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INVESTIGATING STRENGTH AND DURABILITY PROPERTIES OF POZZOMIX-OPC STABILISED EARTH BLOCKS

BY

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DEPARTMENT OF WOOD AND CONSTRUCTION TECHNOLOGY

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DECEMBER, 2016

DECLARATION

CANDIDATE'S DECLARATION

I, ATEYIRE MICHAEL, declare that this Dissertation with the exception of quotations and references contained in the published works which have all been identified and duly acknowledged, is entirely my own original work, and not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE…………………..………………

DATE……………………………………......

SUPERVISOR'S DECLARATION

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

NAME: DR. PETER PAA KOFI YALLEY

SUPERVISOR…………………………………

DATE…………………………………………..

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DEDICATION

I dedicate this work foremost to God, and also to my daughter Ateyire Wemoatu Chrisha, my wife Anyedina Josephine whose effort have made this work a reality.

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LIST OF ABBREVIATIONS

OPC -	Ordinary Portland Cement
BS -	British Standard
ODA -	Overseas Development Administration
SIRDC -	Scientific And Industrial Research and Development Centre
TRADA -	Timber Research And Development Association
CSEB -	Compressed Stabilised Earth Blocks
UNESCO -	United Nations Educational, Scientific And Cultural Organisation
CEB -	Compressed Earth Blocks
RE -	Rammed Earth
GGBS -	Ground Granulated Blast Furnance Slag
PFA -	Pulverised Fly Ash
BRRI -	Bereau of Road Research Institute
PPC -	Portland Pozzollana Cement
ASTM -	American Society for Testing and Material
WDR -	Wind- Driven Rain
LL -	Liquid Limit
PL -	Plastic Limit
PI -	Plasicity Index

ABSTRACT

This research investigates the effect of replacing earth with 5% ($P_{5/0}$), 9% ($P_{9/0}$) and 12% ($P_{12/0}$) Pozzomix cement and 3% pozzomix + 2% OPC ($P_{3/2}$), 6% pozzomix + 3% OPC ($P_{6/3}$), 8% pozzomix + 4% OPC ($P_{8/4}$) on the compressive strength, water absorption and abrasion resistance of earth blocks and to deduce the variable that contributes most to these parameters. The engineering characteristics of the soil from Bernatech campus, Navrongo carried out in accordance with BS1377:1990 reveals that soil fines and coarse fractions constitute about 46.8% and 53.2% therefore suitable for brick production. The total number of bricks selected for the tests were one hundred and forty five (145) and they were 230mm x110mm x 90mm in size. Also the strength and durability criteria of hand-made bricks were investigated after 28 days curing. Results indicate that all the specimens obtained recommended density values with the batch $\mathbf{P_{3/2}}$ recording the lowest (1764kg/m^3) and $P_{12/0}$ the highest (1997kg/m^3) density. The analysis showed that pozzomix contributed the most (71%) to the density of earth bricks. Again all the stabilized earth bricks saw a steady increase in dry compressive strength of 2.06N/mm^2, 2.28N/mm^2, 2.41N/mm^2, 2.47N/mm^2, 3.15N/mm^2 and 4.73N/mm^2 for specimens $\mathbf{P_{5/0}}$, $\mathbf{P_{9/0}}$, $\mathbf{P_{12/0}}$, $\mathbf{P_{3/2}}$, $\mathbf{P_{6/3}}$ and $\mathbf{P_{8/4}}$ respectively. The control and the 5% Pozzomix specimens did not perform well in wet compressive strength. The entire specimens responded negatively to water intake with the specimens $\mathbf{P_{8/4}}$ recording an impressive 0.096g/cm^2/min reduction. The abrasion test values were within acceptable range with batch $\mathbf{P_{8/4}}$ again resisting abrasion the most with a record of 11cm^2/g. Generally the brick specimens saw an improvement when the percentages of the stabilizers increased. It is appropriate to conclude that the use of Pozzomix with OPC will improve significantly the strength and durability properties of compressed earth bricks. The use of Pozzomix cement alone should be used sparingly especially lower percentage and in poor soils

CHAPTER ONE

INTRODUCTION

1.1. Background to the Study

The final results of the 2010 population and housing census in Ghana showed that the total population of Ghana was 24,658,823 (Ghana Statistical Service, 2012). The results indicated that Ghana population increased by 30.4 percent over the year 2000 population census. This massive population increment has serious effect on housing provision in the country, especially in the urban centers where the population is too dense. Currently, the country's housing shortfall is estimated at 1.7 million units, and expected to hit 2 million by 2018 (Danyansah,2015). This indicates that new rooms must be completed in every minute daily for ten years. Despite upward trends in housing production over the years, generally, the increases are not enough to offset the accumulated deficits, and also to meet the needs of the increase in population in urban Ghana (Andersen, Andreasen & Tipple, 2006). This has forced majority of residents to seek accommodation in informal settlements, backyard kiosk, containers, street corners and overcrowded compound houses with little security of tenure. The situation in rural areas in Ghana is no better. Though the rural dwellers have adopted the old method of building with earth, its durability has remained a challenge over ages, since they are continuously called to maintain the buildings. The use of earth bricks as a standard building material began in the early 1900s in most of the African countries. Sand bricks, cement, sand and timber are the major construction materials in Africa up to date which is unaffordable nowadays and an appropriate building material and construction technique needs to devise to solve the urban and rural housing challenges. For example, "earth" can be used as an appropriate construction material in Ghana. The house provides a 'necessary foundation' for every person to live during the social actions and physical actions (Byrne and Diamond, 2007). House became 'more expensive' in many countries from the beginning of 21st century (Haffner and Boumeester, 2010). In the 2010 housing census it was realized that about 57.5% of houses in Ghana were built with cement,sand and concrete while just about 34.2% of houses were built of mud/earth.

The sensitivity of earth based buildings to moisture with the resultant effects of cracks on drying, erosion and structural collapse, have been the major setbacks of earth as building materials (Zami and Lee, 2007). To overcome that, stabilising agents such as fibrous materials, lime and cement were introduced to mix with right earth type to improve their strength and durability to meet the performance requirements for safety, thermal and acoustic comfort, ease of use, adaptability and cost.

Literature review on stabilized earth masonry bricks/blocks revealed that there is a growing interest in stabilized earth building materials development with respect to an energy conscious and ecological design, which fulfils all strength and serviceability requirements for thermal transmittance. The work by Jayasinghe and Mallawaarachchi (2009) was on flexural strength of compressed stabilized earth masonry materials. Venkatarama Reddy, Lal, & Nanjunda (2007) reported on enhancing bond strength and characteristics of soil-cement block masonry. This resurgence of renewed research interest in recent years in stabilized earth building bricks may be partially due to its potential as a commercial construction material. The fact that, a single element can fulfill several functions including structural integrity, thermal transmittance and durability in service makes the material an excellent walling material when compared to the fired earth bricks used in mainstream construction of today. Earth as a construction material has been used for thousands of years by civilizations all over the world. Many different techniques have been developed; the methods used vary according to the local climate and environment as well as local traditions and customs. The compressed earth block is a modern descendent of moulded earth block, more commonly known as the adobe block. The idea of compacting earth to improve the quality and performance of moulded earth blocks is, however, far from new and it was with wooden tamps that the first compressed earth blocks were produced. The use of ordinary portland cement to stabilise the earth blocks has been found to improve the properties of earth blocks but the challenge has to be the cost of OPC. "Pozzolana cement has been tested and proven locally by the bereau of road and research institute to be very durable. It has the potential to replace Portland cement by 40% and reduce the amount spent by the country on clinker importation. The pozzolanic producing companies use almost half of the energy which is used to produce Portland cement. This has a net effect of cost reduction with respect to pozzolana utilization. The production of less expensive pozzolanic material could lead to affordable concrete and mortar formation, provision of less expensive buildings. Moreover approximately $100 Million could be saved from cement importation through the use of locally produced pozzolana in Ghana (Bediako & Frimpong, 2013).

1.2. Statement of the Problem

The motivation of this study is the experience the researcher has had on the ground in upper east region where he grew. During the 2010 population and housing census it was estimated that about 34.2 percent of households in Ghana were built of mud bricks/earth. The main drawback of this building material is the need for continuous maintenance and the lack of durability and resistance to water (Bahar, Benazzoug & Kenai, 2004).

Unfortunately the walls of these mud houses made from wet soils or earth are unable to withstand harsh rainy seasons. Cracks appear on the walls because the soil particles are not held together with sufficient bonding strength. Yalley and Manu (2013) has extablished in their work that fibers such as cowdung could be used to bond the raw soil particles together. This material (Stabiliser) is unfortunately competed for by farmers as manure for their farms. It is for this reason that it has become important to investigate the possibility of stabilizing the earth with alternative sustainable low cost stabilizers with recommended strength and durability of earth blocks.

1.3. Purpose of the Study

The purpose of the study is to examine the effect of selected stabilisers on the physical and mechanical properties of compressed earth bricks for affordable housing . The increase demand for sand cement and conrete as building materials has segregated the poor from owing decent housing due to the high cost of acquiring these materials. Due to the cost of sand and ordinary portland cement, the study seeks to delve into the properties of alternative material which is relatively low cost with enhanced durability. The properties of Pozzomix-OPC earth bricks will be examine. Clay Pozzolana is an innovative product developed by CSIR-BRRI after over 30 years of research, which replaces up to 35 percent of Ordinary Portland Cement (OPC) to obtain Portland Pozzolana Cement (PPC) for both concrete and general construction. The cost of

Pozzolana per 50kg-bag is about 20 percent cheaper than a bag of Portland cement and has relatively greater plasticity and workability than Portland cement. The Institute, following suggestions from clients, also developed a premixed composite Portland Pozzolana Cement, named Pozzo Mix Cement. This is a ready-made product which could be applied right away on site. Pozzolana Cement has the secondary reaction, less permeable and makes buildings; bridges and concrete works especially in water log area more durable.

1.4. Aim and specific Objectives

The study investigates the strength and durability properties of the walling units produced from earth stabilized with pozzomix cement and OPC for low-income housing. The specific objectives of the study are :

1. To investigate local soil to identify their suitability in stabilized earth block production.
2. To study experimentally the effect of altering Pozzomix cement and ordinary Portland cement on the compressive strength of earth blocks.
3. To determine the stability response of Pozzomix and OPC stabilized earth bricks under moist environment.
4. To investigate the abrasion resistance of earth bricks stabilized with varied proportions of Pozzomix cement and OPC.

1.5. Research Questions

1. To what extent will the properties of the soil be suitable for stabilized earth blocks production?
2. To what extent will Pozzomix and OPC improve the strength of earth blocks?
3. How much will Pozzomix and OPC improve the water absorption resistance of earth blocks?
4. To what extent will Pozzomix cement and OPC content improve the abrasion resistance of earth blocks?

1.6. Significance of the Study

The study will investigate the properties of recommended earth for soil brick production. Again the study is going to help improve the strength and durability of stabilised earth bricks by stabilising it with Pozzomix and OPC. The study will promote the use of appropriate technology and local materials in house construction. This will reduce the housing deficit to its minimum bearable situation.The study will significantly serve as a reference material for researchers with interest in green technology.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Modern earth building is alive and well spread over an enormous geographical area using numerous different methods of construction. The new earth buildings developing worldwide have generally utilized the good aspects of the traditional method while adding aspects and technologies. Today Adobe brick construction has been partially adapted to economical projects. In Mesopotamia, some cases of earth brick construction are as far back as 10,000 BC (Heathcote, 1995). Historically some of the building materials are new, while others are very old and started with human shelter.

Blondet, Garcia, Brzev, & Rubiños (2003) illustrated that adobe mud blocks are one of the oldest and most widely used building materials. Use of these sun-dried blocks dates back to 8000 B.C. The use of adobe is very common in some of the world's most hazard-prone regions, traditionally across Latin America, Africa, Indian subcontinent and other parts of Asia, Middle East and Southern Europe.

2.2. History of Earth Materials and Traditional Clay Buildings

2.2.1 Olden Earth Buildings

It is essential to look at historical evidence of the success of earth construction. According to Houben & Guillaud (1989) as cited in Zami (2011), the history of earth building lacks documentation because it has not been highly regarded compared to stone and wood. According to Easton (1996) 50 percent of the planet's humans still live in shelters made of earth. Archeological evidence shows, nearly 10000 years old of entire cities built of raw earth, such as: Jericho, history's earliest city; Catal Hunyuk in Turkey;

Harappa and Mohenjo-Daro in Pakistan; Akhlet-Aton in Egypt; Chan-Chan in Peru; Babylon in Iraq; Duheros near Cordoba in Spain and Khirokitia in Cyprus (Easton, 1996) as cited in Zami, (2011). There are cities built of raw earth, such as: Catal Hunyuk in Turkey; Harappa and Mohenjo-Daro in Pakistan; Akhlet-Aton in Egypt; Babylon in Iraq; (Easton, 1998). Figure 2.1 shows the spread of different kinds of earth structure being used by different regions of the world.

Figure 2.1: Different Forms of Earth Structure Being Used by Different Regions of the World.

Source: Houben & Guillaud (1989).

In Europe, primitive dwellings were constructed of woven wood and clay evolving to un-burnt clay (Houben & Guillaud, 1989). According to Easton (1996) as cited in Zami, (2011) Rammed earth construction was brought to the temperate regions of Europe by the Romans and Phoenicians. Builders in this region seem to have developed unique earth structures like the brick dome at a very early time. During the Roman Empire houses were constructed using earth brick walls before stone replaced them for the rich, while the poor remained housed in buildings of earth until the time of Augustine who recommended the use of earth on a national scale (Houben and Guilland, 1989).

Raw earth construction was not a forefront building method until the 18th century when an emerging use of cob, rammed earth and un-burnt brick could be observed. Building with earth continued until the 1950s and there was a sudden increase in the use of the material after the Second World War, as the demand for housing increased due to war displacements (Houben and Guilland, 1989). From the past to the present day, earth seems to be the material of choice. Mud brick that was made of alluvial soils was mixed with cereal straws. It gave man his first durable construction material and took many forms, such as adobe, rammed earth and straw-clay (Houben & Guillaud, 1994). Earth architecture has also deep roots in all old civilizations, the Middle East, Iran and the cradle of the Sumerian civilization in Iraq (Fig. 2.2.). At Shibam in South of Yemen, there are more than ten stories high of cob buildings (Houben & Guillaud, 1994). Nowadays, unbaked earth buildings shelter about thirty percent of the world's population (Houben & Guillaud, 1994).

Figure 2. 2. Ruins of Earth Shelters (Egyptian Mud-Brick Storage Rooms, 3200 Years)(Middendorf, 2001 cited by Al-Sakkaf, 2009)

2.2.2. Modern Earth Building

One of the first modern stabilised earth projects in Zimbabwe was the British government, Overseas Development Administration (ODA) funded, DfID School block (Fig 2.3) at the Scientific and Industrial Research and Development Centre (SIRDC), Hatcliffe, Harare, Zimbabwe Hatcliffe, Zimbabwe. Source: (Zami & Lee, 2007). This project was mainly constructed to demonstrate that rammed earth (RE) could successfully support a roof span of 8m whilst at the same time being a test bed for the publication of RE Structures: A Code of Practice. The building also incorporates boron treated timber roof, which was designed by the Timber Research and Development Association TRADA. The building was inexpensive, and showed that wide span roofs are possible with the technology, important for classrooms and clinics. In the Hatcliffe building, concrete was used for the foundations at the insistence of the host organisation. This house/classroom block built on SIRDC premises attests to the versatility of RE construction. The creation of this was a milestone in illustrating how RE can be used to lower construction costs. This building technology was 60% cheaper than concrete blocks and could provide double the number of built units for the many African school building programs, as well as clinics, homes and a range of commercial buildings. The In-Situ RE Company also carried out a number of rammed earth projects in the country among some of which were a classroom block (Figure 2.4) in Bonda, Manicaland commissioned by pioneering passive solar architect Mick Pearce in 1997, Office and housing (Figure 2.5) in Chimanda on the North East border with Mozambique. Figure 2.8 and figure 2.9 show compressed earth blocks used for the Bukere art centre in Bolgatanga and projects of students of St. Bernadette's technical institute, Navrongo. Bricks used in the project in figure 2.9 were made from raw soil firmly compressed to improve its durabilities.

Figure 2.3: Rammed Earth DFID Block at SIRDC, Hatcliffe, Zimbabwe. Source: (Zami and Lee, 2007).

Figure 2.4: Bonda Classroom. Source: (Zami and Lee, 2007)

Figure 2.5: Chimanda House under construction Source: Hatcliffe, Zimbabwe. Source: (Zami and Lee, 2007).

Auroville Building Centre (2005) as cited in Maini (2005) explained that the new development of earth construction really started in the nineteen fifties, with the technology of the Compressed Stabilized Earth Blocks (CSEB): a research Programme for affordable houses in Colombia proposed the first manual press–the Cinvaram. Since then, considerable scientific researches have been carried out by laboratories. The knowledge of soil laboratories concerning road building was adapted to earth construction.

The input of soil stabilization has made it possible to build higher with thinner walls, which have a much better compressive strength and water resistance. With cement stabilization, the blocks must be cured for four weeks after manufacturing. After this period of time, they can dry freely and be used like common bricks with a soil cement stabilized mortar (Auroville Building Centre, 2005).

Today, “Our Lady of Seven Sorrows”, the last mud basilica in Ghana still stands, impressive, a masterpiece of Ghanaian heritage and art. In addition to being recognized as a major monument in the country, the Cathedral has been inscribed on the tentative list of sites to be nominated to the World Heritage List of UNESCO (Abadomloora, Taxil, Kwami, Moriset, & Savage, 2004).

Our lady of seven sorrows basilica was built several decades ago (1920) with sun dried mud bricks andhas stood for several decades and will stand for many more, if maintainedproperly. This is sufficient proof thatthe traditional building technique ismore reliable than perceived and not inferior or just meant for the poor. The good conservation of the basilica can have a considerable influence on accessibility to housing and therefore on sustainable development of this sector in the area, based on the use of local materials and the promotion of local skills. This would in turn help to ensure the conservation of the basilica itself, as having led to a revival of the know-how required for effective development. This monumental structure has been reinforced with fiber. Figure 2.6. And Figure 2.7. Show the construction stage and the completed phase of the basilica respectively.

Figure 2.6: Navrongo Basilica Under Construction with Mud

Figure 2.7: Complete Construction Of Basilica

Figure 2.8: Bolgatanga-Bukere Art Center

Figure 2.9: CEBs Projects on St. Bernadette's Tech. Inst. Campus

2.3. Soil Characteristics

Yalley and Manu (2013) indicated in their work that, the characteristics of earth obtained after conducting a laboratory investigation on local earth from Sunyani Polytechnic area of Ghana were as follows: moisture content 10%, liquid limit 35%, plastic limit 24%, plasticity index 11%, maximum shrinkage at 7 days 2.18%, organic content 1.9%, maximum dry density 1762kg/m3, Moisture content 12%, clay content 11%. The properties of the earth were obtained through laboratory investigation in accordance with BS 1881: part 1, 3 and 7; (1990) as cited in (Yalley and Manu, 2013)

2.3.1. Soil Suitability and Stabilization for Compressed stabilised earth blocks

Arumala and Gondal (2008) as cited in El-Sawalhi, and Ajwa, (2013) used the following proportions to manufacture the Compressed Earth Blocks (CEB) in their research: Gravel: 0- 40%, Sand: 25-80% and Clay: 8-30%. They discovered, also that blocks that they made were enhanced by the addition of 5% of ordinary Portland cement.

A soil contains four components: gravel, sand, silt and clay. In concrete, the binder of gravel and sand is cement. In a soil, the binder is silt & clay. But silt and clay are not stable in water. Thus, the aim of stabilization is to stabilize silt and clay against water, so as to give lasting properties with the minimum of maintenance. Topsoil and organic soils must not be used. Identifying the properties of a soil is essential to create, at the end, good quality products. Not every soil is suitable for earth construction and CSEB in particular. But with some knowledge and experience many soils can be used for producing CSEB (Auroville Building Centre, 2005).

The particle size distribution recommended by German Industrial Standards (DIN 18 123) for production of compressed soil blocks indicates that the clay proportion should be (20%). The clay presence is important in the sense that, clay is responsible for the bonding effect amongst the soil particles. The soil should also contain sufficient amount of coarse fraction, i.e. 20% sand by proportion, this amount is sufficient to limit shrinkage of blocks when drying out (Minke, 2000).

Arumala and Gondal (2008) as cited in El-Sawalhi, and Ajwa, (2013) concluded that the suitability of the soil in the Compressed Earth Block (CEB) depends on its constituents that are sand, silt and clay proportions. Too much clay will cause cracks in the blocks while too much sand will cause the blocks to crumble. The suitable soil must contain the right proportions of sand, silt, clay and water. Walker, (1996) states that clay contents of between 5% and 20% are considered suitable for earth block production.

2.3.2. Mineral Compositions of Clay

The importance of clay component lies in the fact that clay particles are responsible for cohesive character of soil and that cohesiveness is of prime importance to the strength characteristics of CEB. Clay particles are only visible under microscope; each particle is coated by a film of water, held by surface tension. According to Norton (1997), it is this water which binds particles together (Namango 2006).

Ogunye (1997) states that the atomic structure of clay minerals consists of two fundamental building blocks i.e. tetrahedral of silica and octahedral of alumina. The {[SiO4]4-} tetrahedron, has one silicon atom equidistant from oxygen or hydroxyls. A silica tetrahedron sheet is formed from a series of tetrahedral which are arranged in a sheet-like hexagonal structure so that the oxygen atoms at the basal corners of the tetrahedral are in a common plane, with each shared between two in a tetrahedral. These sheets have a chemical make-up which varies according to the type of clay, degree of hydration and spacing; the spacing between the sheets is between 7 and 20 Angström (Houben and Guillaud, 1994).

2.4. Principles of CEB Stabilization

The strength of CEBs is also strongly affected by quality control procedures. These range from soil sampling practices to methods of manufacturing. Attention to a wide variety of factors is required: for example, the strength and durability of bricks can be improved through soil testing, gradation, optimum amount of clay in the soil, optimum amount of water while making the bricks, compression force applied and curing conditions. The primary ingredient that allows a soil to be used effectively in construction is clay as indicated earlier, which offers a cohesive effect by binding other fractions. However, the tendency of clay to disintegrate can be problematic, which is why stabilization techniques are so important for the durability of CEBs (Adam and Agib, 2001).

2.4.1. Stabilization Types

Nowadays, stabilisation of earth is a very common modern construction method and it modifies the properties and characteristics of soil but does not improve quality. Where the soil is not disturbed, grouting and in disturbed various methods of stabilisation are used. These methods include three types, namely: - Mechanical, Physical and Chemical stabilisation (Houben & Guillaud, 1989). Mechanical stabilization involves the application of force directly on the soil by compressing or ramming, thus changing the density, mechanical strength, compressibility, permeability and porosity. Physical stabilisation is the modification of the texture by varying the percentages of the mixed particles. Chemical stabilisation makes use of chemicals or other materials to modify the soil properties. According to Houben & Guillaud (1989), the possible ways in which earth can be used as a construction material are very numerous. For the sake of simplicity dozens of building method can be identified which are close to a hundred variations. Among the most widely known and practical construction methods are rammed earth in formwork, brick moulded in raw earth and baked by the sun or 'adobe', and compressed earth blocks, which are produced in presses. Rammed Earth (RE) and Compressed Earth Block (CEB) is the most common earth construction method.

2.4.1.1 Stabilizers Used in CEBs

2.4.1.1.1 Ordinary Portland Cement (OPC) Stabilization

In many parts of the developing world, cement is added to earth bricks to improve their durability and strength. The majority of research into cement stabilization has been heuristic and the reasons for successful or unsuccessful experiments have not been effectively probed. An understanding of the behavior of water in earth structures allows a better comprehension of how the cementing reaction continues within earth bricks. Grewal (2009) illustrated that there are many studies such as (Minke 2007; Houben and Guillaud 1994) have shown that the strength of mud brick buildings increases with increasing cement content up to critical cement content, beyond which the strength reduces with increasing cement content. The reasons for this peak cement content have previously been unclear. Two aspects compete for water within the earth structure; these are the cement reaction, which requires water to form the cementing products, and the formation of liquid bridges which are a result of the relative humidity of the surrounding air. As a result of evaporation of water from the cement stabilized sample, there is insufficient water to form the cementing products, leaving unreacted cement powder within the bricks, which do not contribute to strength. Any increase in volume of cement within a brick will not lead to an increase in strength because there is insufficient water with which to form a cementing matrix.

As previously mentioned, compressed earth bricks are particularly susceptible to erosion caused by water. However, adding cement to CEBs helps to make the bricks water-resistant. This happens because the cement actually limits the amount of swelling caused by water, and it also adds strength to the bricks. Cementation can make soil water-resistant through the limitation of swelling and the augmentation of compressive strength. When ordinary Portland cement hydrates when water is added, a cementitious gel is produced that is independent of the soil. This gel is made up of calcium silicate hydrates and calcium aluminate hydrates, which make up the bulk of the gel, and hydrated lime, which is deposited as a separate crystalline solid phase. This cementation process—which varies with time, temperature, soil type, and cement type—deposits an insoluble binder between the particles of the soil, which embeds them in a matrix of cemetitious gel. At the same time, the lime released during cement hydration forms additional cementitious bonds as it reacts with the clay particles (Adam and Agib, 2001).

Research suggests that optimal levels of stabilization occur when the bricks contain between 3% and 18% of cement content by weight. The correct percentage of cement to use depends primarily on the soil type, since the amount of linear shrinkage affects the cement content that is needed for stabilization.

Auroville Building Centre (2005) explained that many stabilizers can be used. Cement and lime are the most common chemical stabilizers. Others, like chemicals, resins or natural products can be used as well. The selection of a stabilizer will depend upon the soil quality and the project requirements: Cement will be preferable for sandy soils and to achieve quickly a higher strength.

Lime will be rather used for very clayey soil, but will take a longer time to harden and to give strong blocks. The average stabilizer proportion is rather low: Cement stabilization = 5% average. The minimum is 3% and the maximum is 8% (only for cost reasons). Lime stabilization = 6% average. The minimum is 2% and the maximum is 10% (for technical reason).

2.4.1.1.2 Ground Granulated Blast-Furnace Slag (GGBS) Stabilization

GGBSis a byproduct of the steel industry which occurs when iron ore is separated from the remaining slag. This slag is tapped off and rapidly quenched in water to promote its cementitious properties. GGBS is used throughout the UK and approx 2 million tonnes are used per annum. It is commonly used as an additive in cement mixes and lime can be used to activate the reaction rather than PC. Better durability is expected with higher GGBS content but it also slows the curing time (Oti, Kinuthia, & Bai, 2009).

2.4.1.1.3 Pulverized Fly Ash (PFA) Stabilization

PFAis a byproduct from coal fired power stations and over 6 million tonnes are produced annually in the UK. Of this, approximately 3.5 tonnes are used in the construction industry. Coal is ground into a fine dust prior to combustion and it is the finer ash which is cementitious. PFA requires water and a source of alkali, usually calcium hydroxide, to stabilize soil, an application for which it has been used for many years. The benefits of using PFA in terms of enhanced durability and sustainability have been well documented in other applications including pavement stabilisation (Bin-Shafique, Edil, Benson, & Senol, 2004).

2.4.1.1.4. Natural Fibers as Stabilizers

The use of natural fibres as a building material poses a special challenge to science and technology. Their use can, whilst alleviating the housing problem, assist to save energy, conserve scarce resources and protect the environment (Swamy, 1990). Although research data is not quite abundant, some workers have documented the issue of using natural fibers as stabilising or reinforcing agent in earth construction. In discussion on kinds of stabilizers Stulz (1988) as cited in Namango (2006) recognises straw (wheat, rye, barley, etc) and plant fibers (sisal, hemp, elephant grass, coir and bagasse) as an important category of stabilizers but provides no much scientific findings. Accordingly, such fibres check cracking in soils with high clay contents and increase insulating properties, adding however, that excessive use should be avoided due to possibility of increased water absorption. Rigassi (1995) observes that fibers create an omni-directional fibres network which improves tensile and shearing strength and reduce shrinkage. The author states further, without forwarding research data, that although fibres are commonly used to reinforce adobe, they are incompatible with CEB compression process as they render the mix elastic. Minke (2000) agrees with Rigassi (1995) and notes that adding fibres such as animal or human hair, coir, sisal, agave, bamboo and straw may help to reduce shrinkage ratio; the reason being that the relative clay content is reduced and some of the water is absorbed by the fibre pores. Additionally, appearance of cracks is reduced as the mixture binding force is raised by the fibres. The author presents a study on linear shrinkage as a function of fibre (coir, flax straw and rye straw) type and amount but avails no further scientific results. Tests with sisal are also not available.

In work entitled seismic strength of CEB, Vergas, Bariola, & Blondet (1986) observe increase in compression strength of CEB on addition of 0.5-8,0% by weight, 100 mm long straw and explain this by the sewing action of the CEB-mortar interface from straw fibres, i.e. controls micro-cracking produced by drying shrinkage. Filho, Barbosa, & Ghavami (1990) reinforced adobe with sisal and coconut fibres; the investigation brought to surface the problem of high water absorption rates of the fibres-a phenomenon that might be detrimental to the blocks on drying. The authors tried to circumvent this by application of water-repellent agents. However, addition of 4% sisal improved the brittle behaviour of the adobe blocks.

In a more recent related study, Eko, & Riskowski (2001), reinforced soils with a mixture of cement and sugarcane bagasse vegetable fibres. The study used 5 to 10% cement by weight and 5 to 15% bagasse fibres by volume. An improvement in the 28-day unconfined compressive strength with increasing cement content up to a maximum of about 5MPa was recorded. The increase in fibres volume was however, found to be detrimental to strength development.

2.4.1.1.5. Pozzolana Cement

Pozzolan/Pozzolanas are described as any siliceous and aluminous materials, which are themselves not cementitious, but in their finely-divided form react with lime in the presence of water at ordinary temperatures to produce cementitious compounds. Natural materials like volcanic ash are pozzolans in their natural state but materials such as clay, shales, bauxite waste (artificial pozzolana) have to undergo heat treatment before they become pozzolanic.As cited in Solomon –Ayeh's work, Pozzolans have been used in the past as ingredient of Portland cement to construct massive civil engineering structures such as the Bhakra Dam in India (Palta and Rao, 1964), the Davis and Friant Dams in the U.S.A. (Davis, 1949) and are envisaged to be used as dam core material for the proposed Bui Dam in Ghana in 2008. In 2001, the BRRI built a small, prototype plant to produce clay pozzolana from clay deposits at Mfensi (North-West of Kumasi), which is currently producing thousands of cements and sold at an affordable price.This material is an innovative product developed by CSIR-BRRI after over 30 years of research, which replaces up to 35% of ordinary portland cement (OPC) to obtain Portland pozzolana cement (PPC) for both concrete and general construction. The cost of pozzolana per 50kg- bag is about 20% cheaper than a bag of portland cement and has relatively greater plasticity and workability than portland cement

2.4.1.1.6 Lime Stabilization

One limitation of using cement as a stabilizer is that it does not work well with clay soils. However, using lime is a stabilizing agent that can be used effectively to stabilize clay soils. There are several stabilizing effects that lime may have, including cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction has a particularly stabilizing effect because it binds soil particles together as various cemetitious compounds are formed. The addition of lime serves to make clay less absorbent of water; thus, the clay soil becomes more manageable and less susceptible to variations in moisture content (Adam and Agib, 2001). Minke (2006) offers this description of the stabilizing effects of lime:

If there is sufficient humidity, then an exchange of ions takes place in the loam with lime as stabilizer. The calcium ions of the lime are exchanged with the metallic ions of the clay. As a result, stronger agglomerations of fine particles occur, hindering the penetration of water. Furthermore, the lime reacts with the CO_2 in the air to form limestone (Minke, 2006). Therefore, lime can also be used as a stabilizer in CEBs.

2.5. Factors Affecting the Deterioration of CEBs

Naturally, the usefulness of CEBs depends on the durability of the bricks themselves. Durability as defined by Kerali (2000) is the ability of a building material and its parts to perform its required function over a period of time. Any building material when exposed to the environment undergoes deterioration over a period of time, and the rate of deterioration affecting a material can be internal and external (Avrami, Guillaud, & Hardy, 2008). The internal factors that affect deterioration could be related to material composition and production methods and the external factors causing deterioration from environmental influences. These often act on a material simultaneously and manifest themselves in the form of physical, chemical and biological deterioration (Kuhnel, 2004)

2.5.1. Water Absorption and Hydrothermal Deterioration

2.5.1.1. Water Absorption

Yalley and Manu (2013) showed in their work that 20% cow dung stabilization in earth brick reduced substantially the water absorptivity by 10.4% and thus resulted in lower migration of water into the brick (i e. lower permeability). This could be explained that the presence of cow dung up to 20% eventually led to higher hydrated cow dung and higher mortar content. The higher mortar content makes the brick with some amount of cow dung less porous and more impermeable than the earth matrix, probably by infilling the voids and displacing some of the earth with far less permeable cow dung hydration products, thereby reducing paths for water ingression. Again increasing cow dung content above 20% did not much improve the impermeability of the bricks.

Water absorption of bricks is usually measured by 5h boiling and 24h cold immersion test. The 24h cold immersion test allows water to be absorbed into pores, which are easily filled under cold condition while the 5h boiling test gives fully saturated condition where all pores are filled up with water. The saturation coefficient ranges from about 0.4 - 0.95; the lower value of around 0.4 indicates high durability and higher values of around 0.95, low durability (Khalaf and Venny, 2002).

Other durability indices have also been developed based on relationship of porosity and water absorption. Water absorption is a function of clay and cement content and usually related with the strength and durability of earth bricks and therefore it is important to determine the rate of water absorption of earth bricks. Oti et al (2009) stated that water absorption rate decreases with increase in age of earth bricks. High rate of water absorption of a specimen may cause swelling of stabilized clay fraction and resulting in losing strength with time.Water absorption, as well as porosity, increases with clay content and decreasing cement content. Between cement, lime, cement-lime and cement-resin, combination cement and resin stabilization show the lowest water absorption both in capillary absorption and total absorption (Guettala, Abibsi, and Houari 2006). Freidin and Errel (1995) tried to reduce the water uptake by adding a hydrophobic material, in this case was siloxanepolymethylhydrohen- siloxane and combined with slag together with fly ash which is highly absorbent and the result showed that the water uptake with the addition of 0.5% siloxane less than a quarter of the water uptake of fly ash-slag without additive.

Moisture contents affect strength development and durability of the material and have a significant influence on the long term performance of stabilized soil material, especially it has effect on bonding with mortars at the time of construction. When the brick is dry, water is rapidly sucked out of the mortar preventing good adhesion and proper hydration of the cement and when the brick is very wet the mortar tends to float on the surface without gaining proper adhesion (Oti et al., 2009).

Types of compaction affect the optimum water content in the stabilized mixes. Riza, Rahman, and Zaidi (2010) cited Bahar et al (2004) in their work that, dynamic compaction can reduce the optimum water content from 12% to 10% with the compressive strength increased for about 50%. It also stated that, the optimum water content range between 10 to 13% for static compaction, as for vibrostatic compaction slightly increase compressive strength with the same water content for low compressive load. According to Osula (1996) soil-lime mixes required higher optimum moisture content than soil-cement mixes. Standards conform to determine water content such as ASTM D 558, Australian Standards 1289, BS 1924-2 (1990), BS EN 1745 (Oti et al, 2009).

Absorption of water causes swelling in the fabric and evaporation causes shrinkage in the block (Ren and Kagi, 1995). As water percolates, any unstabilized portion can be expected to dissolve, thus leading to softening of the earth fabric with a direct impact on the surface strength. Any loose material on the surface of the block is usually washed away with this force, causing pitting in the blocks, which makes them vulnerable to further erosion (Kerali, 2000). Heathcote (2002) in his study showed that the predominant cause of deterioration of earth walls was due to erosion caused by WDR.

Temperature fluctuation is also responsible for causing physical deterioration in the CEBs. Such fluctuations can occur in ambient temperatures or can be caused by direct sunlight and the resulting thermal loading, both of which result in expansion, but also contraction through shrinkage and drying of the brick fabric (Kerali, 2000). Consequently, there is a fractional reduction in the volume of the bricks, destabilizing the structures built thereof.

2.5.1.2. Hydrothermal Deterioration

Deterioration of CEBs due to moisture absorption and temperature change can be defined as hygrothermal deterioration. The service life of CEBs is strongly related with how the material composition of the CEBs respond to heat, air, and moisture absorption changes (Kunzel, 1995). CEBs can be characterized as being comprised of only a few components, each with an expected performance capability to withstand moisture and recurring water penetration dependent and independent on the climatic conditions in which the CEBs are used. The mechanisms by which CEBs redistribute and transport moisture must be taken into consideration for the potential for moisture induced damages (Karagiozis, 2002). Since water is a solvent, all CEBs will eventually have water related damage, some will be as soon as they have been built while others may take a considerable time. However, the water contained in the original brick will also dry out, and this dehydration will affect its strength. The drying rate of a CEB depends on the loads to which the CEBs have been exposed and drying rate performance characteristic combine with water penetration represent hygrothermal performance (Karagiozis, 2002). Hygrothermal loads on the other hand, include contributions from loads caused by wind-driven rain, mechanical pressures, wind-pressures, stack effect, vapor diffusion, liquid diffusion, sorption and suction storage, and temperature-dependent sorption capabilities as well as evaporation-condensation characteristics. At all times, the thermal transport is fully coupled to moisture transport and can be related to the quality and durability of the materials and their associated mechanical, chemical, and hygrothermal properties which are a variable function of time and the environment to which they are exposed (Karagiozis, 2002).

2.5.1.3. Wind-Driven Rain Erosion

When wind occurs simultaneously with rain, it causes an angled rainfall vector which is scientifically defined as either ―driving rain or ―wind-driven rain (WDR). WDR research is governed by a range of parameters including environment topology, wind speed, wind direction, turbulence intensity, rainfall intensity, raindrop size distribution and rain event duration. This large number of parameters and their variability make the quantification of WDR an extremely complex area of research. Field experimental methods and measurements of WDR science have virtually remained unchanged since the 1930s and have been commonly performed for research purposes only (Blocken & Carmeliet, 2004).

Simulation research was conducted by Cytrin who developed a rain simulation test in 1955 to evaluate the resistance to the forces of driving rain setting up a format of water pressure and exposure to time suggesting an equivalent factor of 10 years of rainfall. In 1970, Wolfskill developed a shower spray test in which he measured the erosion of stabilized soils and correlated the depth of the pitting to the capacity of the tested soil to withstand rainfall. In 1987, Reddy and Jagadish expanded Wolfskill's principles, but developed a soil ratio measuring the test erosion depth related to rain precipitation (Heathcote, 2002).

In 1990, Ola and Mbata developed a vertical spray test with pressures ranging from 6 psi to 65 psi and water flows of 2 gallons per minute to 12.25 gallons per minute respectively, and correlating to annual rainfalls of 25 inches to 275 inches in a period of 50 years. Their experiment also showed that erosion decreased when specimens' compaction and /or cement content were increased (Heathcote, 2002).

In the 1970s, an increased interest in earth-based construction motivated the Commonwealth Experimental Building Station in Australia to develop an accelerated erosion test referred to as the ―Bulletin 5 accelerated erosion test, which is the name of the document. The test is based on spraying the face of a sample for a period of one hour or until the sample is penetrated (Heathcote, 2002).

Bulletin 5 test is performed with water pressurized at 7 psi and delivered though a horizontally mounted nozzle. Specimens are mounted in the rig in the same orientation as proposed for wall construction. A shield ensures that only a limited area of block face is subjected to the water spray. During testing, the spray may be stopped every 15 min to assess performance. The depth of pitting is measured using a 3/8in diameter flat-ended rod. The erosion rate is expressed as the pitting depth per minute of exposure time (Walker, 2004).

2.6 Density of CEB

Commonly, most researchers found that the density of compressed stabilized earth bricks is within therange of 1500 to 2000 kg /m^3. Density of the compressed earth brick is consistently related to its compressivestrength and compactive force applied during production. The dry density is largely a function of theconstituent material's characteristics, moisture content during pressing and the degree of compactive loadapplied and even in India compressive strength is controlled by density. Types of compaction applied such asdynamic, static and vibro will also affect the density. The density of brick can be determined through standardprocedure such as ASTM C 140 and BS 1924-2 (1990) and others (Oti et al, 2009; Bahar et al, 2004).

2.7. Compressive Strength of Earth Blocks

Al-sakkaf (2009) found that the compressive strength of the compressed earth blocks for five samples at 180 days respectively, for cement, lime, lime with cement, calcium silicate, and bitumen, was 13.2 N/mm^2, 6.4 N/mm^2, 16.3 N/mm^2, 11.7 N/mm^2 and 12.6 N/mm^2 while it were 3.8 N/mm^2, 1.5 N/mm^2, 3.5 N/mm^2, 2.8 N/mm^2 and 3.4 N/mm2 for the manually cast blocks.

2.7.1. Dry and Wet Compressive Strength

Yalley and Manu (2013) stated in their study that bricks with 20% of cow dung content had a dry compressive strength of 5.77 MPa which was an increase of about 67% over un-stabilized earth brick but beyond that, there is decrease in dry compressive strength to 5.14 and 4.62 MPa for bricks stabilised with 25% and 30% cow dung content respectively. This then implies that the optimum cow dung content for compressive strength is 20% by weight of earth. This might be attributed to the fact that the hydration products of the cow dung up to 20% was just enough to fill in the pores of the matrix and enhanced the rigidity of its structure by forming a large number of rigid bonds connecting earth particles.

The compressive strength of compressed stabilized earth building blocks (that is, the amount of pressure can resist without collapsing) depends upon the soil type, type and amount of stabilizer and the compaction pressure used to form the block. Maximum strengths (described in MN/m^2) are obtained by proper mixing of suitable materials and proper compacting and curing.

In practice, typical wet compressive strengths for compressed stabilized earth building blocks may be less than 4 MN/m^2. However, some Sudanese black cotton soil when stabilized with hydrated high calcium lime to give wet compressive strengths in the range of 6 – 8 MN/m^2, strength suitable for many building purposes. It also competes favorably, for example, with the minimum British Standard requirements of 2.8 MN/m^2 for precast concrete masonry units and load bearing fired clay blocks and of 5.2 N/mm^2 for bricks. Where building loads are small (e.g. in the case of single storey constructions), a compressive strength of 1 - 4 MN/m^2 may be sufficient. Many building authorities around the world recommend values within this range.

According to Yalley and Manu (2013) the compressive strength after immersion in water for 10 minutes reduced the compressive strength by an average of 67% for cow dung stabilised samples compared to the compressive strength in their dry state. Furthermore, complete disintegration of un-stabilised specimens was observed in a few minutes after immersion in water. Again bricks with 20% cow dung content as stabiliser had the highest wet compressive strength of 2.76 MPa. Specimens with cow dung content above 20% did not give any significant improvement of strength of the wet samples. The lower strength of the wet samples could be prevented by treating the surface with cow dung render, with polymers or cow dung–lime renders, especially when the construction is to be exposed to water.

2.9. Conclusion

From the above literature review, a number of conclusions can be made. Earth-based construction technology has a long history; technologies like adobe, rammed earth, molded earth and stacked earth, have been successful in hot and arid climates throughout the world and for millennia.

Again, the review examines the characteristics of soil and establishes that clay content in the soil affect significantly its durability. This leads to a review of the composition of clay content.The review also shows stabilization techniques and how these techniques improve CEBs physical structure and behave better in humid climates as compared to other methods of building. It is also established that even under normal conditions, durability of the CEBs will be affected by environmental exposure. This condition worsens when the bricks are exposed to hygrothermal conditions and WDR, since the primary agents that weaken the brick fabric are water, temperature, and chemical action within the brick. Water-related action causes the brick fabric to weaken due to factors like wetting and surface abrasion due to rainwater. When combined with temperature fluctuations, this causes the fabric to weaken further, resulting in cracks in the bricks. The literature review shows that when soil is mechanically stabilized, particularly with cement and other additives, it increases the compressive strength and durability of the bricks to some extent, depending on the combination of additives and soil selection.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

The scope of this research project was limited to the evaluation of the strength and durability of stabilised compressed bricks. In other to achieve the objectives of the study, the researcher adopted an experimental approach, thus an experiment was carried out to determine the Strength and durability properties of compressed earth blocks.

3.2 Experimental Design

Variation of any of the several production input variables can influence the quality and performance of blocks. These variables include:

- ✓ Soil(type and proportions of main fractions)
- ✓ Stabilizer (type and content)
- ✓ Mix- water(moisture content)
- ✓ Curing conditions

For any meaningful experiment, it is unhelpful to vary all the input variables at the same time. The experimental design was therefore based on making some variables fixed while varying others. The main fixed variables were soil type, compaction pressure, curing period and mix water. All block samples were made using soil of a fixed composition. In this way the effect of varying the stabilizer type and content on the properties of the brick could then easily be monitored. The main approach adopted here was to compare the properties and performance of traditional (un-stabilized) blocks and improved blocks (stabilized). The scope of this chapter limits itself also to description of materials and equipment used to produce the block samples. Various tests have been carried out on earth in order to determine its properties. Attempts have also been made to provide some information about the equipment that was most fundamental for the success of this work.

3.3 Experimental Materials

The main variable fixed was the soil type. All block samples were made using soil of a fixed composition. In this way the effect of varying the stabilizer type and content on the properties of the blocks could then be easily monitored.Earths (soil), Pozzolana cement and ordinary Portland cementare the raw materials that were used for this study.

The earth for brick production was typically sourced from St. Bernadette's technical institute campus in Navrongo, Upper East region. The researcher therefore collected samples between a depth of 1m to 1.5m using the method of disturbed sampling and air dried for three months. The properties of the earth were obtained through laboratory investigation from the regional Roads and Highways Authority Bolgatanga, Ghana in accordance with BS 1377 (1990), Methods of Testing Soils for Civil Engineering Purposes.

The stabilisers were Portland Pozzolana cement type CEM II/13.0 CLASS 32.5N manufactured by CSIR at Fumesua-Kumasi in the Ashanti region which meets Ghana and International Standards i.e. GS 964 and ASTM C618 specifications, Ordinary Portland cement type CEM I 32.5R manufactured by GHACEM a subsidiary of Heidelberg Cement Group whose properties conformed to BS 12 (1978). Among the two stabilizers Pozzomix cement was affordable and locally manufactured.

Water from the laboratory tap was used for mixing; it was ensured that it was fit for drinking, free from contaminants either dissolved or in suspension as specified by BS 3148 (1980). Engine oil was used to lubricate the mould for easy removal of bricks. These raw materials used for preparation of samples as well as the variables in the raw mix are shown in Table 3.1. Figure 3.1, figure 3.2 and figure 3.3 present samples of raw materials used in the study.

Table. 3.1 Raw Material for Sample Preparation

Experimental Material			
Item	**Type**	**Process**	**Effect**
Soil	Clay Material	Mechanical	Compaction
PzzoMi -OPC)	Mineral	Chemical	Cementation
PozzoMix	Mineral	Chemical	Cementation

Figure 3.1 OPC

Figure 3.2 PozzoMix

Figure 3.3 Clayey Soil Sample

3.4 Preliminary Experiment

3.4.1 Earth Characterization and Preparation

Preliminary tests on the soil used for making the blocks were evaluated first for the purpose of classifying and identifying the types of soils. The tests performed were as follows: Soil Particle Size Test, Moisture Content Test, Specific Gravity Tests, the Atterberg Limits Tests, linear shrinkage and Compaction Test in accordance with BS1377: Part 2:1990. In order to obtain initial uniform moisture content, the soil was stored under a shed at a room temperature of 22 °C for three months before being broken down. In order that the stored soil can dry out more evenly, it was thinly spread out and regularly turned over several times. Attempts have also been made to provide some information about the equipment that was most fundamental for the success of this work.

3.4.1.1 Particle Size Distribution - Wet sieving

Before the sieve analysis was conducted, a sample was submerged in water. Submerging the sample in water revealed that the soil had very small fines and that lets to the decision to conduct a wet sieve analysis for the finer particles. The dry sieve analysis was conducted as far as possible and then the soil washed through the sieves with water in order to disintegrate the finer particles to get a more accurate size distribution.

A particle size distribution analysis was carried out on the air dried soil in accordance with (BS1377: Part 2:1990) to present the relative portions of different sizes of particles. It enabled the researcher to determine the predominant soil component and to a limited extent, which of these size ranges is likely to control the engineering properties of the soil. To conduct the test the soil was crushed and a representative sample was obtained by rifling as shown in Figure 3.4 to give a minimum mass of about 2.5kg. The air dried test sample was weighed to 0.1% of its total mass (m_1).

Figure 3.4 Rifling of Test Sample

The sample was sieved through a 20mm sieve size and the fraction retained on the 20mm test sieve (Figure 3.5) was sieved and weighed.

Figure 3.5: 20mm BS Sieve

Figure 3.6: Washing and Sieving of Soil Sample

The fractioned sample was spread in a large tray and covered with water. Sodium hexametaphosphate was added to the water since the soil is cohesive. The mixture was frequently stirred. The material was washed through a 75µm sieve as shown in figure 3.6, allowing the material passing sieve 75µm to run to waste and the material retained on the sieve transferred on evaporation dish and dried in an oven at 110^0 C.The material was allowed to cool, weighed and sieved through appropriate sieves by mechanical vibration down to the 75µm test sieve for about 10 minutes. The amount retained on each sieve and any fines passing the 75µm was weighed and recorded as shown in Appendix vii

Figure 3.7: Cooled Sample After Oven Dried

Figure 3.8: Sieveing through BS Sieves by Vibrating

Jar test was used to estimate the organic matter content. Dried samples of the soil were crushed and finely pulverized. A tall slender jar was filled with one- quarter full of soil. Water was added until the jar was three – quarters full. A tea spoon full of salt was added. The lid was firmly tightened and shaken for 10 minutes and left undisturbed for 10 minutes before allowing the particles to settle for 2 days. The layers were recorded and calculated as a percentage of the constituents. Test results on grain –size distribution, organic matter and natural moisture content of the soil sample are summarised in Table 4.5.

Figure 3.9 Jar Test

The position of this study is that where the existing soil is not ideal for use in the production of compressed bricks, it is possible to improve its workability through blending with carefully selected stabilizers.

3.4.1.2 Atterberg Limits (Plasticity Index)and Linear Shrinkage Limit

This laboratory test was performed to determine the plastic (PL) and liquid limits (LL) of a fine grained soil. At LL, soil starts to manifest a certain resistance to shearing; at PL, the soil stops being plastic and becomes brittle. The plasticity index (PI) is the difference between LL and PL. PI determines the range of plastic behavior of the soil.

For the present work, the soil's sample Atterberg limits was determined according to BS1377: Part 2:1990. The equipment used for Atterberg limit test include: Casagrande equipment, porcelain (evaporating) dish, flat grooving tool with gauge, Eight moisture cans, Balance, glass plate, spatula, wash bottle filled with distilled water, drying oven set at 105°C. See Figure 3.10, Figure 3.11 and 3.12.

Figure 3.10Atterberg Limit Test Apparatus

Figure 3.11 Drying Oven

Figure 3.12 Digital Balance

To conduct the liquid limit test roughly 3/4 of the soil was taken and placed into the porcelain dish after sieving through a No. 40 sieve, air-dried, and then crushed. The sample was thoroughly mixed with a small amount of distilled water until it appeared as a smooth uniform paste. See Figure 3.13, Figure 3.14 and Figure 3.15

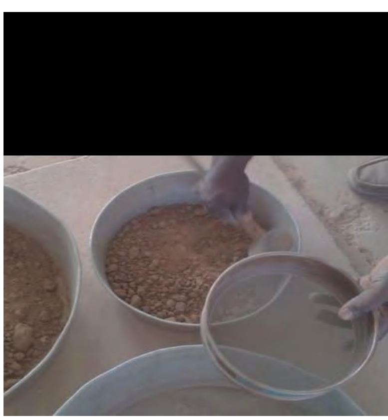

Figure 3.13 Crushing and Sieving

Figure 3.14 Adding Water

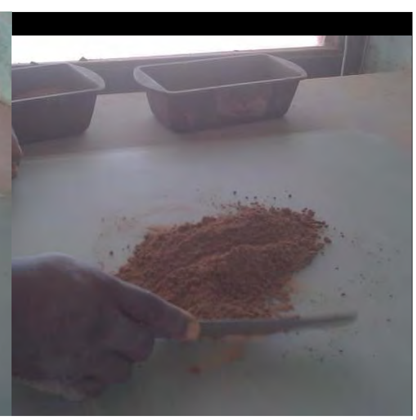

Figure 3.15. Mixing the Sample

The mixture was covered to prevent moisture from escaping. Four empty moisture cans with their lids were weighed and recorded on the data sheet. The mixture was placed on the cup of the Casagrande at the point where the cup rests on the base and squeezed down to eliminate air pockets and spread it into the cup to a depth of about 10 mm at its deepest point. The soil pat was leveled to form approximately horizontal surface. The grooving tool was carefully used to cut a clean straight groove down the center of the cup whilst remaining perpendicular to the surface. The crank of the apparatus was turned at a rate of approximately two drops per second and counted the number of drops it takes to make the two halves of the soil pat come into contact at the bottom of the groove along a distance of 13 mm (1/2 in.). Sample was taken from end to end of the groove using the spatula and kept into a moisture can covered and immediately weighed and recorded its mass. The lid was removed, and placed into the oven. The soil was oven dried for at least 16 hours. The remaining soil was placed on the glass plate and small amount of distilled water added to increase the water content so that the number of drops required to close the groove decrease. The process was repeated for at least two additional trials producing successively lower numbers of drops to close the groove.

To obtain the plastic limit the remaining 1/4 of the original soil sample was taken and distilled water added to a consistency where it can be rolled without sticking to the hands. The soil was formed into an ellipsoidal mass and rolled between the palm and the glass plate. Sufficient pressure was used to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. The thread was deformed so that its diameter reaches 3.2 mm (1/8 in) and immediately the thread cut into several pieces. The pieces were knead and reformed into ellipsoidal masses and re-rolled. This process was continued until the thread crumbled under the pressure required for rolling and could no longer be rolled into a 3.2 mm diameter thread. Portions of the crumbled thread were gathered together and placed into moisture can, then covered and immediately weighed and with the lid removed the content was placed into the oven for at least 16 hours. The process was repeated two times. The water content was determined using the method in the first laboratory.

Shrinkage due to drying is significant in clays, but less so in sand and silt. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease in volume, which is also relevant to the converse condition of expansion due to wetting. The linear shrinkage value is a way of quantifying the amount of shrinkage likely to be experienced by clayey material. Such a value is also relevant to the converse condition of expansion due to wetting. This test was a continuation of the Atterberg limit test but this time round the soil was used without sieving. This test was carried out in accordance with BS 1377: Part 2:1990 a soil paste with moisture content at about the same liquid limit of the previous sample was used. The paste was filled in a mould with a film of lubricant in its inner surface to prevent the soil from adhering to the surface of the mould. The mould was carefully jarred against a firm surface to remove any air pocket in the mixture. The top of the mould was leveled with palette knife and all soil adhered to the rim of the mould removed. The mould with the mixture was air dried for seven (7) days when the soil had shrunk away from the walls of the mould. The drying was completed by drying at 110^{0}C cooled and the mean length of the soil bar was obtained using the equation below:

Percentage Linear shrinkage= $(1-\frac{LD}{LO)})100$

Where

LD is the length of specimen after the oven-dry.

LO is the original length of the specimen

LD = 229.5mm

LO = 230mm

Therefore percentage shrinkage = $(1-\frac{229.5}{230)})100 = 0.22\%$

3.4.1.3 Specific Gravity (Pycnometer Method)

It is needed in nearly all pressure, settlement, and stability problems in soil engineering and it is for this reason the researcher carried out this laboratory test to establish the apparent density of the selected sample. The pycnometer method was used in accordance with BS 1377: part 2:1990. The equipments employed were density bottles (pycnometer) with stopper, drying oven capable of maintaining temperature of 105^0C-110^0C, distilled water in a wash bottle, balance readable to 0.01g.

Oven dried samples were riffled and stored in air tight containers. A density bottle with stopper was dried with a cloth and weighed to the nearest 0.01g. the first soil specimen was transferred to the density bottle direct from the sealed container. The weight of the bottle with soil sample and stopper was recorded to the nearest 0.01g. Air-free distilled water was added so that the soil in the bottle was just covered. The bottle containing soil and water was stirred gradually until no further loss of air is apparent. Air –free water was added until the bottle was full. The stopper was inserted and the bottle immersed in the water bath for at least an hour for the water to attain a constant temperature. The bottle was removed carefully and wiped dry and weighed. The remaining three specimen was tested as before. The specific density was calculated using the formula provided in Ghana Highway Authority standard test method S3

Specific Density, G at $T_x = \frac{g*c}{((e-a)-(d-b))}$

Where ,g= density of water at test temperature

c= Mass dry soil sample

e= Mass of pycnometer+lid+water

a =Mass of pycnometer+Lid

d =Mass of pycnometer+Lid+ soil+water

b= Mass of pycnometer+Lid+dry soil

Test results are shown in table 4.2.

3.4.1.4 Optimum Moisture Content

The optimum moisture content was determined in this study by using the procedure provided by BS 1377: part 4:1990 and adopted by Ghana highway Authority central material laboratory. The Modified Proctor used a heavy compaction test using a 4.5kg rammer (modified proctor) with a greater drop on a thinner layers (3 layers) of soil in an assembled cylindrical compaction mould with internal diameter of 105mm and internal height of 115mm and a volume of 1.0L(1000cm^3). Other important apparatus for this test include: a balance readable to 1g, palette knives or spatulas, container suitable for mixing quantity of material, large metal tray, measuring cylinder, apparatus for moisture content determination, and a scupper.

To conduct this test three samples of 7kg soil were quarted. Each sample was thoroughtly mixed with different amounts of water to give a suitable range of 2 to 6 percent moisture content. Each of the portions was sealed in an airtight container and allowed to cure for a while. The mould and the base plate attached was weighed. The mould was assembled and placed on a solid base. The mould was filled with moist soil up to 1/3 of the height of the mould body. 27 blows from the hammer was dropped freely and systematically to cover the entire surface of sample. The next layer of soil was placed in the mould and the above process was repeated twice more. When all three layers were compacted, the excess soil was striked off and mould dismantled. The soil and the mould with base plate were weighed. The soil was removed from the mould and a representative sample of the soil was taken to determine moisture content. The bulk density for each compacted specimen was calculated from the equation (BS 1377. Part 4: 1990);

Bulk Density, p= $\frac{m2-m1}{V}X1000$

Where

m1, is the mass of mould (in g)

m2, is the mass of mould and compacted soil (in g)

V, is the volume of mould (in cm^3)

Setup of the operation is shown in Figure 3.16

Figure 3.16: Optimum Moisture Content Setup (Modified Proactor Test)

For the purpose of brick production the researcher selected three different ranges of moisture content less than the plastic limit to determine which of this water content would produce bricks with greater density. The optimum moisture content should be less than the plastic limit. Bricks were made with same compaction effort at different moisture contents. A mould similar to what will be used for brick production was used with compaction produced using a 4.5kg hammer (modified proctor) falling 305mm; giving 27 blows per layer in 3 layers. The bricks were allowed to cure for 28 days. Densities of the samples were computed to determine the optimum moisture content. Table 4.4 provides the results of the optimum moisture content.

3.5 Main Experiment

3.5.1 Preparation of Stabilized Earth Block Samples

Preparation of blocks samples followed, after the soil had undergone testing to determine its suitability for earth blocks production. This was carried out in accordance with (BS 1924:Part 2:1990). The stabilised earth block production went through the process outlined in Figure 3.17 :

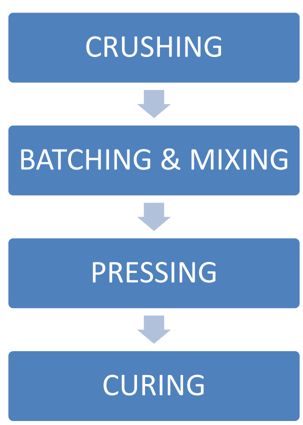

Figure 3.17: Block Specimen Making Process

3.5.1.1 Crushing of Earth

Crushing of the soil sample was done manually in the laboratory as shown in figure 3.18. The researcher ensured that the maximum size of soil lumps passed the 20mm test sieve by rolling on a flat surface. The crushed soils were then spread and allowed to undergo the secondary drying process for a period of 4 weeks. The sieved sample was mixed thoroughly and quartered out a specimen of about 25kg. This was in turn divided into 5 parts of about 5kg.

Figure 3.18: Crushing of Soil Sample on a Flat Surface

3.5.1.2 Batching and Mixing

Mixing of Pozzolana cement and ordinary Portland cement, in soil was done manually by hand in a wheelbarrow in a dry state. The stabilizers were calculated and weighed out in three quantities. The controlled samples were made of raw earth with no stabilizer and denoted by $\mathbf{S_0}$, the pozzoMix cement samples denoted by (**Px**), where **'x' is** percentage pozzomix, thus $\mathbf{P_5}$, $\mathbf{P_9}$ **and** $\mathbf{P_{12}}$. Research suggests that optimal levels of stabilization occur when the bricks contain between 3% and 18% of cement content by weight. The correct percentage of cement to use depends primarily on the soil type, since the amount of linear shrinkage affects the cement content that is needed for stabilization (Minke, 2006). The percentage of stabilizer used usually varies depending on the soil type but is typically between 5 and 20% with the higher proportions being applicable to clayey soils (Browne, 2009). The second for stabilization was the combination of ordinary Portland cement and pozzomix cement denoted by ($\mathbf{P}^{x}/_{y}$) where **X** represents Pozzomix percentage and **Y** represents OPC percentage, thus pozzomix to OPC ratio 3%-2%, 6%-3%, 8%-4% respectively. The batching of the Pozzomix- OPC was done as two part of Pozzomix cement to one part ofordinary Portland cement . All batching was done by weight of material. Figure 3.19 shows the mixing of the raw materials.

Figure 3.19 Mixing of Soil and Stabiliser

3.5.1.3 Moulding of SEB

Bricks were made with an improvised manually operated press similar to "Balram" Block press "artifact gGmbH Glucksburg" . It was not easy for the researcher to find a similar mould in his location so he requested for the assistance of the welding department of St. Bernadette's technical institute to fabricate a mould of same dimensions as the "Balram" block press which was mounted on a metal plate. The difference is that this mould can easily be dismantled and assembled to release bricks. The mould is made of a 5mm thick metal plate with a hinge at one corner and a locking bolt and nut at the diagonal corner. The press has internal nominal dimensions of 230mm (length) 110mm (width) and 90mm (height). Figure 3.20 shows the mould used for fabrication of stabilized earth blocks.

The bricks samples were prepared by oiling the internal faces of the mould in each instance before filling with the mixed soil to ensure that, bricks do not stick to the walls of the mould. The oil had no other observed effect on the bricks. After thoroughly lubricating the face of the mould, the prepared soil was filled in three layers. Each layer received 27 blows from a 4.5kg proctor hammer. The corners were pressed with a rectangular section hammer. The third layer was filled so that the height of the soil was a little above the mould. The top of the mould was leveled with a steel strip and dismantled to release bricks. It was not possible to estimate exactly the compaction pressure, but according to ASTM Standard D1557 using the 4.5kg modified proctor hammer would produce a compacting effort of about 2700kN-m/m^3. The dimensions of the brick did not change significantly.

Figure. 3.20 Improvised Moulding Equipment

Figure. 3.21 "Balram" Block Press

3.5.1.4 Curing of Brick Specimens

The bricks were demoulded under a shed to ensure that they were not affected by the excessive sunlight. The bricks were air dried for 28 days before being tested. The Pozzomix –ordinary Portland cement earth bricks were cured under polythene sheeting for 7 days and moistened daily to allow for complete hydration of the cement. They were then allowed to dry in the open for another 21 days before testing was carried out. Table 3.2 presents the sample fabrication composition:

Table 3.2 BrickSample Fabrication Composition.

No.	Mix Percentage (%)			TEST TYPE	SPECIMEN CODE	NUMBER OF SPECIMENS SELECTED FROM A BATCH
	Earth	**PozzoMix**	**OPC**			
1	100	0	0	All test	S0	25
2	95	5	0	Dry compressive strength	P 5/0	5
	91	9	0		P 9/0	5
	88	12	0		P 12/0	5
3	95	5	0	Wet compressive strength	P 5/0	5
	91	9	0		P 9/0	5
	88	12	0		P 12/0	5
4	95	5	0	Water absorption	P 5/0	5
	91	9	0		P 9/0	5
	88	12	0		P 12/0	5
5	95	5	0	Abrasion	P 5/0	5
	91	9	0		P 9/0	5
	88	12	0		P 12/0	5
6	95	3	2	Dry compressive strength	P 3/2	5
	91	6	3		P 6/3	5
	88	8	4		P 8/4	5
7	95	3	2	Wet compressive strength	P 3/2	5
	91	6	3		P 6/3	5
	88	8	4		P 8/4	5
8	95	3	2	Water absorption	P 3/2	5
	91	6	3		P 6/3	5
	88	8	4		P 8/4	5
9	95	3	2	Abrasion	P 3/2	5
	91	6	3		P 6/3	5
	88	8	4		P 8/4	5
Total Specimen						145

Figure 3.22 Newly Moulded Bricks

Figure 3.23 Dried Bricks

3.6 Testing of Brick Samples

For this research work Four engineering properties have been selected to investigate the strength and durability of the stabilized brick samples after 28 days of manufacturing. The main approach adopted was to compare the properties and performance of two categories of blocks, namely: traditional blocks (unsterilized blocks) and improved blocks (stabilized). These properties are as followes:

1. Block density
2. Dry and wet Compressive strength
3. Initial rate of water absorption
4. Abrasion resistance

3.6.1 Dry Block Density

The first durability parameter measured on the manufactured brick is the practical dry block density (ρ_p). The significance of this test is to determine the effect of soil type, stabilizer, moisture content and compaction effort on the density of the bricks. This density is known to be the ratio of measured block mass to volume i.e. $p_{p}=\frac{m}{v}$. The mass of the bricks were taken after drying in a ventilated oven for 24 hours at a temperature of 105^{0}C in accordance with BS 1880 (1990). The drying process was undertaken in order to ascertain that all block samples had uniform moisture content at testing time. The blocks samples were left to dry in the open, after removing from the oven. The volumes of the bricks were calculated. Averages of the densities of five blocks from each batch were calculated as presented in Table 4.6.

3.6.2 Wet Compressive Strength Test

One durability challenge of compressed earth bricks is resistance to water. After CEB has been exposed to dampness its compressive strength is undermined. This test was conducted to find out whether or not the CEB has improved in strength in damp condition after it has been stabilized with the selected stabilizer.

In this test five bricks were selected from each batch. The bricks were oven dried at 40^{0}C until the moisture in the bricks had been removed and uniform masses were obtained. The bricks were gently removed and air dried for two hours, dusted and fully immersed in water for about 10 minutes. The bricks were removed and dried with a clean cloth. Compressive strength was measured on prisms of dimension 230mm (length), 110mm (width), 90mm (height). The specimens were loaded in an ELE Compact 1500kN Motorized compression machine. Manufactured by ELE International, Hemel Hempstead, Hertfordshire HP2 7HB, England. shown in Figure 3.24. In order that the loading does not concentrate at one point since the jaws of the machine are smaller than specimens, steel plates were placed below and above the specimen before gripping by the machine. Loading was done on the bed face of the brick. The rate of loading could not be determined since the machine is an analogue type, but the operator set it to a continuous and steady rate till failure. Table 4.12. presents results of the test.

3.6.3 Dry Compressive Strength Test

Dry compressive strength test was conducted in accordance with BS1880 (1990). five specimens were selected and placed on a supportive steel block in the lower platen. This lifted the brick within the ambient range of operation of the compressive machine. The specimens were first of all wiped clean of loose materials and dried in an oven before placing in an orientation where the bed faces of the brick rested on the platen, which was the same orientation of the compaction pressure during brick production as shown below. The failure loads for each of the blocks were taken. Results of dry compressive strengths have been presented in Table 4.9.

Figure 3.24: Crushing of Bricks

3.6.4 Initial Rate of Water Absorption

The test was to determine the initial rate of absorption of water with type and amount of stabilization. Waterabsorption is related to the strength and durability of earth bricks and therefore it is important to determine the rate of water absorption of earth bricks. Moisture contents affect strength development and durability of material and have a significant influence on the long term performance of stabilized soil material especially on bonding with mortars at the time of construction.

This test was conducted in accordance with BS 3921. A set of five blocks per sample of SCEB specimen were wiped clean of loose materials and preventively dried in an oven after 28 days curing, till a constant weight was obtained. The cooled bricks were immersed in a 5mm depth of water for 10min. The test setup is as shown in Figure 3.25.

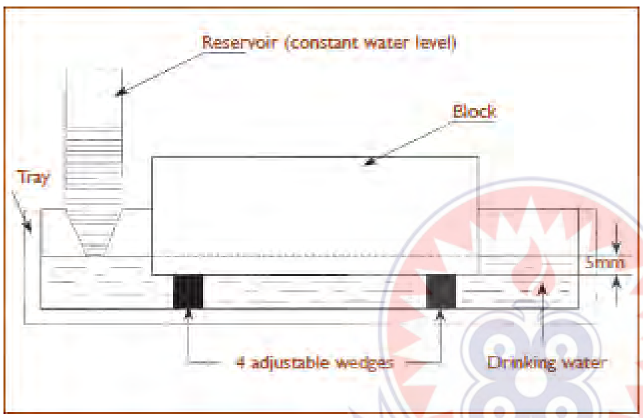

Figure 3.25: Setup of Water Absorption Test

The water absorption coefficient Cb of each block is by convention expressed by the formula:

$$Cws = \frac{Mso - Mdry}{As\sqrt{T}} X100$$

Where: Mso= Mass after absorption (g)

Mdry=Mass before absorption (g)

As=Area of exposed face (mm^2)

T=time (sec)

Cws=initial rate of water absorption

The difference of dry mass and the soaked mass is divided by the product of the contact surface area of specimen and soaking time- expressed in g/(cm^2xmin)

The test results on samples are presented in Table 4.16.

3.6.5 Abrasion Resistance (Wire Brush Test)

This test was conducted to determine the minimum amount of selected stabilizer in the soil to achieve a degree of hardness adequate to resist field weathering . BS 3921 and CraTarre (personal communication Vincent Rigassi) modification of ASTM D559 procedures were followed. The test was used to determine the surface hardness of the soil brick and thus their resistance to wear.

A stiff wire brush made of 50 of 16mm flat 26 gauge wire bristles assembled in 50 groups of 10 and mounted to form 5 longitudinal and 10 transverse rows was used to brush the blocks cyclically. five oven dried bricks were used to average one block. The entire face of the bricks was subjected to mechanical erosion by brushing with a metal brush at a constant pressure over 60 cycles. A cycle consists of a consistent forward and backward motion. The brushed faces were gently wiped with a soft cloth to remove all loose materials. The mass of the detached (loose) matter was weighed from which the abrasion coefficient (Cu) was calculated as follows:

Where (Cu) = $\frac{A}{m1-m2}$ cm^2/g,

A=Area of brushed surface. (cm^2)

m1=mass of brick before brushing (g).

m2=mass of brick after brushing (g).

CHAPTER FOUR

RESULTS OF THE STUDY

4.1 Introduction

This chapter presents results of all experiments conducted in this study. The central premise of this investigation is that, the durability of earth walls in the field can be accurately predicted by the performance of test specimens in the laboratory. The parameters studied in this present work were precisely chosen, such that as much well coordinated information as possible would be revealed. In order to gain knowledge on the physical properties of CEBs, various tests have been carried out. The results are to help understand the suitability of these bricks as building materials as well as the proposed material composition in chapter three. Results of preliminary experiments on characteristics of soil for block production have been presented in this chapter. Again results of the characteristics of bricks (density, compressive strength, water absorption and abrasion resistance) are also presented in this chapter.

4.2 Results of Characteristics of Soil

4.2.1 Particle Size Distribution

From Figure 4.1 it can be observed that 0.09% grain size retained on 4.75mm sieve in the sample sieved. Again size limit passing the 0.075mm sieve was 46.85%. 53.15% represent the percentage of soil fraction retained between BS. Sieves 4.75 to 0.075. The results imply that, Sand fraction formed about 53.06% of the sample composition. Also, silt and clay composition constitutes about 46.85% of the soil sample content while gravels constituted 0.09% of soil fraction. The natural moisture content value was 0.8%. The particle size distribution results suggest that the soil is suitable for earth blocks production.

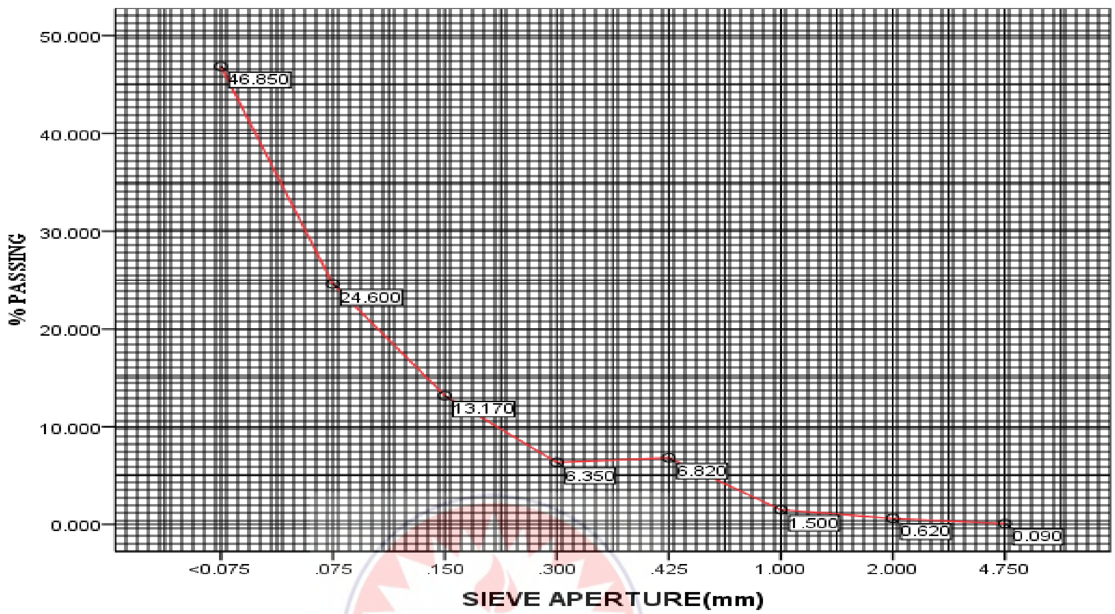

Figure 4.1: Graph of Particle Size Distribution

4.2.2 Atterberg Limit and Shrinkage Limit Test

From Table 4.2, the liquid limit was recorded as 33% after 28, 27, and 23 consecutive drops of the Casagranda equipment. Also the plastic limit was recorded as 17% with the plasticity index computed as 16%.

The percentage of shrinkage was estimated after 7 days of air-dried sample and the difference between the original length and shrunk length of block specimen was computed at 0.22%. The soil used could be classified as low clay as indicated in Figure 4.2.

Table 4.1:Atterberg Limits And Linear Shrinkage Of Soil Sample

Sample Source	Liquid Limit (Ll)%	Plastic Limit (PL)%	Plasticity index (PI) %	Length After Shrinkage (mm)	Original length (mm)	Linear Shrinkage (Ls)%
Bernatech Navrongo	33	17	16	229.5	230	0.22

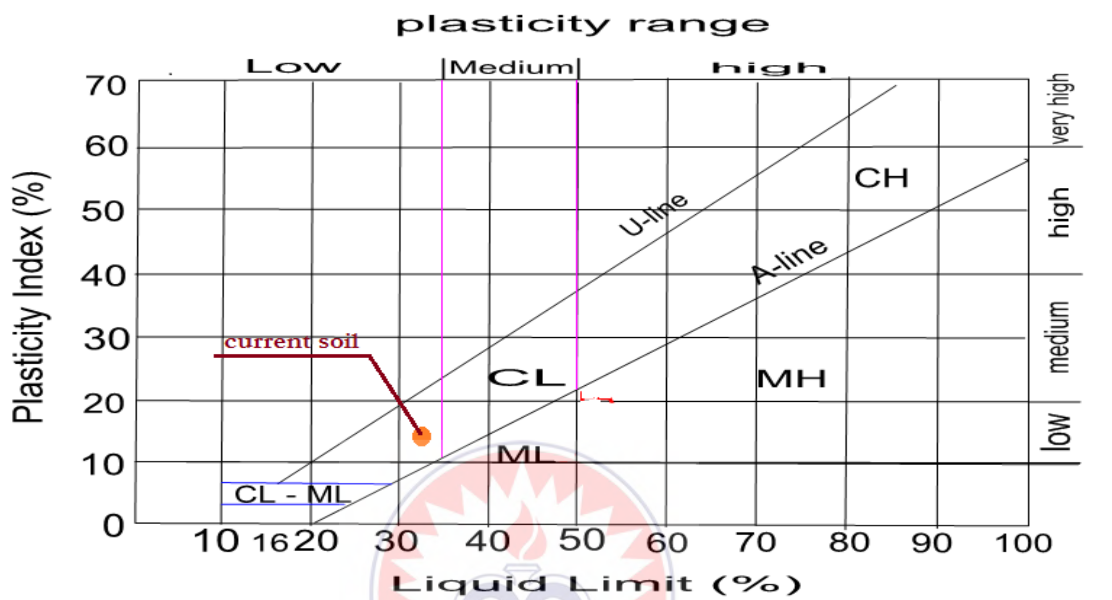

Figure. 4.2: Plasticity Chart for Soil Classification

4.2.3 Specific Gravity (Apparent Density)

The apparent density test results in Table 4.2 were obtained from four trials. The first and fourth trials coincidentally recorded the same outcome of 2.674. The third trial recorded the highest specific gravity of 2.698 while the second trial recorded the least specific gravity of 2.674. It is not yet clear ,the cause of these variations in specific gravity but the possible reason could be variation in the sample quantity.

Table: 4.2: Results of Specific Gravity Test

No. of Trials	1	2	3	4
Temperature of Water	27^0C	27^0C	27^0C	27^0C
Density of Water At Test Temperature	996.5	996.5	996.5	996.5
Apparent Density	2.674	2.640	2.698	2.674
Average Apparent Density	2.672			

4.2.4 Optimum Moisture Content

As was mentioned earlier the optimum moisture content was initially determined using the modified proctor test. In Table 4.3 it can be seen that compacting with 2% water content recorded a dry density of 1885kg/m^3. The highest dry density (2080kg/m^3) of the compacted soil sample was recorded at 4% water content while at 6% water content the dry density dropped to 1983kg/m^3 a fall of 97kg/m^3.

Table: 4.3 Optimum Moisture Content of Soil Sample by Modified Proctor Test

Parameter	Specimen 1	Specimen 2	Specimen 3
Percent water added%	2%	4%	6%
Approx.Dry density(kg/m^3)	1885	2080	1983

The alternative moisture content test results in Table 4.4 show that the optimum moisture content after 28 days air dried specimen was recorded at 13% water addition with a dry density of 2173kg/m^3. The 14% water addition recorded dry density value of 1956kg/m^3 which is higher than that of 12% water addition (1998kg/m^3). From Figure 4.3 it is clear that increasing the water content beyond the 13% water content will reduce the dry density of the brick specimen.

Table.4.4 Results of Optimum Moisture Content Test.

Moisture content %	Mass, g	Dry Density kg/m^3
12	4550	1998
13	4950	2173
14	4454	1956

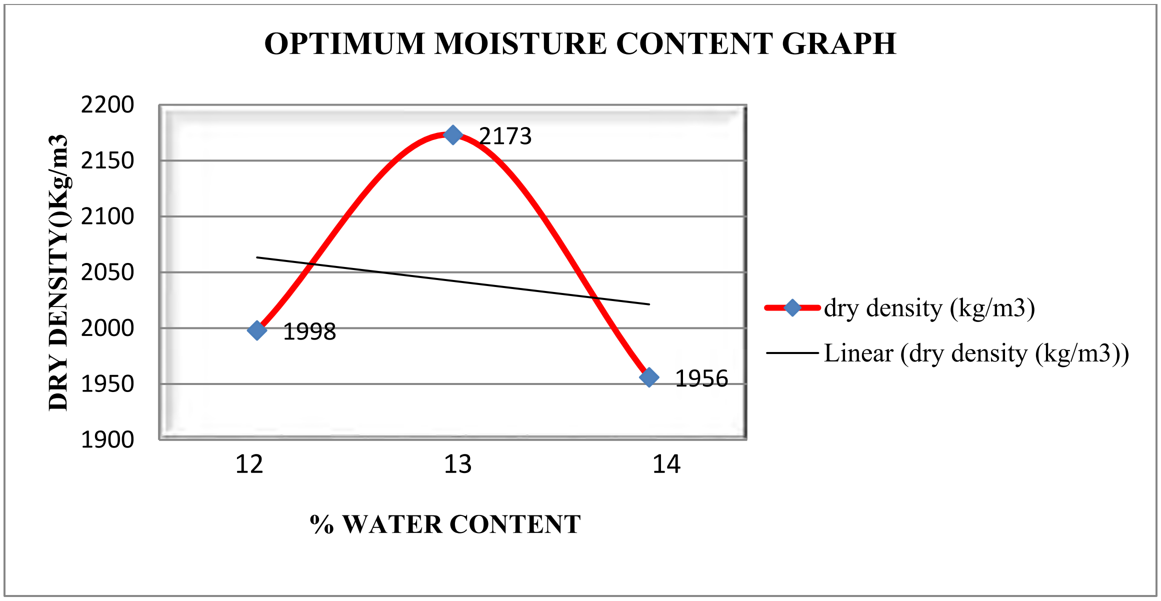

Figure 4.3: Optimum Moisture Content Plot

The optimum moisture content was estimated at 13% with a dry density of 1998kg/m^3 about (28kg/m^3) 1.4% higher than that of 2.5% earlier estimated moisture content.

Table 4.5 Summary of Characteristics of the Clay Soil.

Property	**Laterite-clay soil**
Natural Moisture content (%)	0.8
Percentage passing BS NO. 200sieve(0.075mm)%	46.8
Liquid limit (%)	33
Plastic limit (%)	17
Plasticity index (%)	16
Linear shrinkage (%)	0.22
Specific Gravity	2.672
Condition of sample	Air -dried
AASHTO classification	A-7-6.
Maximum dry density (kg/m^3)	1998
Optimum moisture content (%)	13

4.3 Results of Characteristics of Earth Bricks

4.3.1 Density of Specimens

From the results presented in Table 4.6, it is noticed that density steadily increased as Pozzomix- OPC content increases. Density of 1764.4 Kg/m^3, 1811.9 Kg/m^3, 1885.6 Kg/m^3 and 1997.2 Kg/m^3 were obtained for specimens with no stabiliser, 5%, 9%

and 12% Pozzomix without OPC content respectively. Density of specimens with 3% Pozzomix + 2% OPC, 6% pozzomix + 3% OPC and 8% pozzomix + 4% OPC were 1930.96 Kg/m^3, 1950.96Kg/m^3 and 1987.36Kg/m^3 respectively. Addition of pozzomix from 5% to 12% without any OPC increased the density from 2.7% to 13.2% over the un-stabilised specimens. There were also increases of 9.4%, 10.6% and 12.6% in density for specimens with 3% Pozzomix + 2% OPC, 6% pozzomix + 3% OPC and 8% pozzomix + 4% OPC respectively over the control group. Comparing stabiliser type, it can be observed that specimen with 3% Pozzomix + 2% OPC increased by 6.6% over that with 5% pozzomix cement alone. Specimen with 6% pozzomix+ 3% OPC also recorded an increase of 3.5% over speimen with 9% Pozzomix cement. Again comparing density of specimen with 8% pozzomix + 4% OPC and those with 12% Pozzomix alone revealed a reduction of 0.5% in density of specimen with 8% pozzomix + 4% OPC. Specimens with 12% Pozzomix alone recorded the highest density of 1997kg/m^3 while specimens without stabiliser presented the lowest density of 1764kg/m^3. It is clear that replacing the stabiliser content with one third OPC can improve the density of bricks but decreases when OPC content reaches 4%. This implies that higher levels of Pozzomix can increase the density of brick specimens. Nevertheless, the densities recorded by all the specimens were within recormended limits and approriate for single storey building construction.

Table 4.6: Results of Dry Density of Pozzomix- OPC Stabilised Earth Bricks

Batches	Specimen code	Average Mass(Kg)	Block volumes(m^3)	Average dry density (kg/m^3)
no stabilizer(control group)	S_0	4.0176	0.23x0.11x0.09	1764.
5% pozzomix+0%OPC	$P_{5/0}$	4.1256	0.23x0.11x0.09	1812
9% pozzomix+0%OPC	$P_{9/0}$	4.2934	0.230x.11x0.09	1886
12% pozzomix+0%OPC	$P_{12/0}$	4.5476	0.230x.11x0.09	1997
3%Pozzomix+ 2% OPC	$P_{3/2}$	4.3966	0.23x0.11x0.09	1931
6%pozzomix+ 3%OPC	$P_{6/3}$	4.4422	0.230x.11x0.09	1951
8%pozzomix+4%OPC	$P_{8/4}$	4.525	0.23x0.11x0.09	1987

Table 4.7 presents the correlation among the study variables which indicates that, pozzomix used for producing bricks strongly correlates significantly at the 5% level of significance with density of earth bricks ($r=0.721$, $p<0.05$). Ordinary Portland cement (OPC) was found to positively correlate with density of bricks specimen but insignificante ($r=0.583$, $p>0.05$).

Table 4.7: Correlation among Pozzomix, OPC and Density

	Density	Pozzomix	OPC
Density	1	0.721^a	0.583^b
Pozzomix		1	0.018^b
OPC			1

$^a p < 0.05$; $^b p > 0.05$

The experimental correlation between density, Pozzomix and OPC levels is outlined in Table 4.8.The best fit represented in equation (1)shows a strong linear correlation ($R^2=0.846$), represented in the equation:

$y = 1768 + 1581x_1 + 2959x_2$. ………Equation (1)

Y= Density of specimens Where

$\mathbf{x_1}$ is percentage Pozzomix content.

$\mathbf{x_2}$ is percentage OPC content.

The coefficient of determination value suggests that the percentage replacement of Pozzomix and OPC content explains about 77% of the variation in density of the earth brick specimen (Adjusted R^2 = 0.769). As it would appear to be expected, Pozzomix and OPC content is associated with higher density. The result of the ANOVA test on the density of Pozzomix and OPC stabilised bricks specimens indicates a significant prediction using the model developed (F =10.981, $p<0.05$). The unstandardised coefficient suggests that, an increase in Pozzomix and OPC content by one percent will increase the density by 1581kg/m^3 (t= 3.624, $p<0.05$) and 2959kg/m^3 (t= 2.907, $p<0.05$) respectively when all other variables remain constant. Also when all other variables remain constant the beta value suggests that an increase in the percentages of Pozzomix and OPC by one standard deviation will increase the density on the average by 0.711kg/m^3 and 0.571kg/m^3 respectively. Again this stipulates that Pozzomix contributes the highest of about 71% to the density while OPC contributes to about 57% of the density of stabilised earth blocks.

Table 4.8. Regression Analysis of Density of Specimens

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**Sig.**
	B	**Std. Error**	**Beta**		
Constant	1768.826	33.692		52.501	0.000
Poxomix	1581.182	436.299	0.711	3.624	0.022
OPC	2958.968	1017.861	0.571	2.907	0.044

Model Summary: R^2=0.846 (Adjusted R^2 =0.769); F(2,4) =10.981 , $p < 0.05$

4.3.2 Dry Compressive Strength of Specimen

From Table 4.9, the earth bricks with 8% pozzomix + 4% OPC ratio recorded the highest dry compressive strength of 4.7N/mm^2. The lowest dry compressive strength was recorded for specimens with no stabilizers (1.8N/mm^2). Specimens with 5% pozzomix + 0% OPC, 9% pozzomix + 0% OPC, 12% pozzomix + 0% OPC, 3% Pozzomix + 2% OPC and 6% pozzomix + 3% OPC recorded a steady increase in dry compressive strength of 2.1N/mm^2, 2.3N/mm^2, 2.4N/mm^2, 2.5N/mm^2 and 3.1N/mm^2 respectively. Pozzomix replacement from 5% to 12% saw an increase in dry compressive strength from 12% to 30.1% over the control group. Comparing stabiliser composition, it can be observed that specimens with 3% Pozzomix + 2% OPC increased about 19.5% over brick specimens with 5% pozzomix + 0% OPC content. There was also a significant increase of 38.2% in dry compressive strength of brick specimens with 6% pozzomix + 3% OPC over specimens with 9% Pozzomix content. Comparing specimens with 12% pozzomix + 0% OPC and 8% Pozzomix + 4% OPC, the latter experienced an incredible increase of 96.1% over the former. From Figure 4.4 It can be concluded that increasing Pozzomix and OPC content increases the dry density of earth bricks. Except the control specimens the rest of the brick specimens met the recommended strength values and therefore appriopriate for single storey low rise buildings.

Table 4.9 Results of Dry Compressive Strength of Pozzomix- OPC Stabilised Earth Bricks

Batches	Specimen code	Mean Load (N)	Surface Area(mm^2)	Average Dry Compressive strength (N/mm^2)
no stabilizer(control group)	S_0	46600	230x110	1.8419
5% pozzomix+0%OPC	$P_{5/0}$	52200	230x110	2.0632
9% pozzomix+0%OPC	$P_{9/0}$	57600	230x110	2.27667
12% pozzomix+0%OPC	$P_{12/0}$	61000	230x110	2.41106
3%Pozzomix+ 2% OPC	$P_{3/2}$	62400	230x110	2.4664
6%pozzomix+ 3%OPC	$P_{6/3}$	79600	230x110	3.14624
8%pozzomix+4%OPC	$P_{8/4}$	119600	230x110	4.72727

Table 4.10 presents correlation between Dry compressive strength, ordinary portland cement (OPC) and pozzomix content. The relationship depicts that, pozzomix used for producing bricks have a weak correlation with dry compressive strength of earth

bricks ($r=0.322$, $p>0.05$) at 5% significant level. Ordinary Portland cement (OPC) used for the earth bricks fabrication was found to significantly correlate strongly with Dry compressive strength of bricks specimen ($r=0.891$, $p<0.01$).

Table 4.10. Correlation Between Pozzomix, OPC and Dry compressive Strength

	Dry compressive strength	Pozzomix	OPC
Dry compressive strength	1	0.322^b	0.891^a
Pozzomix		1	0.018^b
OPC			1

$^a p<0.01$; $^b p>0.05$

Table 4.11. presents regression analysis of stabilised earth bricks stabilised with pozzomix and OPC contents which depicts a significant prediction using the model developed ($F=15.977$, $p<0.05$) as obtained by computing ANOVA. The best fit shows a strong linear correlation ($R^2=0.889$) as shown in equation (2)

dry compressive strength = 1.58 + 7.56(pozzomix) +50.98(OPC)……….. (2)

The coefficient of determination value suggests that the percentage replacement of pozzomix and OPC content explains about 83% of the variation in dry compressive strength of the earth brick specimen (Adjusted $R^2=0.833$). The unstandardised coefficient suggests that, an increase in pozzomix by one percent will increase the dry compressive strength by 7.56 N/mm^2 ($t=1.838, p>0.05$) while an increase in OPC content by one percent will increase the strength by 50.98N/mm^2 ($t=5.312$, $p<0.01$). Also the beta value suggests that an increase in the percentages of pozzomix and opc by one standard deviation will increase the density on the average by 0.307N/mm^2 and 0.886N/m^2 respectively when all other variables remain constant. Again this stipulates that Pozzomix contributes to about 30.7% to the dry compressive strength while OPC contributes to about 89% to the dry compressive strength of stabilised earth blocks. This implies that ordinary Portland cement contributes the most in the strength of the stabilised earth bricks.

Table 4.11. Regression Analysis of Dry Compressive Strength of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.584	0.318		4.988	0.008
Pozzomix	7.561	4.114	0.307	1.838	0.140
OPC	50.982	9.597	0.886	5.312	0.006

Model Summary: R^2=0.889 (Adjusted R^2 =0.833); F(2,4) =15.977 , $p < 0.05$

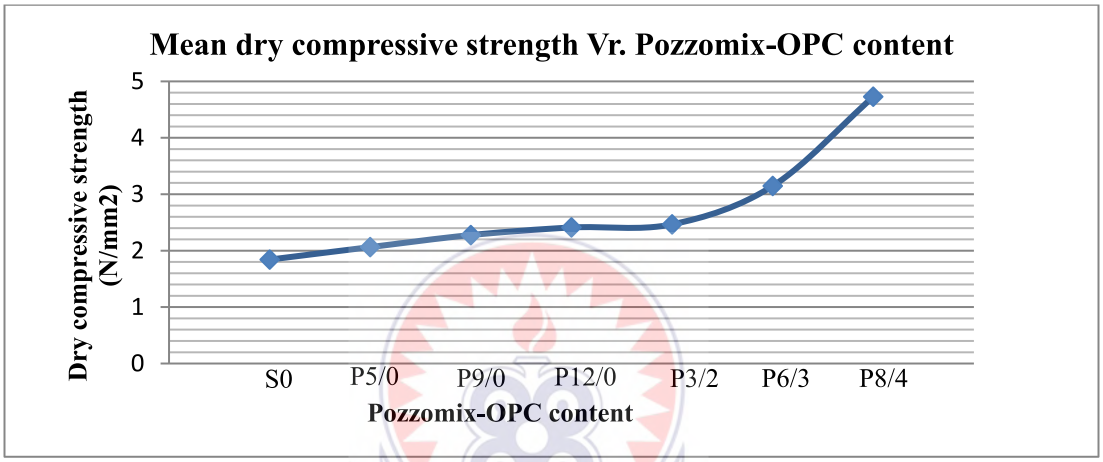

Figure:4.4. Dry Compressive Strength as a Function of Pozzomix- OPC Content

4.3.3 Wet Compressive Strength of Specimen

Again the results presented in Table 4.12, shows a clear increase in wet compressive strength with increase in levels of pozzomix from 5% to 12%. The stength values ranged from 1.02N/mm^2 to 1.83N/mm^2. Also the wet compressive strength values of earth bricks were 1.25N/mm^2, 1.72N/mm^2 and 2.13N/mm^{2}for 3% Pozzomix + 2% OPC, 6% pozzomix + 3% OPC and 8% pozzomix + 4% opc respectively. The trend shows that, increasing Pozzomix content from 5% to 12% increases the wet compressive strength from 148% to 346% over the un-stabilised brick specimens. Again adding 4% Pozzomix + 2% OPC, 6% pozzomix + 3% OPC and 8% pozzomix + 4% OPC improved the earth bricks by 203.8%, 319% and 417% respectively over the control specimens. The specimens maintained a good and recommended wet compressive strength except the un-stabilised bricks and the 5% pozzomix brick specimens.

Table 4.12 Results of Wet Compressive Strength of Pozzomix- OPC Stabilised Earth Bricks

Batches	Specimen code	Mean Load (N)	Surface Area(mm²)	Average Wet Compressive strength (N/mm²)
no stabilizer(control group)	S_0	30800	230x110	0.4111
5% pozzomix+0%OPC	$P_{5/0}$	52000	230x110	1.0198
9% pozzomix+0%OPC	$P_{9/0}$	69400	230x110	1.2885
12% pozzomix+0%OPC	$P_{12/0}$	7100	230x110	1.8340
3%Pozzomix+ 2% OPC	$P_{3/2}$	66200	230x110	1.2490
6%pozzomix+ 3%OPC	$P_{6/3}$	87400	230x110	1.7233
8%pozzomix+4%OPC	$P_{8/4}$	53800	230x110	2.1265

Table 4.13 depicts the correlation between wet compressive strength, ordinary Portland cement (OPC) and pozzomix cement. There is a positive association between pozzomix cement for brick production and wet compressive strength. The corrilation suggest a strong relationship between pozzomix and wet compressive strength of earth bricks ($r=0.768$, $p<0.05$). Ordinary Portland cement (OPC) used for the earth brick stabilisation was found to correlate with wet compressive strength of bricks specimen but insignificant ($r=0.642$, $p>0.05$).

Table 4.13. Correlation Between Pozzomix, OPC and Wet Compressive Strength

	Wet compressive strength	Poxomix	OPC
Wet compressive strength	1	0.768^a	0.642^b
Pozzomix		1	0.018^b
OPC			1

$^a p < 0.05$; $^b p > 0.05$

The experimental correlation between wet compressive strength and Pozzomix and OPC levels is outlined in Table 4.14 and Figure 4.5 the best fit shows a strong linear correlation ($R^2=0.984$), represented by equation (3):

$y=0.44 + 10.92x_1 + 21.15x_2$. (3)

where

y= wet compressive strength

x_1 is pozzomix content

x_2 OPC content.

The coefficient of determination value suggests that the percentage replacement of Pozzomix and OPC explains about 98% of the variation in the wet compressive strength of the earth bricks specimen (Adjusted R^2 =0.976). As it would appear to be expected, higher pozzomix and OPC contents is associated with higher wet compressive strength. The results of the ANOVA test on the Wet compressive strength of Pozzomix and OPC stabilized bricks indicates a significant prediction using the model developed ($F = 123.195$, $p < 0.01$). The unstandardized coefficient suggests that, an increase in Pozzomix and OPC content by one percent will increase the wet compressive strength by 10.92N/mm^2 ($t=11.973$, $p<0.01$) and 21.15N/mm^2 ($t=9.939$, $p<0.01$) respectively. Also the beta value suggests that a percentage increase in Pozzomix and OPC by one standard deviation will increase the dry compressive strength on the average by 0.757N/mm^2 and 0.628N/mm^2 respectively. Again this stipulates that pozzomix and OPC content contribute to about 76% and 63% respectively to the wet compressive strength of stabilized earth blocks, which meant that pozzomix cement as a stabiliser in earth bricks can resist water intake thereby retaining its strength.

Table 4.14: Regression Analysis of Wet Compressive Strength of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	0.436	0.070		6.189	0.003
Pozzomix	10.920	0.912	0.757	11.973	0.000
OPC	21.148	2.128	0.628	9.939	0.001

Model Summary: R^2=0.984 (Adjusted R^2 =0.976); $F(2,4)$ =123.195 , $p < 0.01$

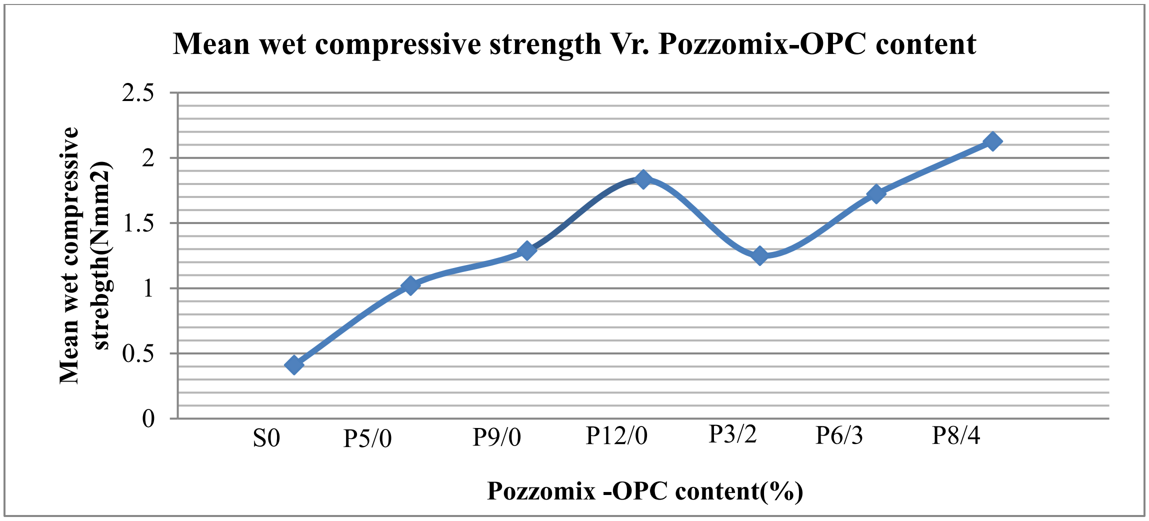

Figure 4.5: Wet Compressive Strength as a Function of Pozzomix –OPC Content

4.3.4. Wet Compressive Strength Versus Dry Compressive Strength

Table 4.15. presents the correlation beween wet and dry compressive strength. This indicates that there is a positive relationship between the wet compressive strength and dry compressive strength. These variables correlate strongly with each other at the 5% level of significance ($r=0.790$, $p<0.05$).

Table 4.15: Correlation Between Wet Compressive Strength and Dry Compressive Strength

	Wet comp. strength	Dy comp. strength
Wet comp. strength	1	0.790[a]
Dy comp. strength		1

[a]$p < 0.05$

Figure 4.6 shows graphical representation of the relationship between wet and dry compressive strength of Pozzomix –OPC stabilized earth bricks. From the curves it is clear that increasing pozzomix –OPC content increases both dry and wet compressive strength. It can be noticed from the graph that, when pozzomix content alone is increased from 5% to 12% the percentage difference in strength increase from 50.5% to 24.1%. Also specimens with 3% pozzomix + 2% OPC, 6% pozzomix + 3% OPC and 8%

pozzomix + 4% OPC saw a percentage difference between dry and wet compressive strength of 49%, 45.4% and 55% respectively. It is clear from the analysis that specimens with 12% pozzomix content have an excellent resistance to the effect of water on its strength. This implies that for effective maximum strength retention in damp areas, bricks should be fabricated with higher contents of pozzomix cement.

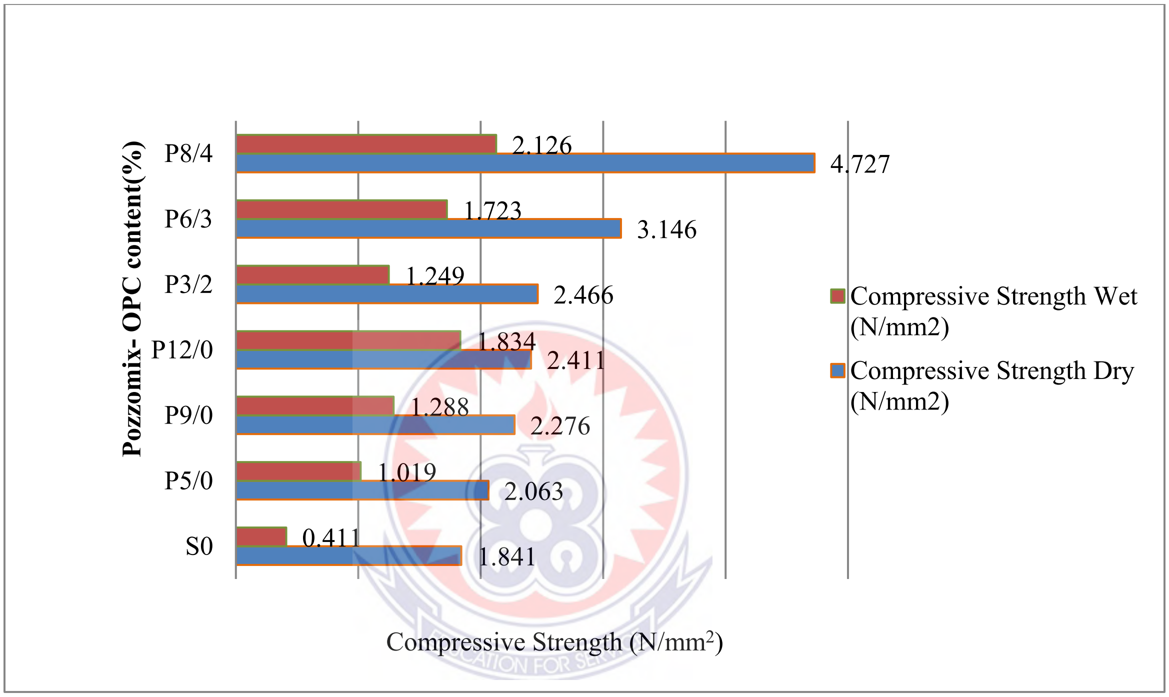

Figure: 4.6. Wet Compressive Strength Versus Dry Compressive Strength

4.3.5. Initial Rate of Water Absorption of Specimens

From Table 4.16, it can be observed that all the earth bricks absorbed some amount of water due to capillary action. Significantly the amount of water absorbed saw a gradual declines as the amount of Pozzomix- OPC replaced increased. Among the pozzomix stabilised earth bricks, the 5% pozzomix + 0% OPC content recorded the highest initial rate of water absorption (IRA) of 0.182g/cm^2 min. while specimens with 12% pozzomix + 0% OPC observed the lowest IRA of 0.121g/cm^2 min. The decline in IRA of the 5% to 12% pozzomix stabilised brick specimens ranged from 25% to 50%

over the un-stabilised bricks. Again among the pozzomix and OPC mix specimens, the earth bricks with 3% pozzomix + 2% OPC recorded the most IRA of 0.16g/cm^2 min which is about 50% decline over the control group. Also specimens with 6% pozzomix + 3% OPC recorded IRA of 0.122 g/cm^2 min, a decline of about 49.2% over the un-stabilised specimens while specimens with 8% pozzomix + 4% OPC experienced the least IRA of 0.096g/cm2 min which is about 60.2% decline in water intake over the control group. It is clear that adding 4% OPC to 8%pozzomix can reduce water intake in earth bricks tremendiously. Generally all the earth bricks had IRA within recommended limits.

Table 4.16 Results of Initial Rate of Water Absorption of Pozzomix- OPC Stabilised Earth Bricks

Batches	Specimen code	Change in mass (g)	Change in Mass(g)	Initial rate of water absorption(g/cm^2 min)
no stabilizer(control group)	S_0	4018.6	191	0.24050
5% pozzomix+0%OPC	$P_{5/0}$	4127.4	146.33	0.18175
9% pozzomix+0%OPC	$P_{9/0}$	4295.4	127.33	0.15975
12% pozzomix+0%OPC	$P_{12/0}$	4555.2	96.333	0.12050
3%Pozzomix+ 2% OPC	$P_{3/2}$	4365.2	125.4	0.15675
6%pozzomix+ 3%OPC	$P_{6/3}$	4444.6	98.2	0.12275
8%pozzomix+4%OPC	$P_{8/4}$	4526.8	76.8	0.09600

Table 4.17 presents the correlationmetrixs between initial rate of water absorption, ordinary Portland cement (OPC) and Pozzomix cement. There is a negative association between pozzomix cement for brick production and initial rate of water absorption. The corrilation suggest a strong significant relationship between pozzomix content and water absorption of earth bricks ($r= - 0.749$, $p<0.05$).Ordinary Portland cement (OPC) used for the earth brick stabilisation was found to correlate negatively with water absorption of bricks specimen but insignificantly. ($r= - 0.653$, $p>0.05$).

Table 4.17. Correlation Between Pozzomix, OPC and Initial Rate of Water Absorption

	Initial rate of water absorption	Pozzomix	OPC
Initial rate of water absorption	1	- 0.749[a]	- 0.653[b]
Pozzomix		1	0.018
OPC			1

[a]$p < 0.05$; [b]$p > 0.05$

The experimental correlation between initial rate of water absorption and Pozzomix and OPC levels is outlined in Table 4.18. The best fit shows a strong linear correlation (R^2=0.970) as shown in equation 4

$$y = 0.231 - 0.886x_1 - 1.793x_2. \quad \text{.............(4)}$$

where

$\mathbf{x_1}$ is pozzomix content,

$\mathbf{x_2}$ OPC content

y = initial rate of water absorption.

The coefficient of determination value suggests that the percentage replacement of Pozzomix and OPC explains about 96% of the variation in the initial rate of water absorption of the earth bricks specimen (Adjusted R^2 =0.955). As it would appear to be expected, higher pozzomix and OPC content is associated with higher initial rate of water absorption. The results of the ANOVA test on the initial rate of water absorption of Pozzomix and OPC stabilized bricks indicates a significant prediction using the model developed (F =64.011, $p < 0.001$). The unstandardized coefficient suggests that, an increase in Pozzomix by one percent will reduce the water absorption by 0.886g/cm^2 min (t= -8.473, p<0.01) and an increase in OPC by one percent will reduce the water absorption by 1.793.g/cm^2 min (t= -7.349, p<0.01). Also the beta value suggests that a percentage increase in Pozzomix and OPC by one standard deviation will reduce the water absorption on the average by 0.738g/cm^2 minand 0.640g/cm^2 min respectively.

This suggests that pozzomix and OPC content contribute to about 74% and 64% respectively to the initial rate of water absorption of stabilized earth blocks. This prediction meant that pozzomix cement has a higher water repellant ability than OPC.

Table 4.18. Regression Analysis of Initial rate of water absorption of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	0.231	0.008		28.591	0.000
Pozzomix	-0.886	0.105	-0.738	-8.473	0.001
OPC	-1.793	0.244	-0.640	-7.349	0.002

Model Summary: R^2=0.970 (Adjusted R^2 =0.955); F(2,4) =64.011 , $p < 0.01$

4.3.6 Abrasion Resistance on Specimens

The results presented in Table 4.19 show a clear increase in abrasion resistance as the amount of Pozzomix- OPC content increases. Thus, bricks with no Pozzomix -OPC stabilization presented the least resistance to abrasion (1.85cm^2/g) whilst those with 8% Pozzomix + 4% OPC stabilized bricks presented the highest abrasion resistance of 11.64cm^2/g among all batches an improvement of about 529% over the un-stabilised brick specimens. Increasing pozzomix content from 5% to 12% saw an increase from 50.8% to 431% over the control group. The results of bricks specimens with 3% Pozzomix + 2% OPC and 6% pozzomix + 3% OPC experienced an increase in wearing resistance of 3.73cm^2/g, and 7.734cm^2/g respectively. Comparing batches, it is clear that specimens with 3% pozzomix + 2% OPC saw an improvement of 33.7% over specimens with 5% pozzomix + 0% OPC content. there was a significant improvement of 28.92% in surface abrasion for bricks specimens with 6% pozzomix + 3% OPC replacement over specimens with 9% pozzomix + 0% OPC. Again, the batch with 8% pozzomix + 4% OPC addition recorded an increase in resistance to surface wearing of about 18.15% over specimens with 12% pozzomix + 0% OPC.

Table 4.19 Results of Abrasion Resistance of Pozzomix- OPC Stabilised Earth Bricks

Batches	Specimen code	mass before brushing(g)	Change in Mass (g)	Abrasion resistance (cm^2/g)
no stabilizer(control group)	S_0	4021.2	113	1.8547
5% pozzomix+0%OPC	$P_{5/0}$	4123.6	73	2.7857
9% pozzomix+0%OPC	$P_{9/0}$	4283.8	33.33	5.9993
12% pozzomix+0%OPC	$P_{12/0}$	4550.2	20	9.8478
3%Pozzomix+ 2% OPC	$P_{3/2}$	4386.2	55	3.72520
6%pozzomix+ 3%OPC	$P_{6/3}$	4436.8	26.66	7.73407
8%pozzomix+4%OPC	$P_{8/4}$	4540.2	17.33	11.6353

Table 4.20 shows the correlation between abrasion resistance,OPC and Pozzomix cement. There is a positive association between pozzomix cement for brick production and abrasion resistance. The correlation suggests a strong significant relationship between pozzomix and abrasion resistance of earth bricks (r=0.783, p<0.05). Ordinary Portland cement (OPC) used for the earth brick stabilisation was found to correlate with wet compressive strength of bricks specimen but insignificant (r=0.560, p>0.05).

Table 4.20. Correlation Between Pozzomix, OPC and Abrasion Resistance

	Abrasion resistance	Poxomix	OPC
Abrasion resistance	1	0.783^a	0.560^b
Pozzomix		1	0.018
OPC			1

$^a p < 0.05$; $^b p > 0.05$

The experimental correlation between abrasion resistance and Pozzomix and OPC levels is outlined in Table 4.21 shows a strong linear correlation (R^2=0.912), represented in the equation:

$$y=0.286 + 71.890x_1 +118.474x_2.$$

where y= Abrasion resistance

$\mathbf{x_1}$ is pozzomix content

$\mathbf{x_2}$ OPC content.

The coefficient of determination value suggest that the percentage replacement of Pozzomix and OPC explains about 87% of the variation in the abrasion resistnce of the earth bricks specimen (Adjusted R^2 =0.868). The outcome revealed that higher pozzomix and OPC content is associated with higher abrasion resistance. The results of the ANOVA test on the abrasion resistance of Pozzomix and OPC stabilized bricks indicates a significant prediction using the model developed (F =20.750, $p < 0.01$). The unstandardized coefficient suggests that, an increase in Pozzomix and OPC content by one percent will increase the abrasion resistance by 71.890cm^2/g(t=5.218, p<0.01) and 118.474cm^2/g (t=3.686, p<0.05) respectively. Also the beta value suggests that a percentage increase in Pozzomix and OPC by one standard deviation will increase the dry compressive strength on the average by 0.774cm^2/g and 0.547cm^2/g respectively. Again this depicts that pozzomix and OPC content contribute to about 77% and 55% respectively to the abrasion resistance of stabilized earth blocks which means that pozzomix cement as a stabiliser in earth bricks contributes the most in wearing resistance of specimens.

Table 4.21. Regression Analysis of Abrasion Resistance of Specimens

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	0.286	1.064		0.269	0.001
Pozzomix	71.890	13.778	0.774	5.218	0.006
OPC	118.474	32.143	0.547	3.686	0.021

Model Summary: R^2=0.912 (Adjusted R^2 =0.868); F(2,4) =20.750 , p < 0.01

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Introduction

The main aim of this study was to evaluate the performance of Pozzomix cement and ordinary Portland cement on the strength and durability properties of stabilised earth blocks (SEB). The properties that were examined were dry density of SEBs, Wet/Dry compressive strengths, rate of initial water absorption and abrasion resistance of stabilised earth blocks. The performance of SEBs also varies widely according to the makeup of the soil, the manufacturing and stabilization techniques used, and the climate in which they are used. This chapter is devoted into discussing the outcome of the study.

5.2 Soil Characterization

The characteristics of the clay soil that are discussed in detail are: particle size distribution, atterberg limit, shrinkage limit and specific gravity. The particle size analysis gives information on the soil ability to pack into a dense structure and the quantity of fines present (combined silt and clay fraction), while the plasticity index gives an idea of cohesion of the fines.

The results of the wet sieve analysis revealed that soil fines (silt and clay) constituted about 46.85 percent. These are particle sizes that pass the BS sieve 0.075mm. Smith& smith (1998) stated that the presence of clay in moderate quantity in a soil is desirable.

The characteristic of the soil used in this study was silt-clay in nature. According to AASHTO soil classification system soils that have more than 35% passing 0.075mm BS sieve are silt-clay. The natural moisture content value of 0.8% shows that the soil is in a near dry state. The term 'Dry' has been used here to indicate that the soil attained constant weight on being heated to 105^0C-110^0C (BS 1377: Part 2: 1990). The dryness of the soil was because samples were collected around March which happened to be the driest period in the year. The outcome according to AASHTO suggests that the soil is classified as plastic clay with group classification A-7-6. According to Smith and Austin (1989) a more useful range of particle sizes suitable for building with earth blocks is from 40-75% sand from 25-60% fines (silt and clay). The high sand fraction in the soil formed the stable constituent, though they lack cohesion when dry, but have a high degree of internal friction between the particles which make them up. This possibly contributed to the high density recorded. The film of absorbent water coating the clay particles sticks strongly to the clay layers, linking the micro-particles of the soil together, and it is this which gave the block its cohesion.

The Atterberg limits test was conducted after realizing that more than 5% of the soil passed 0.075 BS sieve. The Atterberg limits test revealed a liquid limit and plasticity index values of 33 and 16 respectively. This shows that the earth is of intermediate plasticity, according to (Graham & Burt, 2001). According to the commonwealth Experimental Building station the preferred plasticity index for a soil for bricks should be between 10-20%. Rigassi (1995) also recommends a plasticity index of soil for block production to be in the range of 15% and 20%. The PI value falls within the range for lateritic soil suitable for block making.

The specific gravity value 2.672 obtained in the study for the earth sample suggests that the soil is clayey and it is within the range 2.5 and 3.2 suitable for building purpose.The specific gravity of the soil substance of most inorganic soils varies between

2.60 and 2.80 (ASTM D 854-92) and appriopriate for building purposes. The linear shrinkage value recorded suggests that, shrinkage in the soil sample was minimal and negligible.

From the soil characterization it makes sense that sample soil taken from St. Bernadette's Technical Institute laterite site fulfills this requirement. So, the experimental results range for this soil sample is acceptable and suitable for stabilized earth block production. Soil suitable for earth blocks production will result in strong blocks which have good strength and abrasion resistance, handleable blocks that immediately upon remolding can be transferred to a curing area.

5.3 Effect of Pozzomix –OPC on Dry Block Density

The dry density is largely a function of the constituent material's characteristics, moisture content during pressing and the degree of compactive load applied. Density of compressed earth blocks is consistently related to its compressive and compactive force applied during production. This relationship between strength and density has been consistently proven by test data over the past 20 years (Houben & Guillaud, 1994). As demonstrated in other studies, compressive strength increases with increasing density of the mixture (Reddy & Kumar, 2011). The average densities of all the batches were found to consistently increase as the pozzomix –OPC content increased. The recorded values were in line with recommended values. Bricks made of pozzomix and OPC used in the study had their densities within the recommended range of 1500kg/m^3 – 2400kg/m^3 as specified by BS 6073 for dense aggregates masonry units. From the results of the dry block densities in Table 4.6, the densities of collected samples of SEB vary from 1764-

1997kg/m^3. Expected densities commonly range between 1700kgm^3 and 2200kg/m^3 (Houben & Guilaud, 1994; Rigassi, 1995). Densities of individual bricks specimen in a batch varied slightly possibly because of variation in the amount of mix fed into the mould. The errors were minimized else accumulation could affect the durability of the bricks (Lunt, 1980). It was clear that the addition of OPC in the batch effected a significant increase in density. The outcome of the results suggest that increasing the percentage of Pozzomix –OPC beyond 8% pozzomix + 4% OPC will not cause any significant increase in density compared to the density of specimens with 12% pozzomix + 0% OPC. From the regression analysis in Table 4.8 it is clear that variation in ordinary portland cement quality and amount can drastically affect its properties and behavior more than any other input variables (Gooding, 1994). The pozzolanic action has a particularly stabilizing effect because it binds soil particles together as various cemetitious compounds are formed.

5.4 Effect of Pozzomix–OPC on Compressive Strength Brick Specimen

From the results in Table 4.9, it is clear that all the stabilised brick specimens recorded dry compressive strength values above 2N/m^2. There was a general increase in dry compressive strength of all the stabilised earth blocks with increase in stabiliser content. This is in agreement with recent studies by ((Bouassria, Cherraj, Bouabid, Charif D'ouazzane, Tayyibi, 2014); Bahar, Benazzoug, Kenai 2004)) which have shown that the mechanical characteristics increase with increase in the cement proportion. However, this increase varies from one material to the other. The results of dry compressive strength values recorded conforms with the minimum dry compressive strength recommended by

(BS 5628: Part 1, 1978). It has been found that the compressive strength of soil materials adequate for walls in low rise and low- cost buildings is between 2N/mm^2 and 4N/mm^2 (Browne 2009). It is obvious that the raw earth (control specimens) is not recommended for house construction since it is very week in compressive strength.The results suggest that increased addition of OPC in the batches effected a high increase in its dry compressive strength. This is possible because of the artificial cementation by Portland cement on the mechanical behavior of clay. Increase in the peak strength and stiffness of the bricks occur due to the formation of a cementitious structure within the clay soil skeleton.

The results of the wet compressive strength indicate that increasing pozzomix and OPC content improves the wet compressive strength of earth bricks. The wet compressive strength increases from 1.02N/mm^2 and 1.83N/mm^2 among specimens with 5% to 12% pozzomix cement. Again the strength values for specimens with 3% pozzomix and 2% OPC, 6% pozzomix and 3% OPC and 8% pozzomix and 4% OPC were 1.25N/mm^2, 1.7N/mm^2 and 2.13N/mm^2 respectively. Most of the values recorded compared well with most current SEB standards and appropriate for low rise affordable housing. According to literature source, recommended WCS values for compressed earth bricks vary from country to country, author to author. Some recommended minimum values are 1.2MPa (Lunt, 1980) and 1.4MPa (Fitzmaurice, 1958). The value of 1.2MPa is now more widely used (Houben & Guillaud, 1994). This meant that wet compressive strength values for traditional bricks (un- stabilised bricks) and those with 5% pozzomix + 0% OPC are inappropriate for house construction in damp areas. The analyses revealed that pozzomix cement contributed the most to the wet compressive strength of brick specimen.

5.5 Effect of Pozzomix -OPC on the Initial Rate of Water Absorption

Almost allbricks can absorb water by capillary action (Keddi & Cleghorn, 1980). The initial rate of water absorption is a useful measure of brick quality and durability. The reason for this is that the pore space in a bricks can be estimated by the amount of water it can absorb. This property is clearly distinct from the ease with which water can penetrate a brick and permeate through it (Neville, 1995). From the results in Table 4.16 it can be observed that all of the samples tested recorded IRA significantly less than 2g/cm^2/min and, therefore, would be acceptable in traditional construction (Claybrick and Tiles Sdn, 1998-2007). This is so because if the IRA of the bricks rises from 2 g/cm^2/min to 4 g/cm^2/min then the strength of the wall will be reduced by 50%. The results of compressed earth blocks stabilised with increasing pecentages of pozzomix-OPC were incredible because of the Pozzomixcontent. The cementserves to make clay less absorbent of water; thus, the clay soil becomes more manageable and less susceptible to variations in moisture content (Adam and Agib 2001).

5.6 Effect of Pozzomix- OPC on the Abrasion Resistance of Block Specimen

From the results obtained after brushing the exposed faces of compressed earth bricks to simulate wind driven erosion, the control samples showed a decrease resistance to abration. Specimens with pozzomix- OPC content displayed impressive resistance to abrasion. Generally, there was a steady increase in abrasion resistance as the stabilizer content increased. This observation was found to be consistent with those of Eko and Riskowstu (2001) who opined that stabilization of compressed earth block using cement increases the abrasive strength of the blocks.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The principal objective of this thesis was to investigate the strength and durability of SEBs. Tests carried out by the researcher have shown promising results in terms of both strength and durability for the application of SEBs. Interest in the strength and durability of SCEBs is likely to remain a major concern for the foreseeable future given the potentials the material has in reducing the enormous shelter backlog in developing countries.

In the light of the results of experimental test reported in this study it can be concluded that:

The soil used in this study was poorly graded plastic clay with group classification of A-7-6 but suitable for stabilised earth blocks production. The mean dry blocks density of control bricks was 1764kg/m^3 which is within recommended limites. The batch with 12% pozzomix + 0% OPC recorded the higest density of 1997kg/m^3. Pozzomix cement can contribute the most to the density of earth bricks. In this study all the brick specimens recorded densities within recommended limits.

The dry compressive strength values obtained for all the stabilised earth bricks were within specified limits and suitable for single storey dwelling. When optimum strength is required, it will be appropriate to adopt the batches 6% pozzomix + 3% OPC and 8% pozzomix +4% OPC. Stabilisation with Pozzomix-OPC significantly improved the compressive strength of soil blocks, therefore making them suitable as masonry wall units. Generally, increasing the quantity of pozzomix-OPC increased the dry compressive strengths of the earth blocks .The analysis reveals that ordinary Portland cement in the mix contributed the most to the drycompressive strength. Apart from bricks without stabiliser all other blocks had dry compressive strength in excess of the minimum strength requirements for masonry in most codes, confirming their suitability for two or three storey buildings.The wet compressive strength values recorded followed the same trend as those of the dry compressive strength. The pozzomix-OPC stabilised earth bricks still retained good strength values after immersing in water for about 10 minutes while the un-stabilised earth bricks performed poorly ($0.41N/mm^2$) after immersing in water for 10 minutes. Once again the batch with 8% pozzomix + 4% OPC retained a remarkable strength of $2.12N/mm^2$ which is about 417% higher than those recorded for the control samples. With exception to specimens with 5% pozzomix + 0% OPC and un-stabilised earth bricks, the remaining earth bricks fabricated are adequate for a single storey dwelling.

There was a general reduction in water absorption as Pozzomix- OPC content increases. The earth bricks showed a remarkable improvement in their durability properties (water absorption and abrasion). As the the quantity of pozzomix-OPC in the soil bricks increases, the ability of the soil blocks to resist abrasion also increased appreciably. Furthermore, soil bricks also tend to have high water exclusion property as the quantity of Pozzomix-OPC increases making it suitable as a masonry unit. From the initial rate of water absorption test it can be deduced that Pozzomix cement has low permeability of moisture.

It is appropriate to conclude that the use of Pozzomix with OPC will improve significantly the strength and durability properties of compressed earth bricks. The use of

Pozzomix cement alone should be used sparingly especially lower percentages and in poor soils. In other to obtain optimum compressive strength of earth blocks, Pozzomix cement should be used as admixture.

6.2 Recommendations

From the outcome of this current study the following recommendations are made: Block press be used in molding the bricks rather than using the proctor hammer in an improvised mould. In selecting suitable soil for compressed bricks production, earth from different locations should be collected and investigated for their suitability rather than selection based on availability and social acceptance. In reality rain storm is the commonest wearing agent of wall surfaces. This implies that in subsequent studies wind driven rain simulation test be used to test for abrasion resistance test. Again other test such as chemical test and tension should be carried out to determine the resistance of the earth blocks to other weeknesses of earth blocks.

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APPENDIX I

DATA SHEET Pozzo-Mix- OPC Cement Stabilised Compressed Blocks : Dry Block Density				
Specimen Code	Mass Of Dry Block, (Kg)		Dry Block Volume, (M^3)	Dry Block Density, (Kg/m^3)
	(g)	Kg		
S0-1	4020	4.02	0.002277	1766
S0-2	4017	4.017	0.002277	1764
S0-3	4015	4.015	0.002277	1763
S0-4	4017	4.017	0.002277	1764
S0-5	4019	4.019	0.002277	1765
P 5/0-1	4124	4.124	0.002277	1811
P5/0 -2	4130	4.13	0.002277	1814
P5/0-3	4121	4.121	0.002277	1810
P5/0-4	4123	4.123	0.002277	1811
P5/0-5	4130	4.13	0.002277	1814
P9/0-1	4295	4.295	0.002277	1886
P9/0-2	4293	4.293	0.002277	1885
P9/0-3	4292	4.292	0.002277	1885
P9/0-4	4295	4.295	0.002277	1886
P9/0-5	4292	4.292	0.002277	1885
P12/0-1	4546	4.546	0.002277	1996
P12/0-2	4549	4.549	0.002277	1998
P12/0-3	4549	4.549	0.002277	1998
P12/0-4	4547	4.547	0.002277	1997
P12/0-5	4547	4.547	0.002277	1997
P3/2-1	4395	4.395	0.002277	1930
P3/2-2	4396	4.396	0.002277	1931
P3/2-3	4398	4.398	0.002277	1931
P3/2-4	4398	4.398	0.002277	1931
P3/2-5	4396	4.396	0.002277	1931
P6/3-1	4443	4.443	0.002277	1951
P6/3-2	4442	4.442	0.002277	1951
P6/3-3	4441	4.441	0.002277	1950
P6/3-4	4443	4.443	0.002277	1951
P6/3-5	4442	4.442	0.002277	1951
P8/4-1	4526	4.526	0.002277	1988
P8/4-2	4526	4.526	0.002277	1988
P8/4-3	4528	4.528	0.002277	1989
P8/4-4	4523	4.523	0.002277	1986
P8/4-5	4522	4.522	0.002277	1986

APPENDIX II

DATA SHEET Pozzomix- OPC Stabilised Earth Blocks : Dry Compressive Strength				
Specimen Code	Ultimate Load (F),KN	Ultimate Load (N)	Dry Compressive Strength, N/mm^2	Area (mm^2)
	Gross		Gross	
S0-1	45	45000	1.78	25300
S0-2	45	45000	1.78	25300
S0-3	49	49000	1.94	25300
S0-4	48	48000	1.90	25300
S0-5	46	46000	1.82	25300
P 5/0-1	50	50000	1.98	25300
P5/0 -2	51	51000	2.016	25300
P5/0-3	56	56000	2.21	25300
P5/0-4	50	50000	1.98	25300
P5/0-5	54	54000	2.13	25300
P9/0-1	58	58000	2.29	25300
P9/0-2	58	58000	2.29	25300
P9/0-3	57	57000	2.25	25300
P9/0-4	57	57000	2.25	25300
P9/0-5	58	58000	2.29	25300
P12/0-1	60	60000	2.37	25300
P12/0-2	54	54000	2.13	25300
P12/0-3	62	62000	2.45	25300
P12/0-4	65	65000	2.57	25300
P12/0-5	64	64000	2.53	25300
P3/2-1	62	62000	2.45	25300
P3/2-2	60	60000	2.37	25300
P3/2-3	62	62000	2.45	25300
P3/2-4	65	65000	2.57	25300
P3/2-5	63	63000	2.49	25300
P6/3-1	80	80000	3.16	25300
P6/3-2	79	79000	3.12	25300
P6/3-3	82	82000	3.24	25300
P6/3-4	79	79000	3.12	25300
P6/3-5	78	78000	3.08	25300
P8/4-1	115	115000	4.55	25300
P8/4-2	121	121000	4.78	25300
P8/4-3	125	125000	4.94	25300
P8/4-4	126	126000	4.98	25300
P8/4-5	111	111000	4.39	25300

APPENDIX III

DATA SHEET PozzoMix- OPC Cement Stabilised Earth Blocks : Wet compressive Strength				
Specimen Code	**Ultimate Load (F),KN**	**Ultimate Load (F),N**	**Wet Compressive Strength, N/mm^2**	**Area (mm^2)**
	Gross	**Gross**	**Gross**	
S0-1	8	8000	0.32	25300
S0-2	10	10000	0.40	25300
S0-3	12	12000	0.47	25300
S0-4	10	10000	0.40	25300
S0-5	12	12000	0.47	25300
P 5/0-1	25	25000	0.99	25300
P5/0 -2	25	25000	0.99	25300
P5/0-3	24	24000	0.95	25300
P5/0-4	28	28000	1.11	25300
P5/0-5	27	27000	1.07	25300
P9/0-1	32	32000	1.26	25300
P9/0-2	30	30000	1.19	25300
P9/0-3	38	38000	1.50	25300
P9/0-4	31	31000	1.23	25300
P9/0-5	32	32000	1.26	25300
P12/0-1	45	45000	1.78	25300
P12/0-2	48	48000	1.90	25300
P12/0-3	46	46000	1.82	25300
P12/0-4	45	45000	1.78	25300
P12/0-5	48	48000	1.90	25300
P3/2-1	29	29000	1.15	25300
P3/2-2	30	30000	1.19	25300
P3/2-3	30	30000	1.19	25300
P3/2-4	34	34000	1.34	25300
P3/2-5	35	35000	1.38	25300
P6/3-1	41	41000	1.62	25300
P6/3-2	43	43000	1.70	25300
P6/3-3	43	43000	1.70	25300
P6/3-4	46	46000	1.82	25300
P6/3-5	45	45000	1.78	25300
P8/4-1	54	54000	2.13	25300
P8/4-2	56	56000	2.21	25300
P8/4-3	54	54000	2.13	25300
P8/4-4	55	55000	2.17	25300
P8/4-5	50	50000	1.98	25300

APPENDIX IV

DATA SHEET POZZOMix - OPC STABILISED EARTH BLOCKS : INITIAL RATE OF WATER ABSORPTION				
Specimen Code	Mass Before Absorption Test(g)	Mass After Absorption Test(g)	Change In Mass(g)	initial rate of water absorption(g/cm^{2}min)
S0-1	4022	4218	196	0.245
S0-2	4022	4216	194	0.2425
S0-3	4019	4209	190	0.2375
S0-4	4014	4203	189	0.23625
S0-5	4016	4216	200	0.25
P 5/0-1	4130	4276	146	0.1825
P5/0 -2	4128	4276	148	0.185
P5/0-3	4121	4266	145	0.18125
P5/0-4	4128	4270	142	0.1775
P5/0-5	4130	4276	146	0.1825
P9/0-1	4300	4426	126	0.1575
P9/0-2	4265	4392	127	0.15875
P9/0-3	4301	4430	129	0.16125
P9/0-4	4305	4433	128	0.16
P9/0-5	4306	4435	129	0.16125
P12/0-1	4560	4653	93	0.11625
P12/0-2	4555	4654	99	0.12375
P12/0-3	4551	4648	97	0.12125
P12/0-4	4556	4652	96	0.12
P12/0-5	4554	4651	97	0.12125
P3/2-1	4357	4489	132	0.165
P3/2-2	4358	4469	111	0.13875
P3/2-3	4356	4505	149	0.18625
P3/2-4	4398	4512	114	0.1425
P3/2-5	4357	4478	121	0.15125
P6/3-1	4440	4538	98	0.1225
P6/3-2	4440	4535	95	0.11875
P6/3-3	4451	4546	95	0.11875
P6/3-4	4445	4549	104	0.13
P6/3-5	4447	4546	99	0.12375
P8/4-1	4526	4603	77	0.09625
P8/4-2	4526	4605	79	0.09875
P8/4-3	4527	4602	75	0.09375
P8/4-4	4530	4606	76	0.095
P8/4-5	4525	4602	77	0.09625

APPENDIX V

DATA SHEET ABRASION RESISTANCE (WIRE BRUSH) OF POZZOMIX - OPC STABILISED EARTH BRICKS					
Specimen code	Mass of brick before brushing M2(g)	Mass of brick after brushing M1(g)	M2-M1	Area of brushed surface (cm^2)	abrasion coefficient(cm^2/g)
S0-1	4020	3900	120	207	1.725
S0-2	4021	3910	111	207	1.864864865
S0-3	4022	3914	108	207	1.916666667
S0-4	4021	3921	100	207	2.07
S0-5	4022	3900	122	207	1.696721311
P 5/0-1	4121	4051	70	207	2.957142857
P5/0 -2	4125	4050	75	207	2.76
P5/0-3	4122	4048	74	207	2.797297297
P5/0-4	4125	4047	78	207	2.653846154
P5/0-5	4125	4050	75	207	2.76
P9/0-1	4294	4253	41	207	5.048780488
P9/0-2	4291	4256	35	207	5.914285714
P9/0-3	4287	4263	24	207	8.625
P9/0-4	4302	4259	43	207	4.813953488
P9/0-5	4245	4208	37	207	5.594594595
P12/0-1	4545	4525	20	207	10.35
P12/0-2	4551	4532	19	207	10.89473684
P12/0-3	4550	4529	21	207	9.857142857
P12/0-4	4553	4528	25	207	8.28
P12/0-5	4552	4531	21	207	9.857142857
P3/2-1	4383	4327	56	207	3.696428571
P3/2-2	4389	4335	54	207	3.833333333
P3/2-3	4386	4331	55	207	3.763636364
P3/2-4	4386	4331	55	207	3.763636364
P3/2-5	4387	4329	58	207	3.568965517
P6/3-1	4435	4409	26	207	7.961538462
P6/3-2	4436	4408	28	207	7.392857143
P6/3-3	4438	4412	26	207	7.961538462
P6/3-4	4438	4410	28	207	7.392857143
P6/3-5	4437	4411	26	207	7.961538462
P8/4-1	4527	4512	15	207	13.8
P8/4-2	4525	4508	17	207	12.17647059
P8/4-3	4523	4503	20	207	10.35
P8/4-4	4601	4583	18	207	11.5
P8/4-5	4525	4505	20	207	10.35

APPENDIX VI

GHANA HIGHWAY AUTHORITY FORM S3/1 DATE: 17/06/201
CENTRAL MATERIAL LABORATORY APPARENT DENSITY OPERATOR: OSEI
NYARKO

GRADED CRUSHED STONE
PYCNOMETER METHOD

SAMPLE NUMBER: 004				
PROJECT: Earth brick production				
Sample location: BERNATECH				
Sub-sample	**a**	**b**	**c**	**d**
Pycnometer number	10	10	10	10
Mass pycnometer+ lid (g)	818.0	818.0	818.0	818.0
Mass pycnometer + lid+dry crushed stone	1437	1438	1438	1437
Mass dry crushed stone	619.00	620	620	619
Mass pycnometer + lid+ stone + water	2222	2220	2225	2222
Mass pycnometer + lid+ water	1834	1834	1834	1834
Temperature of water	27^0c	27^0c	27^0c	27^0c
Density of water at test temperature	0.9965	0.9965	0.9965	0.9965
APPARENT DENSITY	2.674	2.640	2.698	2.674
Weight average APPARENT DENSITY.			2.672	

DRAFT GHA Standard test Method S3: Reference Density Graded Crushed Stone
REFERENCES. GHA- January 1996.

APPENDIX VII

Ghana highway authority Draft form s7-a Date: 4-3-16
Central Material Laboratory Washed Sieve Analysis Operator: Ateyire Michael

Air –Dried Soil

SAMPLE NUMBER				
SAMPLE LOCATION				
SAMPLE DESCRIPTION				
GRADING OF MINUS 19mm FRACTION		**AIR – DRY MOISTURE CONTENT**		
			Passing 19mm	Retained 19mm
Mass bowl NO. …01…….	1003	Container number	71	
Mass bowl +air-dry(moist) sub-sample	2718	Mass moist Agg+cont.	2599.0	
Mass air-dry (moist) sub-sumple	1715	Mass dry Agg.+cont.	2587	
Mass dry sub-sample	1701	Mass of container	1009.0	
Mass bowl+dry sample after washing	1995	Mass of water	12	
Mass dry sample after washing	992	Mass of dry Aggregate	1578	
Mass minus 0.075 washed away	709	Moisture content %	0.8	

SIEVE APERTURE mm	**MASS RETAINED g**	**% RETAINED %**	**% PASSING MINUS 19mm**	**% PASSING TOTAL SAMPLE**
19.0	-	-	100	100
9.5	-	-	100	100
4.75	1.5	0.09	99.91	100
2.00	10.5	0.62	99.29	99
1.00	25.5	1.50	97.79	98
0.425	116.0	6.82	90.97	91
0.300	108.0	6.35	84.62	85
0.150	224.0	13.17	71.45	71
0.075	418.5	24.60	46.85	47
PAN+	88.0	46.85		
Mass Washed Away	709			
Total -19mm	1701			

DRAFT GHA Standard test Method S3: Reference sieve analysis granular soil
SIEVGRA1. GHA- March 1996.

APPENDIX VIII

Ghana Highway Authority
Central Material Laboratory

Draft Form S5DATE: 5-3-16
Atterberg Limits of Soil Fines

Operator: Ateyire Michael

SAMPLE NUMBER: EARTH 002					
SAMPLE LOCATION: BERNATECH NAVRONGO					
SAMPLE DESCRIPION: EARTH (CLAY)					
Type of test	Casagrande Cup Liquid Limit			PLASTIC LIMIT	
Test Number	1(27-35)	2(23-27)	3(15-23)	1	2
No. Blows	28	27	23		
Container number	D9	D11	D12	39.4	122
Mass of wet soil+container	30	30	32.5	9.0	9.0
Mass of dry soil+container	27	26.5	28	8.5	8.5
Mass of container	16	16	16	5.5	5.5
Mass of water	3	3.5	4.5	0.5	0.5
Mass of dry soil	11	10.5	12	3	3
Moisture content	27.3	33.3	37.5	16.7	16.7
Casagrande Cup Liquide Limit:33					
Shrinkage mould No. 1	Shrinkage: 0.5mm 0.22%				
Average plastic limit: 16.7					
PLASTICITY INDEX: Casagrande: 16.3 (16)					

DRAFT GHA Standard test Method S5:
REFERENCES.GHA- Febuary1996.

APPENDIX IX

GHANA HIGHWAY AUTHORITY FORM S1/2DATE: 8-3-16
CENTRAL MATERIAL LABORATORY MOISTURE-DENSITY RELATIONSHIP
MINUS 19mm FRACTION

SAMPLE NUMBER: EARTH 003			
	Mass minus 19mm		
Parameter	**Specimen 1**	**Specimen 2**	**Specimen 3**
Container NO.	M1	M2	M5
Mass air-dry sample(g)	7000g	7000g	7000g
Mass water added(g)	140g	280g	420g
Percentage water added(%)	2%	4%	6%
Estimated air-dry MC(%)	0.8%	0.8%	0.8%
Est. compaction MC.(%)	2.8%	4.8%	6.8%
Mould number	15	15	15
Mould factor	0.4712	0.4712	0.4712
Mass of mould(g)	4208	4208	4208
Mass mould+wet soil(g)	8612	9148	8987
Mass wet soil (g)	4404	4940	4779
WET DENSITY. Kg/cu.m	2075	2328	2259
Approx. Dry Density	2018	2221	2108
MOISTURE CONTENT DETERMINATION			
Oven- pan number	5	10	27
Mass oven-pan (g)	170	166	169.0
Mass oven-pan+wet soil(g)	1378	1052	1163
Mass oven-pan+dry soil(g)	1267.5	957.5	1041.5
Mass of water(g)	110.5	94.5	121.5
Mass dry soil(g)	1097.5	791.5	872.5
MOISTURE CONTENT(%)	10.1	11.9	13.9
Dry density.kg/cu.m	1885	2080	1983