UNIVERSITY OF GHANA

COLLEGE OF BASIC AND APPLIED SCIENCES

ENGINEERING CHARACTERISTICS OF COMPRESSED EARTH BLOCKS STABILIZED WITH LIME AND COCONUT HUSK ASH

BY

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL IN ENGINEERING GEOLOGY DEGREE

AUGUST 2022

DECLARATION

I therefore declare that this thesis is my own work, based on research I conducted as an MPhil student in the Department of Earth Science at the University of Ghana. It does not contain any previously published materials by another person(s), nor does it contain any materials that have been accepted for the award of any other degree at this University or elsewhere, to the best of my knowledge. All references to the works of other researchers and/or organization(s) have been duly acknowledged.

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ABSTRACT

The cost of renting or owning a property in Ghana has risen considerably as a result of the country's growing population and increasing demand for housing. Expensive building materials is one of the causes of this situation. There is therefore the need to use locally available building materials to come up with innovative ways to provide sustainable housing for the citizens especially the low-income group. This research aims at investigating the engineering characteristics of compressed earth blocks stabilized with lime and coconut husk ash. Laterite blocks of size 300mm x125mm x 200mm were prepared using the following mix ratios: 0%, 5%, 10% lime, and 0%, 2%, 4% coconut husk ash (CHA). The block samples were tested for density, compressive strength, water absorption and abrasion resistance in order to observe their performance after 7, 14, 21 and 28 days of curing. Dry compressive strength increased by 38% - 110% as the amount of lime and CHA was increased in the blocks. Results show that blocks stabilized with 10% lime and 4% CHA recorded the highest compressive strength with a value of 2.53MPa which falls within the required building standards. The stabilized block samples recorded dry density values that were slightly higher than the un-stabilized block samples, as well as a higher resistance to water absorption than the un-stabilized block The durability of the blocks was determined by subjecting the blocks to abrasion resistance test. The stabilized blocks showed higher resistance as compared to the un-stabilized blocks with the blocks stabilized with 10% lime and 4% lime showed the highest resistance to abrasion of 3.0cm/g. The properties of the blocks were therefore improved by the introduction of lime and coconut husk ash. This study will be of great benefit to the construction industry since it provides a low-cost alternative to sandcrete blocks. These blocks are not only durable but also environmentally friendly. The use of coconut husk in compressed earth blocks also helps in solving regional waste disposal problem. This research will also be of benefit to low-income groups since it promotes affordable housing.

DEDICATION

This research is dedicated to God Almighty, my parents, Mr. Lucas Yentumi and Mrs. Evelyn Yentumi and my siblings, Anita Yentumi and Perpetua Yentumi.

ACKNOWLEDGEMENT

I thank the Almighty God for his grace, favor, knowledge, and wisdom e granted me and for a successful completion of my thesis work.

I am grateful to Dr. Francis Achampong, my supervisor for his expert guidance and immerse contribution to making this study a success. My heartfelt gratitude goes out to Dr. Edward Ackom, my co-supervisor, for his constructive recommendations and helpful comments in completing this final work.

My heartfelt thanks go to my parents, Mr. Lucas Yentumi and Mrs. Evelyn Yentumi, as well as my grandmother, Madam Florence Gadagoe, for their affection and financial support during my studies.

My appreciation goes out to Prof. Bruce Banoeng-Yakubo for the financial support to start my MPhil studies.

I am also grateful to Madam Olivia Soli, Research Manager, Materials division at Ghana Highway Authority for the opportunity to carry out my laboratory analyses at the Central Materials Laboratory, Ghana Highway Authority. My sincerest gratitude goes out to the staff of the Central Materials Laboratory (Soil and aggregates division) especially Mr. Fredrick Acquah and Joseph Sosu Agbeko for their assistance throughout my laboratory work.

My heartfelt thanks go to Mr. Philip Dumegah for his invaluable assistance during this study. Lastly, I would like to thank my colleagues, Andy Naah, Obed Nii Aryie, Adam Baradam, Felicia Yeboah and Yaw Kisser for their support and contributions to the success of this thesis.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highways and Transportation Officials
Al_2O_3	Aluminium oxide
ASTM	American Society for Testing and Materials
BS	British Standard
CaO	Calcium oxide
CEB	Compressed Earth Block
CHA	Coconut Husk Ash
CSEB	Compressed Stabilized Earth Block
Fe_2O_3	Iron (III) oxide
K_2O	Potassium oxide
LL	Liquid Limit
L.O.I	Lost On Ignition
MDD	Maximum Dry Density
MgO	Magnesium oxide
MnO	Manganese (II) oxide
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
P_2O_5	Phosphorus pentoxide
SiO_2	Silicon dioxide
TiO_2	Titanium dioxide
XRF	X-Ray Fluorescence

CHAPTER ONE
INTRODUCTION

1.1 Background

Today, both industrialized and developing countries face significant challenges in terms of sustainable development in the building construction sector. As a result of Ghana's growing population and increasing demand for housing, the cost of renting or owning a home has grown considerably in recent years. The situation has worsened because property suitable for this type of construction is becoming increasingly scarce, especially in smaller towns and cities. Most individuals, particularly those in low and moderate income, are unable to purchase them. High cost of building materials is a major factor that is contributing to this problem. Construction materials account for roughly 60% of the entire cost of a structure (Kerali, 2001). The manufacturing process for these materials is very energy demanding, unfriendly to the environment, and a source of waste (Murmu & Patel, 2018). The use of locally accessible materials and processes in the construction of building can help promote sustainable building (Dayaratne, 2018; Mazraeh & Pazhouhanfar, 2018).

Earth building is the most cost-effective way to house the most people while using the fewest resources. The low energy consumption and simplicity of the manufacturing process, justifies their widespread use as a primary housing material in developing countries such as Ghana. However, earthen structures are not limited to developing countries. Several advanced nations, like France, Australia, and many European and Asian countries, continue to have a significant rural population that lives in earthen houses.

Because of its minimal carbon output, low heat conductivity, and good hygroscopic qualities, Earth is recognized as an environmentally acceptable alternative (Chauhan et al., 2019 ; Valero et al., 2019). However, some disadvantages of earth building include a lack of strength and durability, as well as vulnerability to rain erosion (Arooz & Halwatura, 2018; Costa et al., 2018; Anysz & Narloch, 2019). Unfortunately, because of these issues, earth building materials have not been used in the construction industry for years and being replaced by long lasting and effective materials such as concrete and burnt bricks (Danja et al., 2017).

Growing environmental concerns have resulted in a greater understanding and appreciation of the value of natural earth materials in solving many of the world's environmental and construction issues. When compared to traditional building materials, the usage of earth materials does not result in the same level of resource depletion, pollution, waste generation, or biological changes if properly managed (Bachar et al., 2015).

As such, there is the need to device and present technology that can easily be implemented with the country's available resources. Manufacturing of Compressed Stabilized Earth Blocks (CSEB) is one of these technologies. Stabilizers are used in the manufacturing of CSEBs to give enough compressive strength and durability, allowing them to be used as building blocks. To stabilize the compressed earth blocks, this experimental investigation uses lime and coconut husk as partial replacements for cement in certain quantities.

1.2 Problem Statement

The cost of renting or owning a property in Ghana has risen considerably over the years as a result of the country's growing population and increasing demand for housing. This is exacerbated by the fact that property suitable for this type of construction is becoming increasingly scarce, particularly in smaller towns and cities. Most people, particularly those with low and moderate incomes, are unable to acquire them. Among other things, the expense of construction materials is to blame for the scarcity and high cost of housing (Tekle, 2018). As a result, suitable and long-term low-cost housing is required in Ghana.

Sandcrete block is the most accepted and widely utilized walling material in most underdeveloped countries, and cement is its primary element. The biggest issue with cement manufacture is the fact that raw materials used in its production need to be imported from other countries at a huge cost. This causes the price of cement to keep increasing as the years go by (Danso et al., 2019) Building materials made from locally available natural and renewable materials have been promoted as a means of ensuring a sustainable environment and effective use of resources. One of these alternatives is to replace cement blocks and blocks with earth blocks. As a result, the goal of this research is to come up with alternate wall-building materials. This study therefore seeks to analyze the engineering characteristics of compressed earth blocks stabilized with lime and coconut husk ash.

1.3 Aim and Objectives

The aim of this study was to investigate the engineering characteristics of compressed earth blocks stabilized with lime and coconut husk ash.

The specific objectives of the study are the following:

1 To produce compressed stabilized earth blocks using lime and coconut husk ash as stabilizers

2 To ascertain the geotechnical properties of compressed earth blocks improved with lime and coconut husk ash

3 To determine the compressive strength of compressed stabilized earth blocks at different ratios of lime and coconut husk ash added to laterite soil

4 To analyze the water absorption and durability of the compressed stabilized earth blocks

5 To carry out a cost comparative analysis between a conventional block and a lime and the compressed stabilized earth block.

1.4 Justification

Because developing countries have limited resources, it is critical to find new ways of reducing building expenses, particularly for affordable housing, additionally to apply cheap and efficient repair and maintenance results. This is possible with the help of Compressed Stabilized Earth Blocks (CSEB), which is made from locally available resources. Because of previous failures, CSEB are not frequently used. It is crucial to make people understand that these blocks are strong and long lasting, as this will encourage the use of CSEB and benefit the underprivileged. Furthermore, the utilization of agricultural waste for block production will contribute in the solving of regional waste disposal challenges, fostering healthier environments.

This research will be extremely beneficial to the construction industry because it will provide an affordable alternative to sandcrete blocks. The use of coconut husk in compressed earth blocks also helps in solving regional waste disposal problem. This research will also be of benefit to low income groups since it promotes affordable housing.

1.5 Project Location

Afienya is in the Ningo-Prampram District, which spans 622.2 square kilometers. Its geographical coordinates are 5^0 48' 0" N and 0^0 10' 0" E. The area is located 15 kilometers east of Tema and 40 kilometers east of Accra. The Shai-Osudoku district borders it on the north, the Gulf of Guinea on the south, the Ada East district on the east, and the Kpone-Katamanso district on the west. (Ghana Statistical Service, 2014)

1.6 Geology of the Study Area

The study area lies within the Accra plains. The area is underlain by ancient igneous rocks. The western boundary contains metamorphosed ancient strata, whereas the south and southeast have relatively new, unconsolidated layers. Situated in the west is the Akwapim range, which is mainly made up of quartzite, mica schist and medium-grained sandstone. The Accra plains itself are mainly occupied by the Dahomeyan gneisses and schists, which are divided into three belts running north – south across the region and consist of a westerly and easterly felsic gneiss belt separated by a mafic gneiss belt. The felsic belt consists mainly of felsic gneiss granitoids whereas the mafic gneisses are entirely garnet-amphibolite gneisses (Ghana Statistical Service, 2014).

1.7 Relief and Drainage

The research site is in the heart of Accra's lowlands. The terrain is generally mild and undulating, with a low plain rising to a height of 70 meters. Throughout the area, a few notable inselbergs, isolated hills, outliers, and knolls interrupt the plains in isolated spots. The drainage system in the area is dendritic, with most streams receiving water from the Akwapim range (which also functions as a watershed) and flowing northwest to southwest into coastal lagoons. Most streams that flow across relatively flat terrain have carved out enormous valleys that remain dry for the majority of the year. Because of the seasonal nature of most streams, which is produced by high temperatures and similarly high insulation levels, a variety of artificial dams and ponds of varied sizes have been built for irrigation and recreation (Ghana Statistical Service, 2014).

1.8 Climate

Afienya lies in the coastal savanna zone which is two seasonal characterizations: the rainy and dry seasons. There are two rainy seasons in the year: The main rainy season runs from April to July, while the minor season runs from September to November. May, June, and early July see the most rain. Rain falls in intensive short storms and where drainage is poor, local flooding occurs. After the rainy season, there is a long dry period that lasts from December to March. The average yearly rainfall is between 730 and 790 millimeters. Temperatures are high throughout the year, with substantial daily and seasonal changes. In the major rainy season average annual temperatures range between 25^{o}C and 30^{o}C while temperatures range between 27^{o}C and 35^{o}C in the minor season (Ghana Statistical Service, 2014).

1.9 Vegetation and Soil

The study area comprises of the following: grassland, shrub land and few patches of semi deciduous forests. The study area has soils comprised of clay, sand, gravel, humus and stone. The sandy and humus quality of the soil promotes vegetable farming, while the clayey nature is used in the manufacture of bricks. The presence of this clay could however have negative effects on general construction activities (Ghana Statistical Service, 2014).

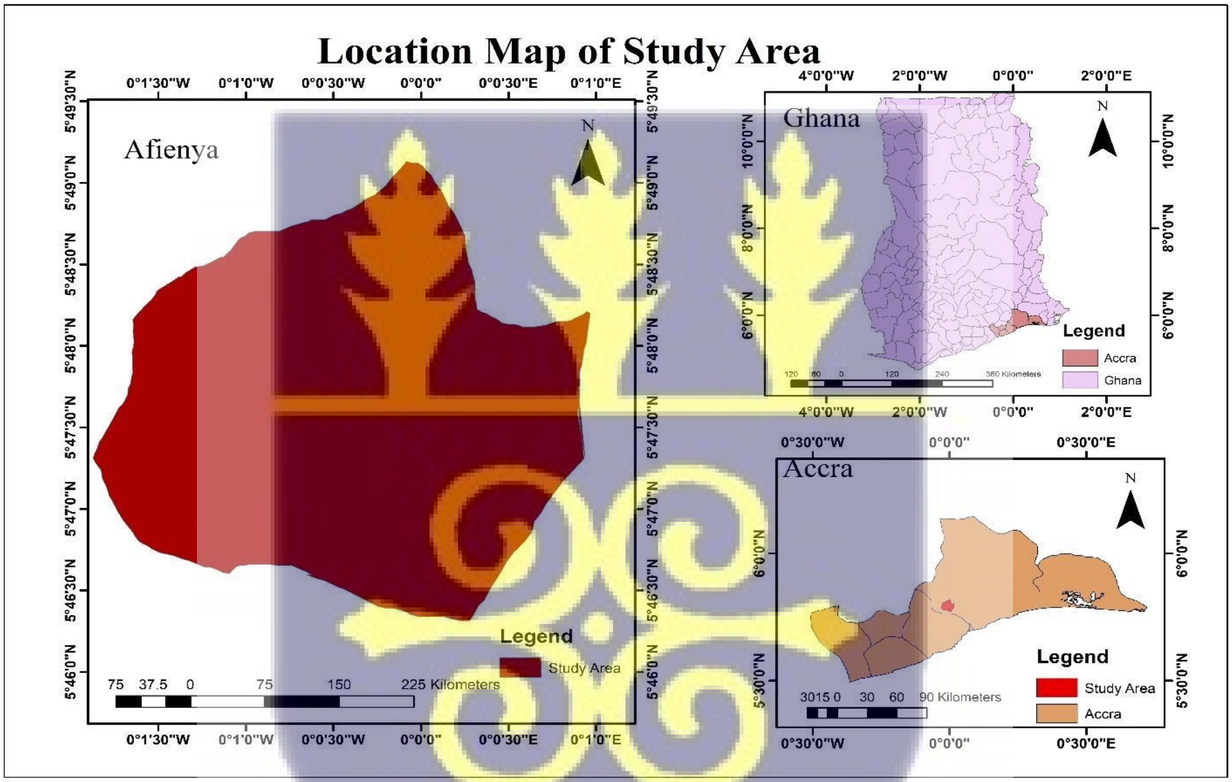


Figure 1. 1 Location map of study area

CHAPTER TWO
LITERATURE REVIEW

2.1 Earth Construction

Since time immemorial earth has been used in the construction industry in all parts of the world. This practice existed in most cultures around the world, and in certain nations, it is still the primary method of construction (Costa et al., 2016). Earth has long been utilized as a building material due to its abundance, accessibility, ease of construction, and the properties it exhibits, which imply its building performance. Earth construction has numerous advantages, including the fact that it is fireproof, regulates temperatures, and is 50% to 60% less expensive than typical cement-based construction (Adegun & Adedeji, 2017). Earth-based construction is also less harmful to the environment. When compared to traditional cement blocks, earth blocks utilize up to 30% less water in their creation (Oyelami & Van Rooy, 2016). Earth materials are also recyclable and environmentally friendly as compared to standard blocks that require fossil fuels to manufacture.

The oldest known manmade earth constructions, dating back to 10 000 BC, were discovered in Mesopotamia and are made of heaped earth bricks (Vyncke et al., 2018). All around the world, there are many historical monuments composed of earthen structures. Ancient vaults that are present in the Temple of Ramses II at Gourna Egypt, the citadel of Bam in Iran (figure 2.1) and the Great Wall of China, are among the finds (Costa et al., 2016).

Earth remains an essential building material up till date with an estimated 30% of the world's population living in earth buildings (Vyncke et al., 2018).

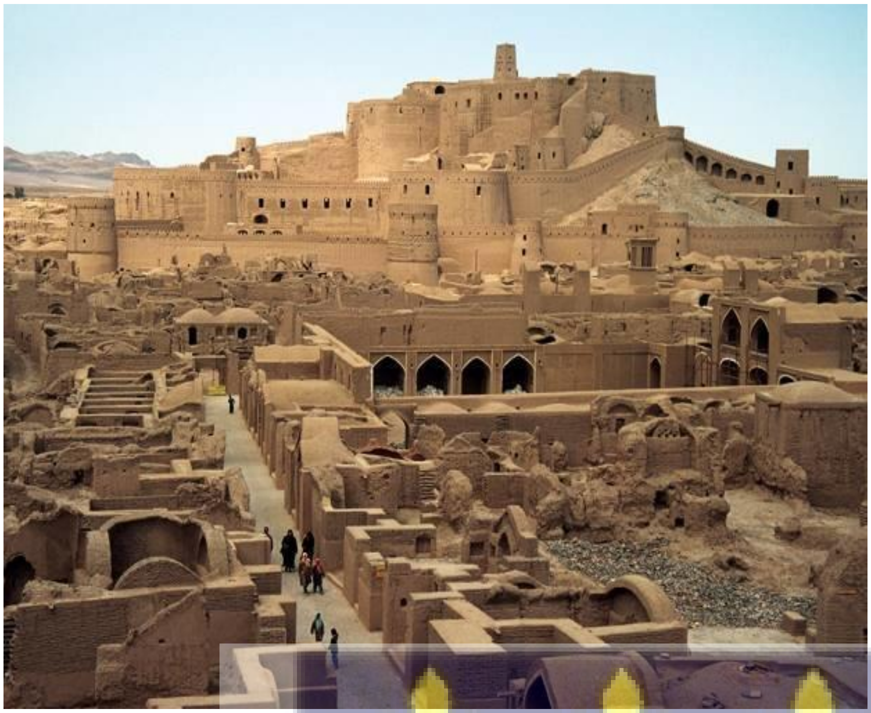


Figure 2. 1 The citadel of Bam (Langenbach, 2005)

2.2 Earth Construction Methods

2.2.1 Adobe Blocks

Adobe blocks (figure 2.2) are the most popular types of earth blocks. These blocks are constructed from clay and straw or manure (Wu et al., 2012). They are produced by combining natural occurring clay, water, and sometimes fiber to create a mud-like mixture, which are set into boxes known as "forms." After the blocks are formed the form is removed and the blocks are cured for a month before they are used for building (Molla, 2012). Adobe's strength and resilience varies according to its water content. Excessive water weakens the block.

The biggest advantage of adobe over the other ways is that it is the simplest approach and can be used to build a suitable housing with the least amount of construction ability. If done correctly, it can result in robust walls that are largely free of cracks (Yazew, 2015).

Figure 2. 2 Adobe blocks (Jarju, 2019)

2.2.2 Cob

Cob (figure 2.3), a type of ancient earthen building made of soil and straw, is comparable to adobe (Danso, 2016). Cobs are formed by kneading moist subsoil with sand and unchopped straw into solid mud loaves, then hand-ramming them together to form a self-designed structure. The mud must be hard enough to resist collapse. If the mud sags or spreads, it is either replaced or the rest of the mud is removed and re-fixed on the upper parts. The walls of the structure is best built in phases to ensure the bottom section hardens before continued, as this prevents collapsing. The walls are built in stages to allow each layer to cure before more mud is added. Treating the top surface before adding successive layers ensures that the layers stay together. Cob houses have the advantage of being simple to build and requiring little equipment. Shrinkage cracks, on the other hand, are rather common and can be quite severe (Yazew, 2015).

Figure 2. 3 Cob structure (Danso, 2016)

2.2.3 Rammed Earth

This approach involves piling moist subsoil into a temporary formwork and compacting it by hand or mechanically. There is no need to wait for each layer to dry out before ramming the layers together until the wall is complete. After the frame is removed, the walls are left to dry naturally.

Because of the shuttering required, rammed earth (figure 2.4) is more expensive than cob. Some of them have been around for centuries (Danso, 2016).

Figure 2. 4 Rammed earth (Danso, 2016)

2.2.4 Wattle and daub

Wattle and daub (figure 2.5) is a technique in which hardwood strips are braided together and coated with a combination of straw and soil. To minimize shrinkage cracks after drying, a highly clayey soil is combined with straw or other vegetable fibers. The wattle and daub technique, like adobe, can be dated back many years and is common in regions of the world for providing shelter from the elements (Tekle, 2018).

Figure 2. 5 Wattle and daub house (Bloom, 2010)

2.2.5 Compressed Earth Block (CEB)

This method (ie CEB) (figure 2.6) is one that involves mechanically compressing soil particles into a mold to create a soil/earth block. The difference between CEB and rammed earth is that CSEB use a larger formwork to complete a wall. Compacting soil/earth in a mold improves the material's engineering qualities (Tekle, 2018).

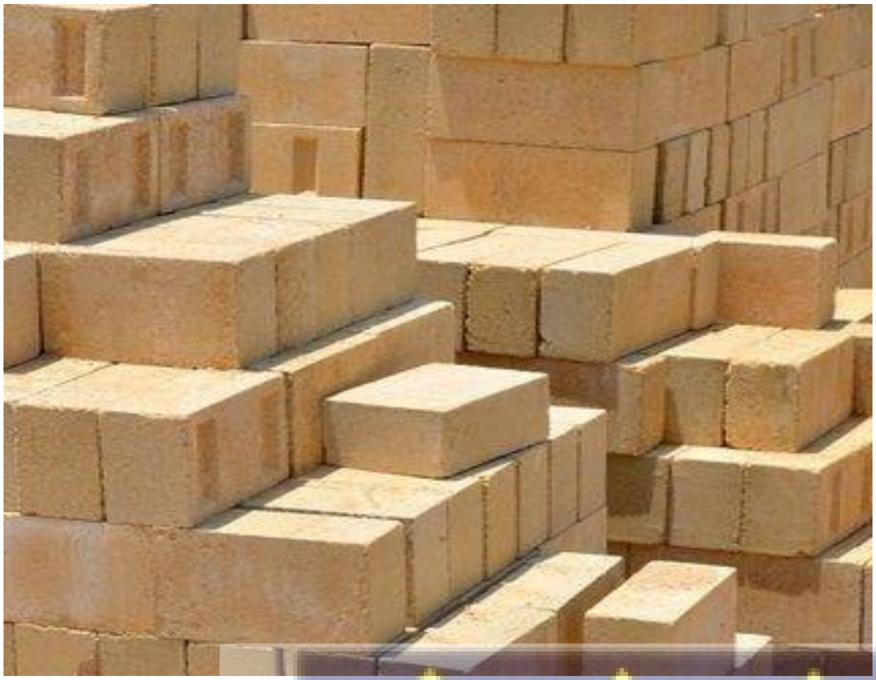


Figure 2. 6 Compressed earth blocks (www.humanitarianlibrary.org)

2.3 Stabilizing compressed earth blocks

Stabilization is the process of mechanically mixing soil and stabilizing agents to create a uniform mixture, or applying a stabilizing agent to undisturbed soil and allowing it to infiltrate through soil voids to achieve contact (Abood et al., 2007).

The major reasons for doing soil stabilization are as follows (Firoozi et al, 2017; Rigassi, 1985):

- To decrease the volume of interstitial spaces in order to minimize porosity and increase density.
- To strengthen the bonds between grains, particularly when the soil is wet.
- To enhance the cohesiveness and mechanical characteristics.

To increase the quality of soil blocks, a number of soil stabilization technologies are extensively utilized. The following are a few of the most common methods of stabilization.

2.3.1 Mechanical Stabilization

This a method of enhancing the strength and durability of soil-aggregate mixes by changing its gradation (Afrin, 2017);(Yoder, 1957). It is also referring to the alteration of soil porosity and inter-particle friction/interlock, which can be accomplished by compaction or other mechanical techniques (Hall et al., 2012). Mechanical energy is used to compact and densify the soil by utilizing rollers, rammers, vibration methods, and, in rare cases, blasting (Afrin, 2017). The purpose of compacting soil is to increase its shear resistance, compressibility, permeability, and porosity (Lemougna et al., 2011).

2.3.2 Physical Stabilization

It entails altering soil characteristics by inserting certain size ratios into the distribution of particle size of the soil. The soil texture may be changed by combining different fractions of soil particles together in a measured and controlled manner. Because the grains are packed closer together, most of the holes that existed before physical stabilization are filled. An anisotropic network is formed, which restricts grain movement in a soil. Unfortunately, unlike mechanical stabilization, the effect of physical stability alone is not long-lasting. Soil grains are easily distributed or washed away when saturated with water. Physical soil stabilization should therefore be integrated with the other methods for better outcomes (Tekle, 2018).

2.3.3 Chemical Stabilization

Chemicals and emulsions are employed in chemical stabilization as an aid for compaction for soils, water repellents and binders, and to influence the behavior of clay. The additives used in chemical stabilization of soils include hydraulic binders which comprises of Portland cement, lime (Hydrated lime, quicklime, slurry), fly ash, pozzolanic. And organic binders such as polymers and organic resin.

2.3.3.1 Cement Stabilization

Cement known as the go-to stabilizing agent because of its ability to cause stabilization effect all by itself (Makusa, 2013).

When calcium-aluminates and calcium-silicates, and water interact, they cause hydration which creates compounds of calcium-silicate-hydrate, calcium-aluminate hydrate and calcium hydroxide, which are cementing compounds. Because of the presence of cementitious components and calcium hydroxide, cement may successfully stabilize fine-grained and granular soils as well other soil materials (Onyelowe, 2012).

Hydration is a process by which cement, and water react. When cement is mixed with water it hardens up and encloses. Cement hydration is a complex process involving a complex series of unknown chemical reactions. Depending on the soil type, the content of the cement required for adequate stabilization ranges from 4% to 16% by weight (Tekle, 2018).

2.3.3.2 Lime Stabilization

Lime is an inorganic mineral that contains lime. It is composed of calcium oxide and/ calcium hydroxide. Lime is a cost-effective method of soil stabilization. When lime is applied to damp soil, it loads the soil with calcium ions. The calcium ions are subsequently replaced by exchangeable cations in the soil components, such as magnesium, sodium, potassium, and hydrogen, in a process known as cation exchange. The volume of the exchange is determined by the number of exchangeable cations contained in the soil's overall cation exchange capacity. Soil grains flocculate and tend to accumulate as a result of cationic exchange and an increase in the number of electrolytes in the pore water. The accumulations in the fine fraction grow. Both the distribution of particle size and the structure of the grain are altered. Lime combines with CO_2 in the atmosphere to generate weak carbonated cements.

This reaction consumes some of the lime that would otherwise be available for pozzolanic reaction. The material's strength is largely due to the dissolving of clay minerals in an alkaline environment formed by the lime, as well as the recombination of the silicate and alumina in the clays with the calcium to form complex aluminum and calcium silicates, which cement the grams together. The range of lime content required for optimal stability is between 4% and 12% by weight depending on soil type, and this will increase as clay content increases (Tekle, 2018).

2.3.3.3 Fly-Ash Stabilization

Fly-ash stabilization has gain popularity in recent years due to its widespread availability. When compared to other ways of soil stabilization, this process is cheap and does not consume so much time. It is a byproduct of coal-fired power plants. Fly-ash is mostly referred to as a secondary binder and, as such, cannot achieve the desired effects on soil stabilization on its own. It can however generate cementing properties when activated (Afrin, 2017).

There are two known types of fly ash based on their calcium oxide (CaO) content: class C and class F fly ash. The combustion of sub-bituminous coal produces class C fly ash ashes. Class F fly ashes, on the other hand, are generated by the combustion of arithracite and bituminous coal (Reimer, 1992).

2.3.4 Bituminous Stabilization

This method of stabilization involves the mixing of a particular ratio of bituminous soil material or aggregate material which will generate a stable surface (Matthew & Paul, 2018).

Bitumen emulsion is classified into two types: anionic bitumen emulsion and cationic bitumen emulsion. Cationic emulsifiers are often based on long hydrocarbon nitrogen compounds such as alkyl amines. These are potent surface-active chemicals with a significant effect on surface tension. Anionic bitumen emulsions are often based on fatty acids, whose molecules are made up of long hydrocarbon chains that terminate with a carboxyl group. The "emulsifier solution" is created by reacting the anionic emulsifier with sodium hydroxide in a process known as saponification. Chemical chemicals that can enter the natural reactions of the soil and control the moisture going to the clay particles, turning the clay portion to permanent cement that binds the mass of aggregate together (Matthew & Paul, 2018).

2.3.5 Pozzolana stabilization

Pozzolanas are generally made of aluminous and siliceous materials which don't have cementing abilities and/or capabilities. However, when in a finely divided form and with moisture present, a chemical reaction with calcium hydroxide at ambient temperatures produces a by-product that possesses cementing compounds (Makusa, 2013). To attain this, the pozzolanas should be finely divided to create a large surface for effective reaction with the alkali solution. Generally, two types of pozzolanas exist which are the natural and artificial pozzolanas. Naturally, they occur as tuff, opaline shale, volcanic ash, pumicite, etc. naturally occurring pozzolanas are used in alkali-silica reactions and in dam controls. Metakaolin, silica fume, coal fly ash, slag, crushed granulated blast furnace, and other artificial pozzolanas can exist.

The popularity of pozzolana being used as a temporal substitution for Portland cement or lime has increased massively over the years in the construction discipline. Pozzolana is preferred for usage in structure construction due to its ability to withstand alkali-aggregation reaction and better durability features as a result of its resistance to sulphate attack (Momade & Atiemo, 2004). In the past, pozzolana was mainly used as an additive to cement binders for mass concrete work such as the construction of dams (Kale, 1981). In recent time, there has been leading research in the use of pozzolanic materials as alternative cementing materials as a means of reducing the over dependency on cement.

2.4 Compressed Stabilized Earth Blocks (CSEB)

It is a type of building material made of earth that has been uniformly mixed with a stabilizing agent, such as cement or lime, and compressed into a block. CSEBs are modern earth blocks produced in a mechanical press (Postell & Gesimondo, 2011). They are environmentally friendly, strong and long-lasting, and have great insulating capabilities. CSEB is composed of earth mixed uniformly with a stabilizing agent, such as cement or lime, and compressed into a block (Reddy et al., 2007).

2.4.1 Advantages of CSEB

According to Auroville Earth Institute report (2005), some of the advantages of CSEBs are:

1. Cost efficiency: Produced locally, with a natural resource and semi-skilled labour, almost without transport, it will be definitely cost effective.

2. Energy efficient and ecofriendly: Requiring only a little stabilizer the energy consumption in a m3 can be from 5 to 15 times less than a m3 of fired bricks. The pollution emission will also be 2.4 to 7.8 times less than fired bricks.

3. Management of resources: Each quarry should be planned for various utilizations: water harvesting pond, wastewater treatment, reservoirs, landscaping, etc. it is crucial to be aware of this point: very profitable if well managed, but disastrous if unplanned.

4. Bio-degradable: Well-designed CSEB houses can withstand, with minimum of maintenance, heavy rains, snowfall or frost without being damaged. The strength and durability have been proven since half a century.

5. Market opportunity: According to the local context (materials, labour, equipment, etc.) the final price will vary, but in most of the cases it will be cheaper than fired bricks.

6. Reducing deforestation: Firewood is not needed to produce CSEB. It will save the forests, which are being depleted quickly in the world, due to short view developments and the mismanagement of resources.

7. Provide local employment: CSEB allow unskilled and unemployed people to learn a skill, get a job and rise in the social values.

2.4.2 Disadvantages of CSEBs

1. Not suitable for high-rise buildings.
2. Correct soil identification is essential.
3. Requires skilled labor.
4. Requires quality control at all stages of production to avoid low-quality products.
5. Low technical performance compared to concrete.

2.5 Soil properties recommended for CSEB

2.5.1 General properties

The physical properties of soil are of great importance in the creation of CSEB. These properties determine how the soil will react to the whole stabilization process and the moulding of the blocks. Some of these properties include porosity, permeability, shrinkage, dry compressive strength among others.

It is also important to control monitor the amount of clay in the soil before use in CSEBs. Increasing amounts of clay results in expansions in very high degrees when wet. This requires excessive amounts of cement to compensate for this. Vice versa also causes drastically low adhesion between the soil particles and consequently enhances the rate of breakage when demoulding the blocks. A soil containing minimum quantity of silt and clay is suitable for making the blocks. In the case where chemical additives are included in the mixture, then factors such as mineral content, metallic oxides, composition, pH levels and sulphates are of importance (Tekle, 2018).

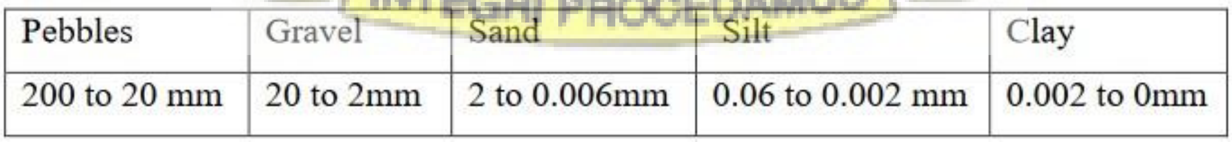
2.5.2 Soil classification

Soils can be classified in several different ways, including its function, origin, size, texture, color, and density. Soil can be classified for building purposes in two ways: plasticity index and particle size distribution analysis. Particle size analysis provides data on the soil's capability to settle tightly into a compact structure, as well as the amount of particles present whereas the plasticity index indicates the particles' cohesiveness (Tekle, 2018).

2.5.2.1 Particle Size Distribution

This test determines the mass of particles present in a sample of soil. The classifications are done as gravel, sand, silt and clay. Currently, several particle size classification systems that are used in engineering. The American Society for Testing and Materials Particle Size Classification System (ASTM) which is mostly used in Ghana is illustrated below (Table 2.1).

Table 2. 1 Particle size classification based on the Standard (2006)



Pebbles	Gravel	Sand	Silt	Clay
200 to 20 mm	20 to 2mm	2 to 0.006mm	0.06 to 0.002 mm	0.002 to 0mm

Usually, gravel is not a component in CSEB, as these large particle sizes lead to a rough finished surface. A much more suitable combination would contain clay, silt and sand sized particles. A particle size analysis will bring to light, the percentage of particles in a soil that fall into each of the above size ranges. It is critical that the soil utilized be "well graded" if dense block is to be formed. The fuller curve is the foretold distribution of the particle sizes that results in a perfectly packed form. The fuller distribution can be described as an ideal model, which is impossible in nature. Natural soil with a uniform distribution of particle size, referred to be well graded, is a suitable approximation (Tekle, 2018).

The benefit of well-graded soil pertaining to compressed stabilized earth blocks is, the size distribution results in a compact structure possessing an averagely low specific surface area. A dense structure is necessary for several reasons. A closely packed arrangement will contain more touching particles, resulting in a stronger load-bearing backbone. The number and size of inter-particle voids, as well as the number of connected voids, will be reduced, lowering the porosity of the soil and hence its permeability, and thus its susceptibility to water penetration. Because the interlocking calcium silicate matrix extends through the soil voids, a more compact void system necessitates less cement to provide an equally efficient matrix (Tekle, 2018). Based on African Regional Standards (1996) and experiences from laboratory investigations, if a soil has its granular composition falling within the shaded portion of the graph below (figure 2.7), it is considered suitable for block production. Soils with granular compositions beyond the shaded area may still produce acceptable results, but it is advised that they be submitted to a series of tests to determine their suitability (African Regional Standard, 1996).

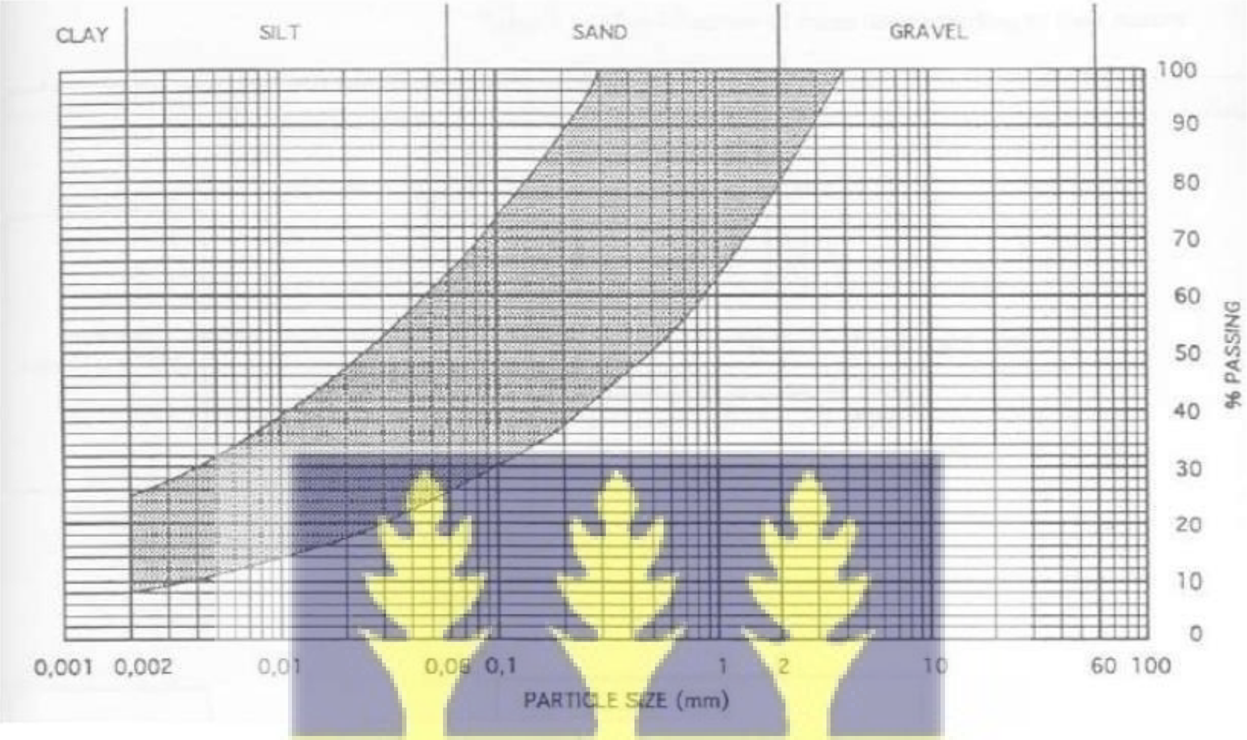


Figure 2. 7 Granular Composition Criteria based on African Regional Standards (1996)

2.5.2.2 Plasticity Index

The Atterberg tests are used to measure the plasticity of a soil's finer fraction. The liquid limit test estimates the percentage of water content at which soil transitions from a liquid to a plastic condition. The percentage water content at which the soil transitions from a plastic to a solid form is determined by the plastic limit test. The plasticity index, which is the water content at which the soil is considered plastic, distinguishes the plastic limit from the liquid limit. The soil's fluidity indicates the soil's cohesiveness (Tekle, 2018).

Certain criteria have been set to determine the suitable plasticity of a soil for use in CSEB. According to the African Regional Standard (1996), soils that have their plasticity index falling inside the shaded portion of the graph below (figure 2.8) are said to be suitable for block production. Soils that have their plasticity index falling outside the shaded portion are also likely to give suitable results, however they should be subjected to tests to determine their suitability (African Regional Standard, 1996).

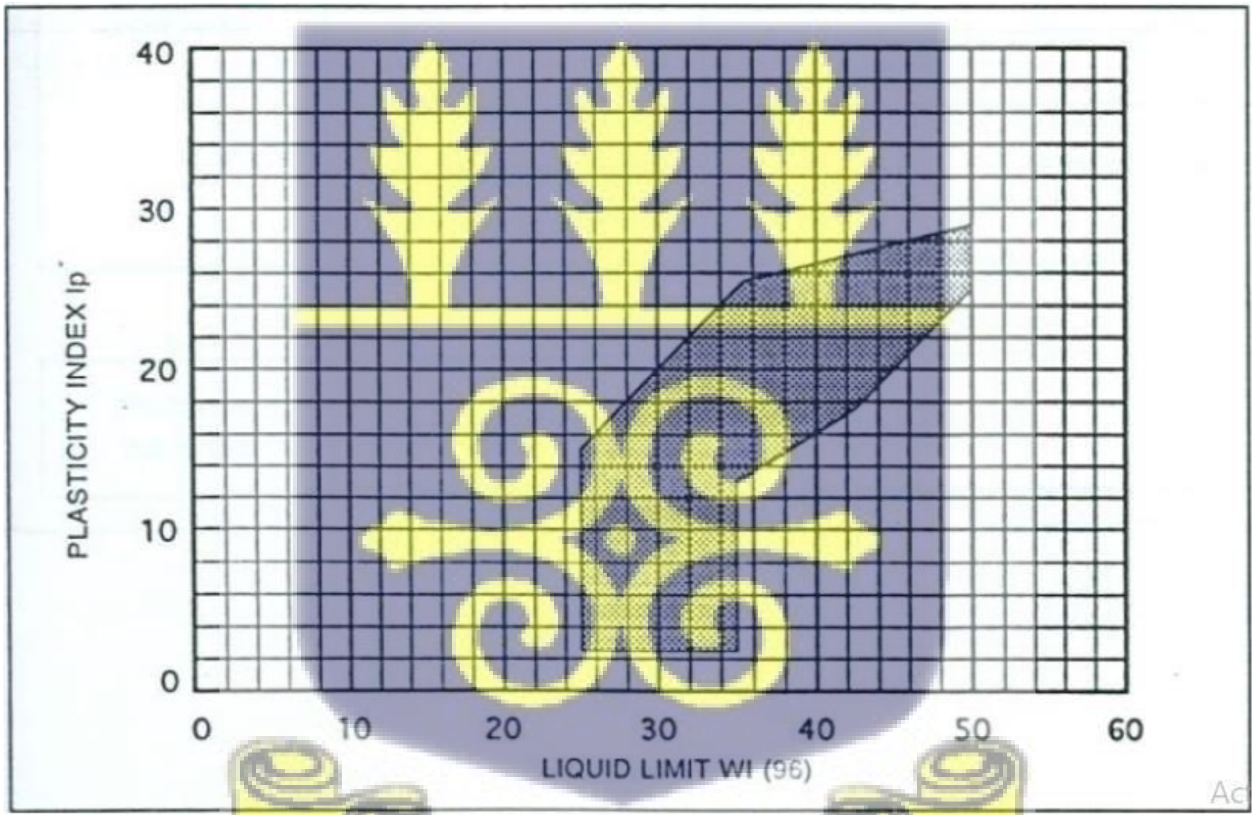


Figure 2. 8 Plasticity Criteria based on African Regional Standards (1996).

CHAPTER THREE
METHODOLOGY

3.1 Desk Study

Information on previous studies conducted on similar projects was obtained. Articles, journals, and books concerning the research topic were read and information acquired. Such information like a map of the study area, geographic coordinates, the geology of the area and the vegetation were obtained. The desk study was carried out to identify area in Accra with laterite soil deposits. Methods of stabilizing earth blocks was also researched.

3.2 Reconnaissance Survey

The study area was then visited to carry out reconnaissance study in order to locate areas where laterite deposits can be found. The availability of the site was assessed, and sampling locations were identified.

3.3 Materials

The materials used in this study was laterite soil, lime, coconut husk and water.

3.3.1 Soil

The soil sample (figure 3.1) was obtained from Afienya area. A pit was dug using a pickaxe and a shovel and the sample was taken at a depth of 1.5m to 2.0m using the method of disturbed sampling.

Figure 3. 1 Laterite soil

3.3.2 Lime

Good quality commercially available lime (figure 3.4) was acquired from the local market. The chemical composition of the lime was tested in the Department of Earth Science Geochemical laboratory.

Figure 3. 2 Hydrated lime

3.3.3 Coconut husk

The coconut husk was collected from coconut vendors in Afienya. The coconut husks were dried in the sun for three days to remove excess moisture and burnt in a controlled environment until it was completely turned to ash. After cooling, the ashes (figure 3.3) were sieved through a 4.75mm sieve. To avoid moisture loss and contamination, the ashes were stored in airtight containers.

Figure 3. 3 Coconut husk and its ash

3.3.4 Water

Tap water was used throughout the research since it mixes and forms a paste that binds the aggregates together.

3.4 Methods

The soil sample was subjected to laboratory examination to determine the mechanical and geotechnical qualities of the soil. The geotechnical qualities were tested at the Ghana Highways Authority's central materials laboratory, while the chemical analysis was performed at the University of Ghana's Department of Earth Science Laboratory. The tests performed include Particle size analysis, Atterberg limits, compaction test and moisture content test. Figure 3.1 illustrated the methodology followed for producing the CSEB.

3.4.1 Laboratory Tests

3.4.1.1 X-Ray Fluorescence Test

The chemical composition of hydrated lime and coconut husk ash was determined using an X-Ray Fluorescence (XRF) test at the Department of Earth Science Geochemical laboratory. The percentages of oxides composed in the hydrated lime and coconut husk ash were determined.

3.4.1.2 Particle Size Analysis

This test (figure 3.5) was conducted in accordance with ASTM D6913 – 04 (2009) test method. The soil sample was dried in an oven for 24 hours and lumps present were broken down with the used of the mortar and pestle. The soil sample was weighed with the use of a measuring balance and the mass recorded in grams. The sieves were positioned in ascending order of aperture size, with the largest aperture size at the top and the smallest aperture size at the bottom: 19.00mm, 9.5mm, 4.75mm, 2.0mm, 1.0mm, 0.425mm, 0.30mm, 0.15mm and 0.075mm. A pan was then placed under the last sieve to collect soil that passes through No. 200 sieve. The sample was then poured into the first sieve and shaken manually for 15 minutes. The amount of soil remaining on each sieve was weighed and documented. The weight of the soil remaining in the pan was also taken.

Figure 3. 4 Particle sieve analysis

3.4.1.3 Atterberg Limit Test

Atterberg limit tests (figure 3.6) are used to assess the consistency limits of soils, namely the liquid and plastic limits, from which the plasticity index can be determined. The ASTM D4318-17e1 test method was used to conduct this test. After crushing the soils, they were sieved through a #40 (0.425mm) sieve. For the liquid and plastic limits, a #40 soil passing sieve was used. Plastic and liquid limit values were used to calculate the Plasticity index. The liquid limitations were calculated using the Casagrande cup method.

Figure 3. 5 Atterberg limits test

3.4.1.4 Standard Proctor Test

The proctor test measures the maximum unit weight of a soil that can be compacted with a regulated compactive force at an optimum water content. The test was carried out in accordance with the ASTM D698-12 test procedure. The standard proctor test was used. The dirt was compressed with a 2.5kg rammer, which was dropped one foot into a mould containing the soil sample. The mould was filled with three equal layers of soil, each of which was subjected to 25 blows.

3.5.2 Preparation of blocks

The soil sample was dried in the oven for 24 hours then sieved using a No. 4 sieve (4.75 mm). Soil that passed through the sieve was used in preparing the CSEBs. The soil was measured and spread on a mixing platform, lime and coconut husk ash were also measured and spread on the soil. In this investigation, two different lime contents, 5% and 10% and three different CHA contents, 0%, 2%, and 4% by weight of the soil-were examined for the fabrication of CSEBs.

The dry material quantities utilized in each mix design were measured using a weighing balance. The soil was combined until it formed a uniform paste, the required amount of water was measured and poured on top of the paste and mixed until a homogeneous paste was formed. This procedure was repeated for each mixing batch based on the lime-CHA content. The mixture was stirred with a shovel until it was homogeneous (figure 3.7). The blocks were cast in moulds measuring 300 x 125 x 200 mm.

The blocks were cured by wrapping them with wet jute bags and placed under a shed. Thirty blocks were created for each mix, making a total of two hundred and ten blocks (210). Five (5) blocks were measured after curing for 7, 14, 21 and 28 days. Each block sample was meticulously labeled for easy identification.

Table 3. 1 Mix Proportions

Label	**Laterite (%)**	**Lime (%)**	**CHA (%)**
B1 (Un-stabilized)	100%	0%	0%
B2	95%	5%	0%
B3	93%	5%	2%
B4	91%	5%	4%
B5	90%	10%	0%
B6	88%	10%	2%
B7	86%	10%	4%

Figure 3. 6 mixing of the materials

Figure 3. 7 Produced Blocks

3.5.3 Testing of the Blocks

The following tests were conducted on the CSEBs, density test, compressive strength test, water absorption test.

3.5.3.1 Density

Density was calculated after 7, 14, 21, and 28 days of curing in accordance with British Standard, BS EN 772:11 (2001). The blocks were dried at a constant temperature and measured until they reached a consistent mass. The dimensions of the blocks were measured using a tape measure, and the volume calculated. The weight of the blocks was estimated, and the density calculated using

$$\rho = \frac{m}{V}$$

Where ρ = density

m = mass

v = volume

3.5.3.2 Compressive Strength Test

This test was carried out in accordance with ASTM C140. Prior to testing, the surfaces of the blocks were cleaned, then two steel plates were inserted at both ends to ensure even contact and uniform loading. The strain rate is kept constant at 1.0 percent each minute. The maximum load at which failure occurred was measured and the compressive strength calculated as a ratio of the maximum load and the cross-sectional area. The values were measured in MPa.

Figure 3. 8 Compressive Strength test

3.5.3.3 Water Absorption by Capillary Action

This test was carried out with the purpose of assessing the ability of the block to absorb water after days of curing. Capillary testing for water absorption was carried out according to BS EN 772-11 (2001). After 28 days of curing, block samples were oven dried at 35°C until an uniform mass was achieved. Each block specimen was weighed and recorded in terms of mass. For 10 minutes, each block specimen's bedside (300 x 125 mm) was immersed in a constant head-water bath (figure 3.9) to a depth of 5 mm, and the mass of each water-absorbed block specimen was measured. The water absorption by capillarity rise was calculated using this equation;

$$Cb = \frac{100\ x\ (M1 - M2)}{S\sqrt{t}}$$

$= g/cm^2min.$

Where;

M1 – M2 = mass of absorbed water in grams,

S = submerged surface area in centimeter square,

t = duration of immersion in minutes.

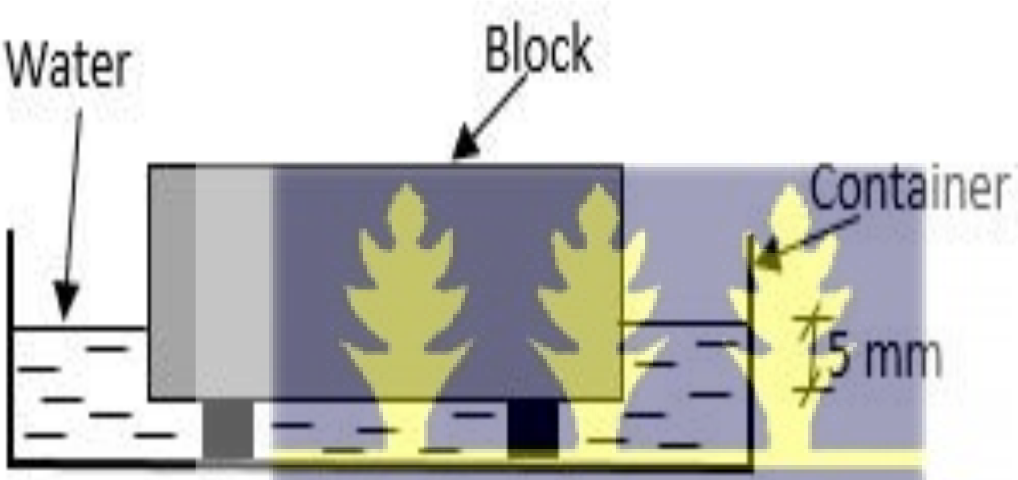


Figure 3. 4 Set-up diagram for capillary water absorption (Danso, 2016)

3.5.3.4 Abrasion resistance test

The resistance of a lateritic block to abrasion determines its durability. The test was carried out in line with BS 3921 (1921). It was carried out in order to determine the proportion of soil particles that would be abraded from the block specimens. The blocks were placed on a wooden surface, and a wired bush was stroked 50 times in a forward and backward motion across the surface of the sample. The blocks were weighed on a balance after being brushed through, and the weight after abrasion was recorded.

The abrasion coefficient is calculated using the equation.

$$Cu = \frac{S}{M1-M2} = \quad cm^2/g$$

Where;

Cu = abrasion coefficient

M1-M2 = mass of the material detached by brushing

S = Area of the brushed surface

3.6 Data and statistical analysis

The data was entered into Excel 2016, which was then utilized to generate analysis graphics. Correlation studies were carried out to discover the correlations between the attributes of the compressed earth block specimens studied. To establish the significant difference between the control and the Lime-CHA stabilized compressed earth blocks, a One-Way Repeated Measures Analysis of Variance (One-Way RM ANOVA) test and a One-Sample t-test were performed using IBM SPSS Statistics version 20.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Geotechnical properties of the Laterite Soil

The index properties of the laterite soil are displayed in table 4.1. The particle size distribution curve (figure 4.1) was generated from the sieve analysis data. The results show that the soil is a fine-grained soil with 58% fines, 8% gravel and 34% sand. The plasticity chart was utilized to accurately characterize the soil. The liquid limit, plastic limit and plasticity Index are 36%, 23% and 13% respectively.

The laterite soil is classified as a lean clay (CL) under the Unified classification system and clayey soil under the American Association of State Highways and Transportation Officials (AASHTO) classification system.

The soil has a Plasticity Index (PI) of 13%, which is less than the maximum value of 35% prescribed by BS 1377 (1975), indicating that it is an excellent laterite soil that is cohesive and hence easily compacted to improve the laterite's strength and durability. The Optimum Moisture Content (OMC) is 14.3% and the Maximum Dry Density (MDD) is 1990 kg/m3. The amount of water added to the CSEB mix was 14.3% of the total weight of the soil during the mixing process

Table 4. 1 Physical properties of the soil

Property	Parameter	Value
Grain size distribution	Gravel (%)	8
	Sand (%)	34
	Fines (%)	58
Atterberg Limits	Liquid Limit (LL) (%)	36
	Plastic Limit (PL) (%)	23
	Plasticity Index (PI) (%)	13
Compaction Test	Optimum Moisture Content (%)	14.3
	Maximum Dry Density (kg/m3)	1990
Soil Classification	Unified Soil Classification	CL
	AASHTO Classification	A- 6

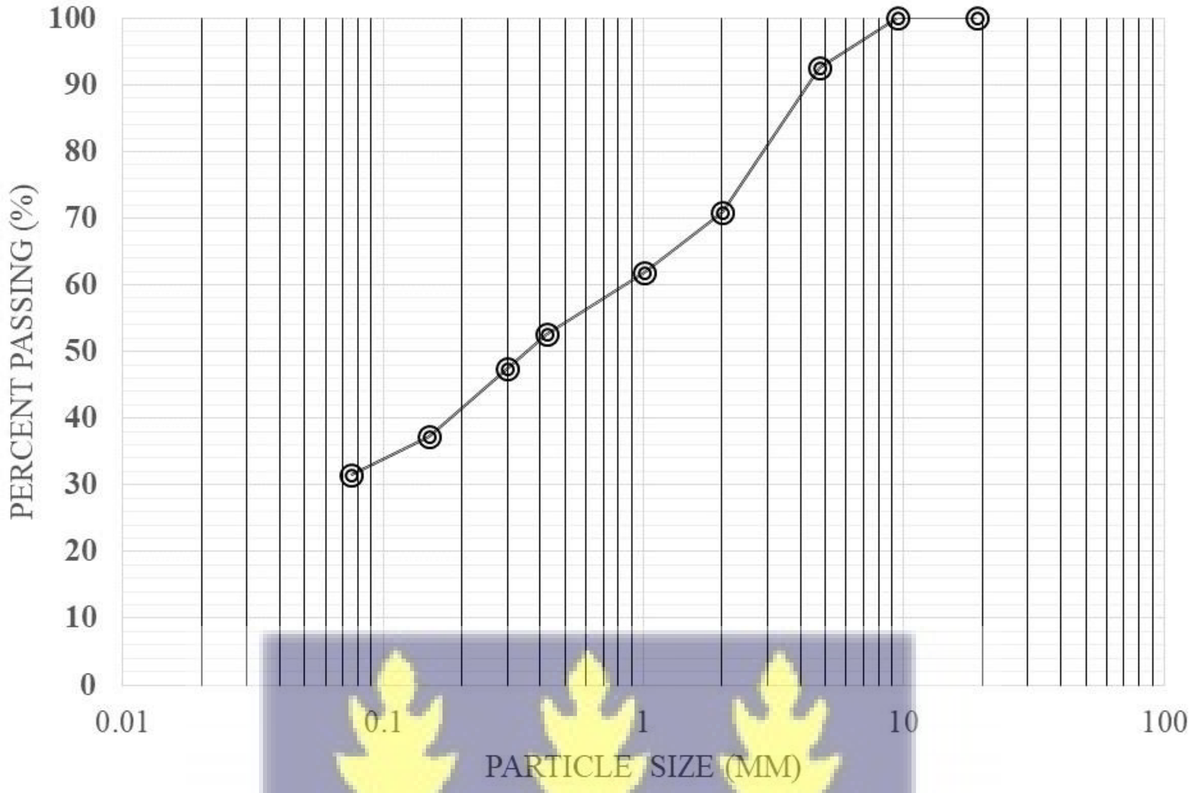


Figure 4. 1 Particle size distribution curve of soil used in the study

4.2 Chemical Composition of Lime and Coconut Husk Ash (CHA)

The XRF test results are displayed in table 4.2. The chemical composition of CHA comprised of 34.5% Silicon dioxide (SiO_2), 6.24% Aluminium oxide (Al_2O_3), 3.56% Iron (III) oxide (Fe_2O_3), 15.00% Calcium oxide (CaO), 9.49% Magnesium Oxide (MgO). According to ASTM C618 (1978) pozzolanas should have combined proportion of SiO2, Al_2O_3 and Fe_2O_3 of not less than 70%. Results of the X-ray fluorescence test showed that CHA was comprised of 34.5% SiO_2, 6.24% Al_2O_3, 3.56% Fe_2O_3 which when summed does not meet the minimum requirement of 70% for pozzolanic materials. Hydrated lime is predominantly made up of CaO which comprises of 97.3%.

Table 4. 2 Chemical compositions of lime and coconut husk ash (CHA)

Compound	Chemical Composition (%)	
	Hydrated Lime	Coconut Husk Ash (CHA)
SiO_2	0.21	34.5
Al_2O_3	0.20	6.24
Fe_2O_3	0.06	3.56
CaO	97.3	15.0
MgO	1.24	9.49
K_2O	0.03	13.2
TiO_2	0.03	0.52
MnO	0.01	0.18
P_2O_5	0.00	4.41
Na_2O	0.00	9.05
LOI	N/A	N/A

4.3 Density of CSEBs

The density test was conducted to determine the physical qualities of CEBs. Five block samples were tested for each mix ratio. The mean value of each test was recorded. The density was in kilograms per cubic meter (kg/m^3). Figure 4.4 depicts a graphical representation of the compressed earth blocks' mean dry densities. In this investigation, the dry density of the blocks varied from 1726 kg/m^3 to 1966 kg/m^3. These values fall within the BS 6073 range of 1500kg/m^3 – 2400kg/m^3 for dense aggregates masonry units. According to the findings, there was an increase in dry density values as the number of curing days increased. The dry density mean values of the un-stabilized block samples and the Lime-CHA block samples were similar for all curing days. This suggests that the density of the block specimen did not change noticeably as a result of the addition of the lime and CHA. Danso et al. (2019) used clay pozzolana in a prior work, and the density of the specimens seemed to be about the same. This was attributable to a constant compaction rate and an identical quantity of the mix utilized for each test block sample, as corroborated by an earlier analysis (Danso et al., 2015). For samples B1, B2, B3, B4, B5, B6, and B7, the mean dry densities were 1726.25kg/m^3, 1782.25kg/m^3, 1823.5kg/m^3, 1856kg/m^3, 1838kg/m^3, 1897kg/m^3, and 1972kg/m^3.

Table 4. 3 Dry densities of CEBS

Mix ratio	**7days (kg/m^3)**	**14 days (kg/m^3)**	**21days (kg/m^3)**	**28 days (kg/m^3)**
B1 (control)	1632	1725	1760	1788
B2 (5% lime & 0% CHA)	1743	1788	1794	1804
B3 (5% lime & 2% CHA)	1810	1820	1826	1838
B4 (5% lime & 4% CHA)	1830	1856	1863	1875
B5 (10% lime & 0% CHA)	1827	1840	1841	1844
B6 (10% lime & 2% CHA)	1879	1902	1903	1904
B7 (10% lime & 4% CHA)	1926	1980	1989	1993

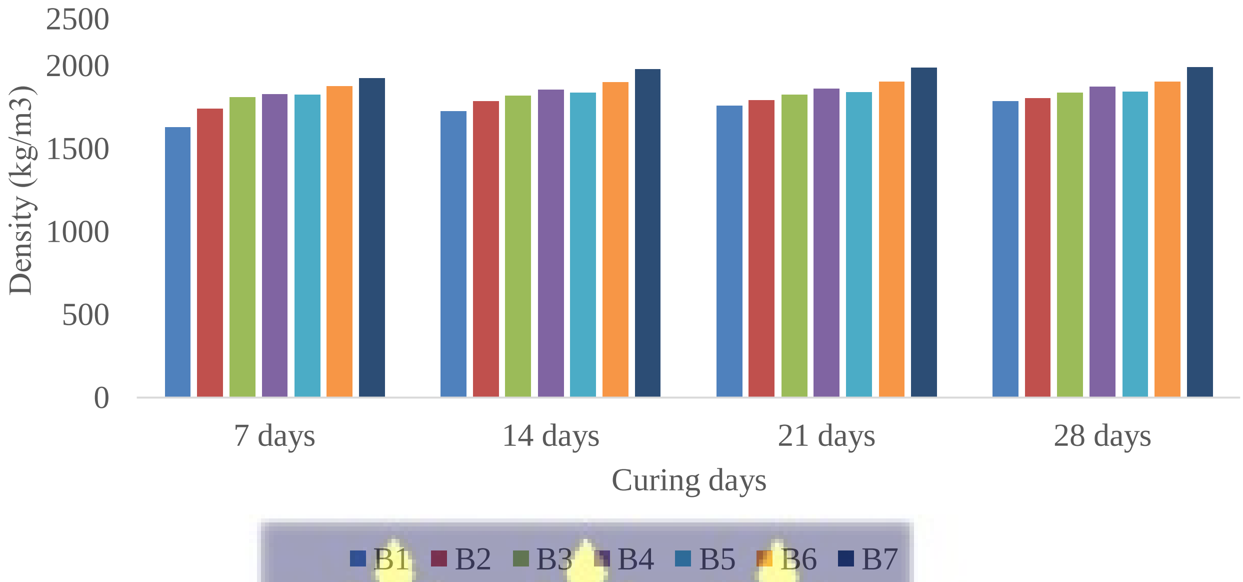


Figure 4. 2 Dry densities of CEBs

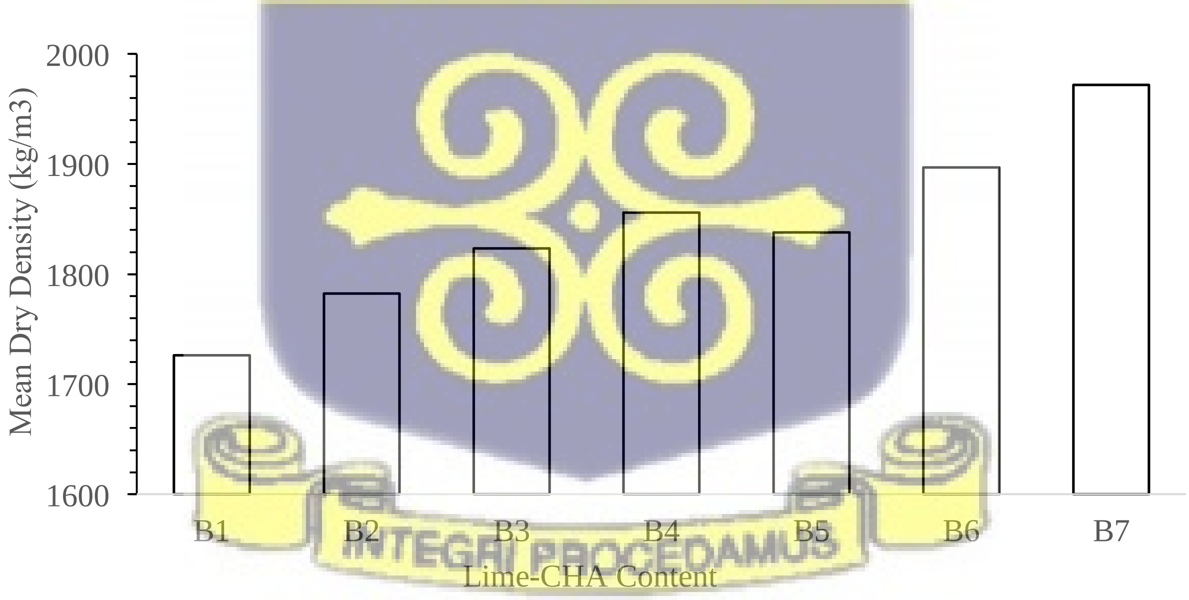


Figure 4. 3 Average dry densities of the blocks at 28 days of curing

4.4 Compressive Strength of CEBs

Results of the compressive strength test are displayed in figure 4.4. There was increasing strength as number of curing days increased. It can also be seen that all of the Lime-CHA stabilized block specimens outperformed the un-stabilized block specimens in compressive strength.

The block samples containing higher amounts of lime and coconut husk showed higher compressive strength values as compared to those with lower lime-CHA content. The increase in strength is due to the stabilizers' combination with water, which creates strong and rigid hydrates, fills voids, and binds particles together independently of soil reactions (Danso et al., 2019). On the 28th day of curing, the compressive strengths of the compressed earth blocks were 1.20 MPa, 1.65 MPa, 1.87 MPa, 2.35 MPa, 2.10 MPa, 2.48 MPa, and 2.53 MPa for B1, B2, B3, B4, B5, B6, and B7, respectively. The compressive strength of all the blocks were within the prescribed minimum values for usage in structural work of 1 MPa (TS 704, 2001) and 2 MPa (Houben & Guillaud, 1994). The compressive strength of the block specimens with a 10% Lime-4% CHA (B7) composition was 110% higher than that of the un-stabilized block samples.

The purpose of carrying out One-Way RM ANOVA test was to determine if there was a significant difference in compressive strength between the un-stabilized and stabilized after 28 days of curing. The test result yielded a p-value of 0.001, indicating a statistically significant difference between the un-stabilized block specimens and the Lime-CHA block samples. This means that the addition of lime and CHA to compacted earth blocks considerably improved their mechanical properties.

To determine the pair where the difference occurred, a paired sample t-test was used. The results show that there is no statistically significant difference between the pairs B1-B2, B3-B5, and B4-B5. Apart from that, all the other block pairs differ significantly.

Table 4. 4 Compressive strengths of CEBs

Batch	**7 DAYS (MPa)**	**14 DAYS (MPa)**	**21 DAYS (MPa)**	**28 DAYS (MPa)**
B1	0.67	0.74	1.00	1.20
B2	0.72	0.83	1.18	1.65
B3	0.80	0.97	1.30	1.87
B4	0.94	1.15	1.80	2.35
B5	0.86	1.11	1.66	2.10
B6	0.99	1.34	1.95	2.48
B7	1.08	1.48	2.15	2.53

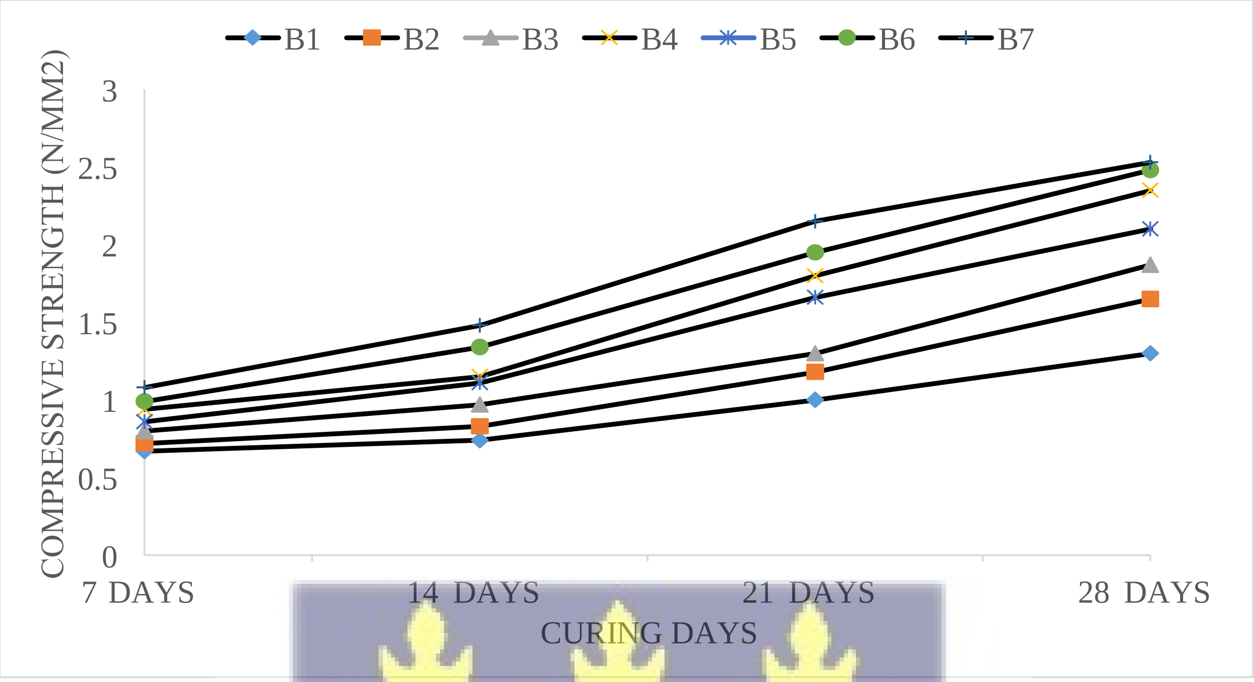


Figure 4. 4 Compressive strength of CEBS

Table 4. 5 One-Way RM ANOVA summary of Compressive strength of CEBs after 28 days curing age

Sample	Mean compressive strength	Standard deviation	F- value	P-value
B1	0.9275	0.2860	17.808	0.000
B2	1.0950	0.4188		
B3	1.2350	0.4714		
B4	1.5600	0.6414		
B5	1.4325	0.5565		
B6	1.6900	0.6593		
B7	1.8100	0.6521		

4.5 Water Absorption

The ability of the bricks specimen to absorb water after being partially immersed in water for 10 minutes was studied in this test. In general, the blocks with high coefficients have a high absorption rate and consequently high porosity, whiles samples with low coefficients are less porous and absorb less water. The rate of water absorption by compressed earth block samples decreased gradually as the quantity of Lime-CHA in the block samples increased (figure 4.6). The un-stabilized block samples had the maximum water absorption of 12.2, whereas the stabilized earth blocks with 10% lime-40% CHA had the lowest water absorption of 2.94. The enhanced water absorption of CEBs could be ascribed to the stabilizer's capacity to plug spaces between soil particles, reducing the blocks' porosity (Danso et al., 2015).

Table 4. 6 Coefficient of water absorption of CEBs

Sample	**Dry mass (Kg)**	**Wet mass (kg)**	**Coefficient of water absorption (g/cm^{2}min)**	**Mean Coefficient of Water Absorption(g/cm^{2}min)**
B1	13.5	14.7	10.11	
	13.5	15.2	14.33	12.2
B2	12.8	14.2	11.8	11.8
	12.8	14.2	11.8	
B3	12.0	14.2	9.28	9.28
	12.0	14.2	9.28	

B4	13.8 13.8	14.7 14.7	7.59 7.59	7.59
B5	13.1 13.1	14.1 14.1	8.01 8.01	8.01
B6	13.6 13.6	14.1 14.1	4.21 4.21	4.21
B7	13.9 13.9	14.3 14.3	2.94 2.94	2.94

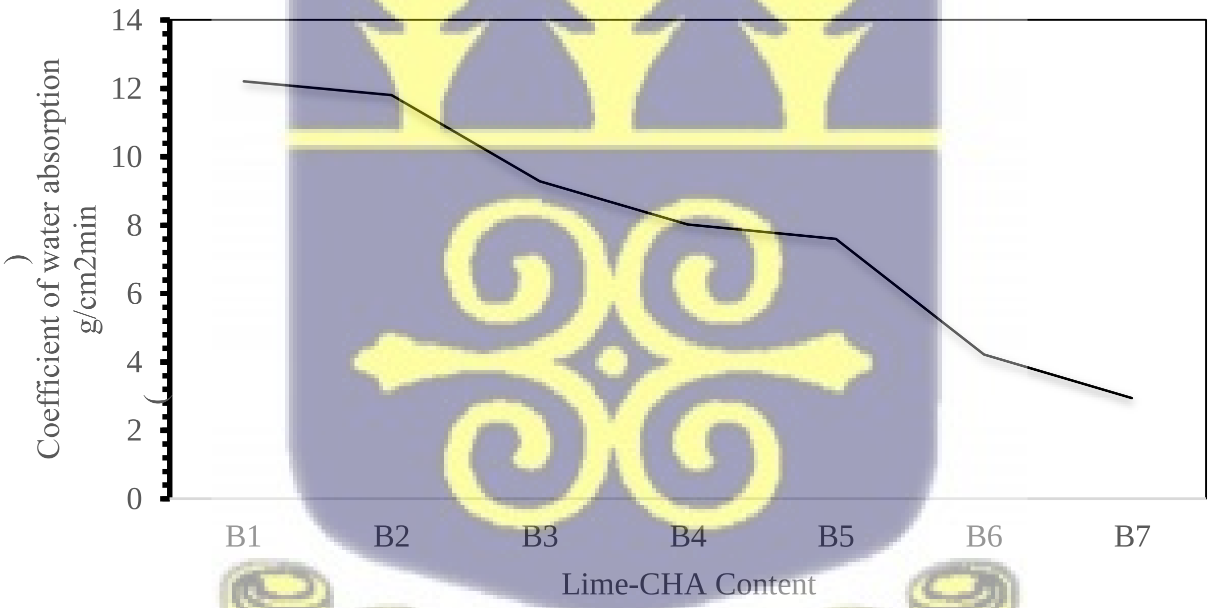


Figure 4. 5 Coefficient of water absorption of CEBs

4.6 Abrasion Resistance

From the results, the block samples generally showed a steady increase in their resistance to abrasion (wear) as the amount of stabilizer were increased. The un-stabilized block samples had the lowest resistance to abrasion with a value of 0.60cm^2/g whiles the highest abrasion resistance value was recorded by blocks stabilized with 10% lime- 4%CHA with a value of 3.0cm^2/g.

The increase in abrasion resistance of the soil blocks as the stabilizers increase is attributed to the improved cementitious action between the stabilizers and that of the soil resulting in an enhanced bond strength which holds the particles in a matrix.

Table 4. 7 Abrasion resistance of CEBs

Sample	Mean Abrasion resistance (cm^2/g)
B1	0.60
B2	0.86
B3	1.00
B4	1.04
B5	2.00
B6	2.25
B7	3.00

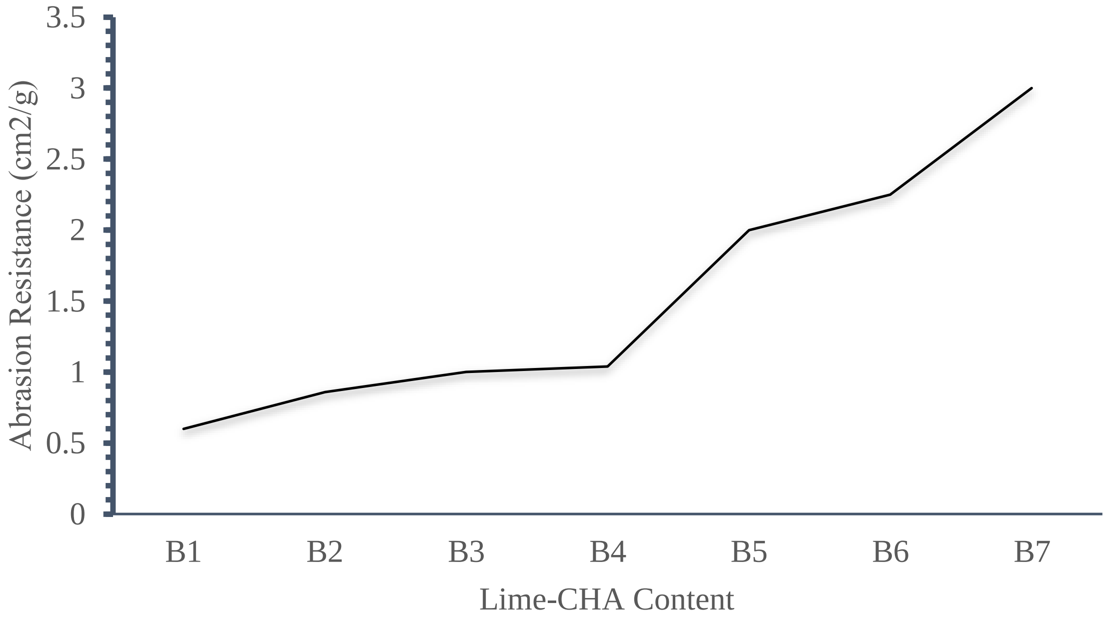


Figure 4. 6 Abrasion resistance of the CEBs

4.7 Cost Analysis

4.7.1 Unit Cost of A Block

Table 4. 8 Unit cost of a compressed stabilized earth blocks

Material	**Quantity**	**Calculation**	**Cost**
Laterite	1 Cement bag		GHS 32.00
Lime	1 bag		GHS 105.00
Coconut husk			GHS 0.00
Laterite	1 4L container	$\frac{32}{8}$	GHS 4.00
Lime	1 4L container	$\frac{105}{8}$	GHS 13.12

Laterite	10 parts	10 x 4.00	GHS 40.00
Lime	1 part	1 x 13.12	GHS 13.12
CSEB	40	40.00 +13.12	GHS 53.12
Cost of 1 CSEB		$\frac{53.12}{40}$	GHS 1.32
Labour	10% of the unit cost of CSEB	$\frac{1.32 X 10}{100}$	GHS 0.13
Water	20% of the unit cost of CSEB	$\frac{1.32 X 20}{100}$	GHS 0.26
Total cost of a unit compressed earth block = 1.32+0.13+0.26 = GHS 1.70			

From the calculations above, the unit cost of a compressed earth block is GHS 1.70.

4.7.2 Comparative Cost Analysis Between A Compressed Stabilized Earth Block And A Sandcrete Block

The Comparative cost analysis between Compressed Stabilized Earth Blocks (CSEB) and Sandcrete blocks (SBs) for residential buildings in Ghana was conducted through quantitative and case study approaches. The estimation was done for a single room. Prices of SBs were obtained from various building materials shops in Accra.

Table 4. 9 Comparative cost analysis between a sandcrete blocks and compressed stabilized earth blocks

SANDCRETE BLOCKS	COMPRESSED STABILIZED EARTH BLOCKS
For a single room of area 12 x 12, approximately 500 blocks will be required If a block = GHS 4.00 Then 500 blocks = GHS 2000.00	For a single room of area 12 x 12, approximately 800 blocks will be required If a block = GHS 1.70 Then 800 blocks = GHS 1,360.00

The cost difference between using SB and CSEB = GHS 640.00.

Results from the cost analysis shows that the cost of incurred in the use of CSEB for the construction of proposed single room is cheaper than using sandcrete blocks. The cost of production is reduced by 38%.

CHAPTER FIVE
CONCLUSON AND RECOMMENDATION

5.1 Conclusion

The main objective of this study was to investigate the engineering characteristics of compressed earth blocks stabilized with lime and coconut husk ash. Based on the investigations and deduction from the results, the following conclusions are drawn

1. Laterite soil from Afienya shows acceptable properties in regard to its physical and chemical compositions for the production of compressed stabilized earth blocks.
2. There was no noticeable change in densities of the stabilized and un-stabilized blocks.
3. The compressive strength test results showed significant increase in strength of the stabilized blocks than the un-stabilized block. The tests further suggest a statistically significant difference in strengths based on the p-value of 0.001.
4. The water absorption results showed that the stabilized blocks absorbed less water as compared to the un-stabilized blocks which is an improvement with sample B7 being the most promising.
5. Lastly, the stabilized blocks were significantly resistant to abrasion as compared to the un-stabilized blocks with sample B7 being the most durable.
6. For practically all of the studies, the highest improvements were reported at the 10% Lime-4% CHA contents, and hence 10% Lime-4% CHA content is recommended for usage in earthen buildings.

7. Results of the cost analysis shows that the cost incurred in the use of CSEB for the construction of the proposes single room is cheaper than using sandcrete blocks. The cost of production is reduced by 38%.

5.2 Recommendation

1. Studies should be carried out on soils from different areas to better understand the effects of lime and coconut husk ash as stabilizers.
2. The influence of lime and coconut husk ash must be considered when determining the maximum dry density to be employed in production.
3. Wet compressive strength should also be assessed to better understand the blocks performance in humid environment.

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APPENDICES

Appendix A: Particle Size Analysis Test

CENTRAL MATERIALS LABORATORY

DRAFT FORM Date 16/06/21
WASHED SAMPLE ANALYSIS
MOIST GRANDUAL Technician
SOIL

SAMPLE NO.	
SAMPLE LOCATION	AFIENYA
SAMPLE DESCRIPTION	LATERITE
MASS SAMPLE RECEIVED	1090.0
GRADING OF AIR-DRY COURSE AGGREGATE	AIR-DRY MOISTURE CONTENT

Sieve Aperture	Mass Retained	Dry Mass	Percent Retained	Percent Passing		Passing 19.00mm	Retained 19.00mm
75.0					Container No.	Z - 7	
53.0					Mass Moist Agg + Cont	1531.0	
37.5					Mass Dry Agg+ Cont	1501.5	
26.5					Mass of container	962.0	
19.0					Mass of water	29.5	
Pan					Mass of Dry Aggregate	539.5	
Total Dry Mass					Moisture Content	5.47	

GRADING OF MINUS 19mm FRACTION

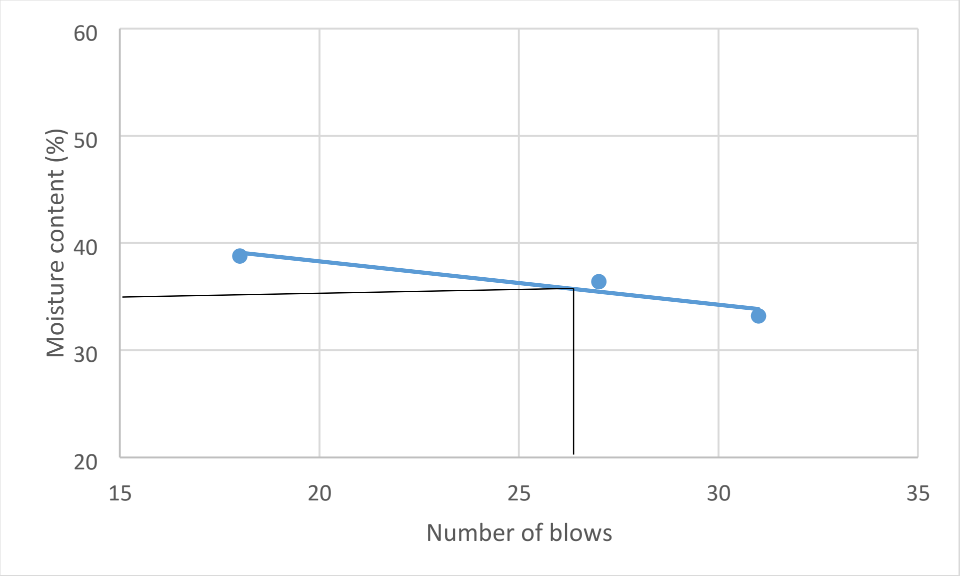
BOWL NO.	B – 9
Mass Bowl No.	867.5
Mass Bowl + air dry (moist) sub sample	1385.0
Mass air dry (moist) sub-sample	517.5
Mass dry sample	490.7
Mass Bowl + dry sample after washing	1206
Mass dry sample after washing	338.5
Mass minus 0.075 washed away	152.2

Sieve Aperture (mm)	Mass Retained (g)	Percentage Retained (%)	Percentage Passing (%)	Percentage Total Passing Sample
19.0	0.00	0.00	100.00	100
9.5	0.00	0.00	100.00	100
4.75	36.5	7.35	92.65	93
2.00	108.0	21.74	70.91	71
1.00	45.5	9.16	61.75	62
0.425	45.5	9.16	52.58	53
0.300	26.0	5.23	47.35	47
0.150	50.0	10.07	37.28	37
0.075	28.5	5.74	31.54	32
Pan	4.5	0.91		
Mass Washed away	152.17	30.64		
Total	344.5	100		

Appendix B: Atterberg Limit Test

Liquid Limit

Type of test	Casagrande cup liquid limit		
Test number	1 (27-35)	2 (23-27)	3 (22-25)
Number of blows	31	27	18
Container number	511	518	544
Mass of wet soil + Container	25.13	27.34	29.58
Mass of dry soil + Container	21.23	22.58	23.98
Mass of container	9.47	9.51	9.53
Mass of water	3.9	4.76	5.6
Mass of dry soil	11.76	13.07	14.45
Moisture content	33.2	36.4	38.8



Relationship between moisture content and number of blows

Plastic Limit

Type of test	Plastic Limit	
Test number	1	2
Container number	C0	H4
Mass of wet soil + Container	13.63	13.59
Mass of dry soil + Container	11.74	11.70
Mass of container	3.35	3.28
Mass of water	1.89	1.89
Mass of dry soil	8.39	8.42
Moisture content	22.5	22.4

Appendix C: Moisture – Density Relationship

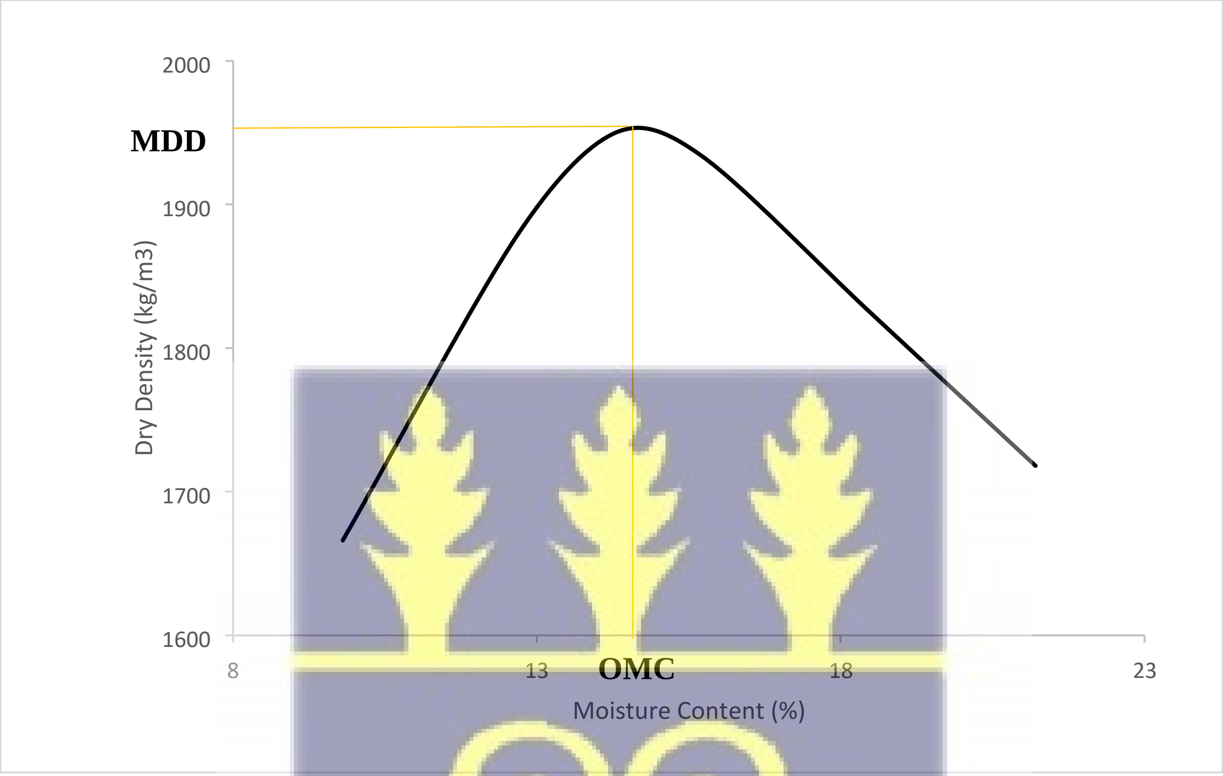
GHANA HIGHWAY AUTHORITY FORM S1/2
DATE

MATERIALS DIVISION **MOISTURE –DENSITY RELATIONSHIP**
MINUS 19mm FRACTION

SAMPLE NUMBER										
Mass minus 19mm		Mass plus 19mm			Total mass				% Oversize	
Row	Parameter	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen 6		Specimen 7	Specimen 8
1	Container No.									
2	Mass air-dry sample (g)									
3	Mass water added (g)									
4	Percent water added	0%	3%	6%	9%	12%	4.35%		4.35%	4.35%
5	Estimated air-dry MC (%)									
6	Est. compaction MC. (%) (4) + (5)									
7	Mould Number	M2	M2	M2	M2	M2	M2		ST	ZM8
8	Mould factor	0.4727	0.4727	0.4727	0.4727	0.4727	0.4727		0.4727	0.4727
9	Mass of mould (g)	4175	4175	4175	4175	4175	4175		4120	4092
10	Mass of mould + wet soil. (g)	8045	8657	8910	8748	8580	8965		8635	8296

11	Mass of wet soil. (g) (10)- (9)	3870	4482	4735	4573	4405	4790		4515	4204
12	Wet density. Kg/cu.m. (11) *(8)	1829	2119	2238	2162	2082	2264		2134	1987

13	Approx. Dry density. 100*(12)/(100+ (6))	1829	2057	2111	2040	1859	2170	2045	1904
MOISTURE CONTENT DETERMINATION									
14	Oven-pan Number	MKZ	MAS	CRO	BNS	UNO	ORC	ORS	KAM
15	Mass Oven-pan (Kg)	1.205	1.203	0.835	1.049	1.188	0.853	0.800	0.926
16	Mass oven-pan + wet soil (g)	1727	1728	1740	1754	1777	1755	1732	1745
17	Mass Oven-pan + dry soil (g)	1680.5	1669.0	1617.0	1644.0	1673.5	1642.5	1615.0	1643.0
18	Mass of water (g). (16) – (17)	46.5	59	123	110	103.5	112.5	115	102
19	Mass of dry soil (g). (17) – (15)	475.5	466	782	595	485.5	789.5	815	717
20	MOISTURE CONTENT	9.8	12.7	15.7	18.5	21.2	14.2	14.1	14.2
21	Black Calc. Air –dry MC (%) (20) –(4)								
22	Dry density. 100*(12)/(100+(20))	1666	1880	1934	1824	1718	1982	1870	1740
23	RELATIVE COMP. 100*(DD/MDD)						100%	94%	87%



Relationship between dry density and moisture content

Appendix D: T-Test

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	B1	.9275	4	.28605	.14303
	B2	1.0950	4	.41877	.20938
Pair 2	B1	.9275	4	.28605	.14303
	B3	1.2350	4	.47149	.23574
Pair 3	B1	.9275	4	.28605	.14303
	B4	1.5600	4	.64140	.32070
Pair 4	B1	.9275	4	.28605	.14303
	B5	1.4325	4	.55650	.27825
Pair 5	B1	.9275	4	.28605	.14303
	B6	1.6900	4	.65934	.32967
Pair 6	B1	.9275	4	.28605	.14303
	B7	1.8100	4	.65212	.32606
Pair 7	B2	1.0950	4	.41877	.20938
	B3	1.2350	4	.47149	.23574
Pair 8	B2	1.0950	4	.41877	.20938
	B4	1.5600	4	.64140	.32070
Pair 9	B2	1.0950	4	.41877	.20938
	B5	1.4325	4	.55650	.27825
Pair 10	B2	1.0950	4	.41877	.20938
	B6	1.6900	4	.65934	.32967
Pair 11	B2	1.0950	4	.41877	.20938
	B7	1.8100	4	.65212	.32606
Pair 12	B3	1.2350	4	.47149	.23574
	B4	1.5600	4	.64140	.32070
Pair 13	B3	1.2350	4	.47149	.23574
	B5	1.4325	4	.55650	.27825
Pair 14	B3	1.2350	4	.47149	.23574
		1.6900	4	.65934	.32967

	B6				
Pair 15	B3	1.2350	4	.47149	.23574
	B7	1.8100	4	.65212	.32606
Pair 16	B4	1.5600	4	.64140	.32070
	B5	1.4325	4	.55650	.27825
Pair 17	B4	1.5600	4	.64140	.32070
	B6	1.6900	4	.65934	.32967
Pair 18	B4	1.5600	4	.64140	.32070
	B7	1.8100	4	.65212	.32606
Pair 19	B5	1.4325	4	.55650	.27825
	B6	1.6900	4	.65934	.32967
Pair 20	B5	1.4325	4	.55650	.27825
	B7	1.8100	4	.65212	.32606
Pair 21	B6	1.6900	4	.65934	.32967
	B7	1.8100	4	.65212	.32606

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	B1 - B2	-.16750	.13326	.06663	-.37955	.04455	-2.514	3	.087
Pair 2	B1 - B3	-.30750	.18839	.09420	-.60727	-.00773	-3.264	3	.047
Pair 3	B1 - B4	-.63250	.35743	.17872	-1.20126	-.06374	-3.539	3	.038
Pair 4			.27598				-3.660		.035
	B1 - B5	-.50500		.13799	-.94415	-.06585		3	
Pair 5	B1 - B6	-.76250	.37933	.18967	-1.36610	-.15890	-4.020	3	.028
Pair 6			.38117				-4.630		.019
	B1 - B7	-.88250		.19059	-1.48903	-.27597		3	
Pair 7			.05888				-4.756		.018
	B2 - B3	-.14000		.02944	-.23369	-.04631		3	
Pair 8	B2 - B4	-.46500	.23116	.11558	-.83282	-.09718	-4.023	3	.028
Pair 9			.15840				-4.261		.024
	B2 - B5	-.33750		.07920	-.58956	-.08544		3	
Pair 10			.25736				-4.624		.019
Pair 11	B2 - B6	-.59500	.27234	.12868	-1.00451	-.18549	-5.251	3	.013
Pair 12			.19140				-3.396		.043
	B2 - B7	-.71500		.13617	-1.14835	-.28165		3	
Pair 13			.12868				-3.070		.055
	B3 - B4	-.32500		.09570	-.62956	-.02044		3	
	B3 - B5	-.19750		.06434	-.40226	.00726		3	
Pair 14	B3 - B6	-.45500	.21564	.10782	-.79813	-.11187	-4.220	3	.024
Pair 15			.24090				-4.774		.017
	B3 - B7	-.57500		.12045	-.95833	-.19167		3	
Pair 16			.09142				2.789		.068

	B4 - B5	.12750		.04571	-.01798	.27298		3	
Pair 17	B4 - B6	-.13000	.05888	.02944	-.22369	-.03631	-4.416	3	.022
Pair 18			.10551				-4.739		.018
	B4 - B7	-.25000		.05276	-.41790	-.08210		3	
Pair 19			.10500				-4.905		.016
Pair 20	B5 - B6	-.25750	.11587	.05250	-.42458	-.09042	-6.516	3	.007
	B5 - B7	-.37750		.05793	-.56187	-.19313		3	
Pair 21	B6 - B7	-.12000	.06481	.03240	-.22312	-.01688	-3.703	3	.034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