
CS	0.488	2.297	0.953	0.433	0
CAD -30	0.488	2.297	0.953	0.303	0.130

According to Bernama stated in New Straits Times, the current water tariff is RM 1.38 per one thousand litres of water consumed. Moreover, one ton of fined sand is around RM 37.00 while the price of clay is about RM 0.80 per kg as per quoted by Man Thong Hardware Trading Sdn Bhd. Furthermore, the cost of cement and electricity as per mentioned above are RM 0.36 per *kg* and RM 0.38 per *kilowatt-hour* for the first 200 *kWh* per month. In this additional research, the mixer was used to improve the mixing efficiency consumed 2.050 *kWh* while the grinder consumed 0.7 *kWh*. The grinder is being used to grind the AD into more powder form contribute to strength gaining as the surface area of AD increased for the reaction with cement.

Table 4.10: Cost Comparison Between CS and CAD-30

Composition	Fabricated CSEB		
	CS	CAD-30	Difference (%)
Water cost (RM)	6.73 x 10^{-4}	6.73 x 10^{-4}	0
Sand cost (RM)	0.085	0.085	0
Clay cost (RM)	0.762	0.762	0
Cement cost (RM)	0.159	0.109	45.87%
Electricity cost (For grinding and mixing) (RM)	1.20 x 10^{-6}	1.80 x 10^{-6}	50.00 %
Total Cost (RM)	1.007	0.957	4.97 %

Based on **Table 4.10**, the cement cost for CAD-30 had reduced by 45.87% as the cement being replaced by 30 % of AD and consequently contribute to reduction in overall cost for CSEB fabrication by 4.97 % although CAD-30 required 50 % more cost for electricity. In this research, the parameter that contribute to the reduction in cost is the amount of cement used for CSEB fabrication. Since red soil brick consist of large amount of clay for fabrication, its selling price can be used as reference for CSEB's price. In Malaysia, red soil brick is cost around RM 1.20 per piece (Red Brick or Cement Brick – Which Should You Buy?, 2021). As the cost for CAD-30 is about RM 0.957, it will contribute to a profit earn of RM 0.243 per piece which is 25.91 % more profit as compared to CS. Moreover, as abovementioned, the reduction in cement used will contribute to reduction in environmental pollution based on the life cycle of cement production. Hence, CAD-30 is considered as eco-friendly brick that keeping AD out from the ecosystem and prevent the contamination to environment. Moreover, eco-friendly brick had become a trend for sustainable development and eventually increase the market for CSEB with AD substitution (Hodgkinson, 2019). Therefore, CAD-30 is feasible for market purpose since it will generate higher profit as compared to common brick that highly depends on the usage of cement for strength gaining coupled with the achievement on the recommended strength as masonry unit and also sustainability.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Regarding the objectives listed at the beginning of the research, all of the objectives have been achieved successfully. Most of the compressed stabilized earth brick (CSEB) fabricated under this research with and without aluminium dross (AD) substitution had achieved the brick industry's standard. Moreover, various laboratory tests had been conducted to determine the CSEB mechanical properties and durability. Hence, the outcome of this research could be summarized as stated below:

1. Most of the CSEB after 28 days of curing period had achieved the recommended requirement on density, compressive strength and water absorption rate as a masonry brick except for CAD-35.
2. CAD-10 is the optimum cement replacement percentage to enhance the optimum mechanical properties in term of density (1922.39 kg/m^3), compressive strength (6.336 N/mm^2), water absorption rate (13.96 %), porosity (25.43 %) and air permeability (6.9 x 10^{-13} m^2).

3. CAD-15 is the most feasible cement replacement percentage since it shows similar mechanical properties compared to CS and contributes to environmental benefits and human health.
4. CAD-30 is still considered feasible to be fabricated as the recommended requirement density, compressive strength and water absorption rate as a masonry brick had been achieved although the performance might lower than CAD-15.
5. It can conclude that the AD substitution for partially cement replacement could reduce the carbon dioxide emission to the ambient air and eventually increase the market feasibility and profit earned as the production cost is lower.

This research has proved that CSEB is suitable for replacing conventional fired brick as masonry unit as the benefits abovementioned. Furthermore, from the results obtained and evaluated, AD could be considered a sustainable stabilization material for brick fabrication compared to cement. Hence, the fabrication of CSEB incorporated with AD substitution for cement replacement should be widely adopted by brick industry to achieve sustainable development goals such as SDG 9 (Industry, Innovation and Infrastructure) and 11 (Sustainable Cities and Communities).

5.2 Recommendations

In this research, the feasibility of AD substitution for partially cement replacement had been evaluated to achievement sustainable goals and widely production as an eco-brick coupled with providing the benefits for social, economy and environmental sustainability. The suggested recommendations for future CSEB fabrication are proposed as stated below:

1. Deeply evaluate the possible reaction between the various compositions in AD, cement and water that might not show in short period of time.
2. Determine various curing methods to enhance the strength gaining.
3. Further research on the feasible percentage for soil replacement with AD coupled with the feasible cement replacement percentage.

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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