EVALUATION OF THE EFFECT OF PULVERISED BURNT BRICKS (PBB) ON STRENGTH CHARACTERISTICS OF LIME STABILISED COMPRESSED EARTH BRICKS

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A DISSERTATION SUBMITTED TO SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA IN PARITAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN CONSTRUCTION TECHNOLOGY

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Declaration

I declared that the work in this dissertation titled:Evaluation of the effect of Pulverised Burnt Bricks (PBB) on the strength characteristics of lime stabilised compressed earth bricks has been carried out by me in the Department of Building under the supervision of Prof. M.M. Garba and Dr. I. M. Khalil. The information derived from the literature have been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another Degree or Diploma in any university.

____________________ _____________________ ____________________

Name of student Signature Date

Certification

This dissertation titled ―Evaluation of the effect of Pulverised Burnt Bricks (PBB) on the strength characteristics of lime stabilised compressed earth bricks by Mu'azu Balarabe Babangida, meets the regulations governing the award of the degree of Master of Science (M.Sc. Construction Technology) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

Prof. M.M. Garba Date

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Dedication

This dissertation is dedicated to my father Alhaji Mu’azu Balarabe may Allah subhanahu wata’ala continue to protect and guide him.

Acknowledgement

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Abstract

The demand for sustainable construction material at low cost is growing as environmental issues evolve in today's society and has been the focus of many studies in many developing countries. Stabilised Compressed Earth Bricks Technology offers an alternative to the traditional Building practices that is relatively in-expensive, uses local resources and has been found to last long. The present rate of construction in developing countries as opined by Krishnaiah and Reddy, 2008 is generally sufficient to meet the need of only 10% of the net increase in population per year, due to the unavailability and soaring cost of conventional Building material. More efforts are being made to develop cheap, serviceable and energy efficient construction materials. Lime stabilization provides benefit to mortar and plaster, thereby enhancing workability and water retention and also react with CO_2 to generate calcium carbonate.

Earth as an ancient building material is constantly being improved and used in many different ways. It has been used locally to make bricks in many part of Nigeria without stabilization. Therefore, this research investigates the effects pulverized burnt brick on the strength characteristics of lime stabilised compressed earth bricks with a view to establishing the possibility of using PBB for improving the hydration of lime. The laterite used in this research was stabilized with lime and PBB by additive method. A total of 162 samples were produced and tested for compressive strength at 7, 14, 21, 28 and 56 days. And abrasion resistance, water absorption and sorptivity at 28 and 56 days respectively. From the chemical test, oxides of silicon, aluminium, iron and titanium had higher values of 39.357%, 28.357%, 17.045% and 12.402% respectively. It was observed from the results that samples containing 5% lime and 5% PBB stabilization had the highest average compressive strength of 1.35N/mm^{2}at 28 days and the lowest average compressive strength was obtained at 7 days for 5% lime and 15% PBB. A continuous increase in compressive strength of the bricks from 7 days to 28 days were observed. The highest compressive strength recorded for 0% was 1.10N/mm^2 at 28 days and the lowest compressive strength recorded was 0.82N/mm^2 at 7 days. Higher resistance to abrasion of 0.35% for 5% PBB at the age of 56 days and the lowest of 0.58% for 15% PBB at 28 days were recorded. The lowest absorption capacity of 1.88% at 56 days occurred for 5% PBB stabilization and the higher of 2.44% at 28days occurred 15% PBB stabilization. However, all un-stabilized samples partially dissolved in water. Sorptivity result shows that samples produced with 5% PBB stabilization were observed to have the higher resistance to capillary action of water at 28 and 56 days. It was observed that 15% PBB stabilization have the lowest resistance. The stabilization of laterite with Lime and PBB was found to be effective in enhancing strength and durability. Therefore, the use of Lime and Pulverized Burnt Bricks for stabilization of Lateritic Soil for the production of Compressed Earth Bricks is recommended in order to improve the quality of the bricks.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Research work

The term laterite is used to refer to the formation of soil, particularly clay and silt, by weathering of rocks especially in a tropical climate; it is mainly composed of iron and aluminium hydroxides. Laterite is also used to describe all the reddish residual and non-residual tropically weathered soils formed from decomposed rocks through clays used as a building material(Hashim & Deboucha, 2010).

Laterite being available has invariably been the main traditional construction material in providing housing systems. It offers a seriesof environmental benefits, including lower embodiedenergy levels; high thermal mass and maximizing the applicationof locally sourced materials (Walker, 2004).

Many researches have taken place in modern times to make earth a sustainable construction material. Thisdevelopment led to the technology of ramming earth and unfired bricks popularly known as compressed earth blocks/bricks. Among the main advantages of manufacturing compressed earthbricks are; it requires lesser energy than fired bricks, and the expelling of CO_2 into the atmosphere is about 80% less thanfor firedbricks (Oti, Kinuthia,& Bai, 2009; Heath, Walker, & Fourie, 2009).

Earth is among the many alternative building materials that can be used in place of residentialcorn stalk buildings. Various traditional construction materials exist in Nigeria which have proved to be suitable for a wide range of buildings and which have great potential for increased use in the future. One of such material is the compressed stabilized earth brick, an improved form of one of the oldest materials used in building construction (Adam &Agib, 2001).

A lot of binders are being used to stabilize earth for construction. Such binders are aimed at improving wear resistance and water proofing properties of earth based constructions. Such binders include casein, sodium silicate, lime, molasses, fats and oil, cements, bitumen's, tars, and some locally specific plant-based materials such as gum Arabic, Makuba and other specific resins and the sap, latexes and juices from specific trees (Corum, 2005).

Soil stabilization according to Krishnaiah and Reddy (2008) is the change or alteration of any of the properties of a soil to improve its engineering characteristics and performance. The factors that are affecting stabilization are the type of soil, binder(lime/cement) content, compaction and method of mixing with the soil type being very important.

Soil stabilization as opined by Adam and Agib (2001)means modifying soil properties by adding another material to improve its durability and strength. Soil stabilization has been used widely since 1920s mainly for road construction (Adam and Agib, 2001). When a soil is successfully stabilized one or more of the following benefits will be evident; strength and cohesion of the soil will increase, permeability of the soil will be reduced, the soil will be made water repellent, the durability of the soil will increase, and the soil will shrink and expand in dry and wet conditions (Adam and Agib, 2001).Therefore, Lime-soil chemical reaction has two stages. The first stage, which is known as immediate or short-term treatment, occurs within a few hours or days after lime is added. The second stage requires several months or years to complete and is thus considered the long-term treatment.

Lime basically, is derived from the process of burning limestone at a temperature higher than 900℃ and the lime obtained from the above decomposition, is generally calledquicklime. The quicklime subsequently slaked with water to produced hydrated lime (Herrier, Berger, & Bonelli,2012).

Pozzolanic materials as defined by the American Society of Testing Materials (ASTM) specification C618 – 01 (2005) are materials that have siliceous or siliceous-aluminous contents which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Natural pozzolanas are usually substances of volcanic origin or sedimentary rocks with suitable chemical and mineralogical composition (Lea, 2004). The natural pozzolanas have lost their popularity in view of the availability of more active artificial pozzolanas (Shetty, 2004). Artificial pozzolanas are either calcined clays or byproducts of various industrial and agricultural processes such as Pulverised burnt bricks whereby calcination has occurred. Others from steel and coal production are pulverized fly ash, electric arc furnace slag, blast furnace slag, silica fume etc. (Anwar, Yagawa and Gaweesh, 2000).

1.2Statement of the Research Problem

The demand for sustainable building materials at low cost is growing as environmental issues evolve in today’s society and has been the focus of many studies in many developing countries. Stabilizedcompressed earth brick (SCEB) technology offers an alternative to traditional building practices that is relatively inexpensive, uses of local resources, and in some cases, has been found to last long (Khalil, 2017). The most widely known means of stabilization is the application of chemicals such as lime and Portland cement.

The present rate of construction in developing countries as opined by Krishnaiah and Reddy (2008) is generally sufficient to meet the need of only 10% of the net increase in population per year. This is partly due to the unavailability and the soaring costs of conventional building materials. As this shortage of housing is becoming worse, more efforts are being made to develop cheap, serviceable and energy efficient constructionmaterials for the construction of affordable and sustainable buildings. Materials such as burnt bricks, stabilized earth bricks and un-stabilized ones are some of the cheaper materials being used and researched upon for improvements.

According to Graymont (2017) lime provides benefits to mortar and plaster in both the plastic and hardened state. In the plastic state, lime can enhance workability and water retention. In the hardened state, lime products react with carbon dioxide to regenerate calcium carbonate or limestone. This is a slow, gradual process that increases the hardness of the finished surface and allows for the closing of hairline cracks by a process called autogenous healing.

Since initial strength is needed in most applications, additives such as gypsum, cement or pozzollans are mixed with lime in construction applications. Lime can react with pozzolanic materials in the mortar or plaster to produce a cement-like product. The strength of lime-based mixes can be modified according to the needs of aparticular application. This is beneficial in restoration applications where low strengths and high vapor permeability are needed (Graymont, 2017).According to the research done by Ayodeji (2015), the highest value recorded at 3% stabilization indicates that lime alone cannot be used to stabilize soil for brick production. Lime should be used together with one or more stabilizers to improve the strength properties of the bricks.

Thus, due to the fact that limehas slow rate of drying and hydration, this has necessitated the investigation on the scientific method of combining the lime and a pozzolana in thestabilization process. Therefore, this work investigated the suitability of using Lime and PBB for the production of Compressed Earth Bricks (CEBs) with a view to establishing the possibility of using PBB for improving the hydration of lime.

1.3 Justification of the Research

Due to the high cost of conventional building materials there is need to produce durable low-cost building components, using locally available raw materials. In viewof the availability of lime and PBB in most parts of this country, the possibility of using PBB to improve lime stabilization for bricks production is of great importance and can serve as an alternative to expensive chemical stabilization.

Lime can react with pozzolanic materials in the mortar or plaster to produce a cement-like product. The strength of lime-based mixes can be modified according to the needs of a particular application.The pozzolana chemically reacts with lime and form a cementitious material which makes the mortar denser and thus improves its strength. The reaction between the pozzolana and lime is affected by the type of pozzolana, the temperature and the lime type (Umar, 2014).

1.4 Aim and Objectives of the Research

1.4.1 Aim

The aim of this research is to evaluate the effect of Pulverised Burnt Bricks (PBB) on strength characteristics of Lime Stabilised Compressed Earth Brickswith a view to establishing the possibility of using PBB for improving the hydration of lime.

1.4.2 Objectives

The aim of the study will be achieved through the following objectives:

i. Determine the oxide compositions of lime, laterite and PBB.

ii. Identify the proportions of lime and PBB for the stabilization of Compressed Earth Bricks (CEBs).
iii. Determine the fresh properties of laterite mix made with lime and PBB for the Compressed Earth Bricks (CEBs).
iv. Assess the effects of lime and PBB on the strength of Compressed Earth Bricks (CEBs).
v. Examine durability properties of bricks at different proportions of PBB in lime.

1.5Scope and Limitations

1.5.1 Scope

This study focused mainly on the evaluation of the effect of Pulverised Burnt Bricks (PBB) on strength characteristics of Lime Stabilised Compressed Earth Bricks (LSCEBs). The soil type (laterite) was sourced locally from Kofar Kona, Zaria City.Physical properties of the lateritewere examined before use. Pulverized burnt bricks from bricks sellers at PZ, Zaria was used. High quality hydrated lime from Kaduna State Water Board, Zaria was used.

Tests on specimens was confined to water absorption test, compressive strength test, Sorptivity test and abrasion resistance test.

1.5.2 Limitations

The result of the research work may be applicable to the samples with laterite soils obtained from Kofar-Kona or any laterite soils with the same characteristics, since most laterite soils are known to be variable.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1Building Materials

Soil is variably a highly material which continuously formed over a long period of time. It is being used over the years for different purposes by different professionals. According to Tawfiq (2004) soil engineers see soil as a material which is used in any kind of Civil Engineering job, either as a foundation material to support the lord exerted by structures, or as a construction material itself, as in the cases of highway construction and earth fill dams.

Soil is formed when rocks undergo a process named “weathering” that is the disintegration and decomposition of rocks and minerals at or near the earth surface through the actions of natural and or mechanical and chemical agents into smaller grains. The weathering factors may be atmospheric, such as changes in temperature and pressure; erosion and transportation by wind, water and glaciers; chemical action as crystal growth, oxidation, hydration, carbonation and leaching by water, especially rainwater, with time. The intensity of weathering depends upon the presence of water and temperature and the dissolved materials in water (Fetra, Rahman & Zaidi, 2011).

Fetra*et al.*(2011) also opine that soils formed by mechanical weathering (that is, disintegration of rocksby the action of wind, water and glaciers) bear a similarity in certain properties to the minerals in parent rock, since chemical changes which could destroy their identity do not take place. In chemical weathering, some minerals disappear partially or fully, and new compounds are formed. Carbonic acid and oxygen are the most effective dissolved materials found in water which causes weathering of rocks.

Rutherglen (2003) observes that soils initially come from rocks; this is termed the ‘parent material’ which may be directly below the soil, or great distances away if wind, water or glaciers have transported the soil. In addition to the soil parent material, soil formation depends on other prevailing processes such as climatic conditions which affect both the form and rate of physical and chemical weathering of the parent material.

Soil types vary, depending on the parent material from which they originate and from the surrounding environment. Rutherglen (2003) further explains that the way in which soil forms depends on:

i. Parent Material
ii. Climate
iii. Topography
iv. Time
v. Living Organisms

He also explains that the formation of soils can be seen as a combination of the products of weathering, structural development of the soil, differentiation of that structure into horizons or layers, and lastly its movement or translocation. Soil is made up of mineral particles such as clay, silt and gravel. It also consists of organic matter which includes decaying plants and animals. Air, water and living organisms such as bacteria, fungi and earthworms are also basic components of soil.

Earth, is undoubtedly the oldest known building material. Even though the use of earth in building once fell out of popularity when a modernize methods and materials for building were discovered. Modernize earth buildings are still alive and well spread over an enormousgeographical area using numerous different construction methods. In Mesopotamia, some earth brick constructions are as far back as 10,000 BC (Smith, 2004 and Smith, 2017).

According to Marwan and Nasim(2016), recent interest in making use of natural materials is due to the increasing demand for housing caused by rapid population growth and the need to reduce the consumption of energy in the building industry. Earth been a construction material offers a high resistance to fire if well treated, and provides comfortable living environment due to its high thermal and heat insulation values.

2.2Types of Soil

There are different types of soil as some are essentially good for engineering works while others can only be used for agricultural purposes. Soil classification and description may be based on particle size, constituent material, colour, shape texture etc.BS 1377: Part 2, (1990) classify soils based on their particle size distribution range as shown Table 2.1. In this system, each of the terms gravel, sand, silt and clay refers to a range of particles or grain sizes in a soil.

Table 2.1: Soil Classification According to Particle Size Distribution

Name	Subdivision	Diameters of Particles (mm)
Gravel	Coarse	20 - 60
	Medium	6.0 - 20
	Fine	2.0 - 6.0
Sand	Coarse	0.6 - 2.0
	Medium	0.2 - 0.6
	Fine	0.06 - 0.2
Silt	Coarse	0.02 - 0.06
	Medium	0.006 - 0.02
	Fine	0.002 – 0.006
Clay		<0.002

Source: BS 1377 Part 3, (2018)

2.2.1 Organic Soils

These are the organic components of soil consisting of small plant residues, small living soil organisms, decomposing organic matter, and stable organic matter (humus). Organic soils have a dark brown to black colour. Their ability to improve water retaining properties of the soil and make it more workable and recommendable for most agricultural use. Soil structure is highly dependent on organic matter content, particularly in loamy and sandy textured soils. Organic soils are weak for construction purposes and since the organic matter tends to concentrate on the upper part of the soil, it is important to remove the topsoil before any construction work commences.

According to Robert (2010), classification system for organic soils is presented as follows:

I. Organic Soils: These soils composed of 5 to 30% organic material. These soils are typically classified as soils of high plasticity or low plasticity.

II. Slightly Organic Soils: These soils typically have less than 5% organic matter. Is used to indicate the presence of organic matter.

III. Organic matter: These materials consist almost entirely of organic material. Which include fibrous peat and fine grained peat.

IV. Highly Organic Soils: These soils composed of 30 to 75% organic matter mixed with mineral soil particles. Which includes silty peat and sandy peat.

2.2.2 Clay Soil

As observed by Soni (2013), clay soils are fine textured soils composed of microscopic and sub-microscopic particles with size less than 0.002mm derived from the chemical composition and disintegration of rock constituents. They are plastic in nature within a moderate to wide range of water content and are also known as expansive soils since they contain swelling clay minerals which are hazardous to the foundations of light buildings. Swelling clays can control the behavior of virtually any type of soil if they are present in a high percentage.

Clay soils are characterized by poor drainage. This is attributed to the presence of lots of small pores in which they can store water. Clay soils have poor drainage i.e. good water holding capacity, the soil tends to stay wet and soggy after rain or irrigation. Clay soils also have poor aeration because the particles are small and closely packed, it is very difficult for air to enter or leave the soil. Clay soils are also naturally alkaline, become hardened when fired or baked and have very poor bearing capacity and hence the buildings constructed on such soils are liable to settlement.

2.2.3 Sandy Soil

Soni (2013) points that sandy soils are coarse cohesion less aggregates of either rounded, sub rounded, angular or flat fragments of more or less unaltered rock or minerals consisting of 90% of the particles of size greater than 0.06mm and less than

2mm. Sandy soils are easy to work on but have a poor water holding capacity. They are often known as thirsty soils. These soils do not exhibit the swelling and shrinkage properties on moistening and drying respectively. They are very permeable but do not allow water to rise up through the capillary action. They provide good foundation footing for buildings. Soni (2013) subdivides sandy soils into:

i. Coarse sand: contains 90% particles of size greater than 0.6mm and less than 2mm.
ii. Medium sand: Contains 90% particles of size greater than 0.2mm and less than 0.6mm.
iii. Fine sand: Contains 90% particles of size greater than 0.06mm and less than 0.2mm.

2.2.4 Laterite Soil

Laterite have been described by many authors based on their different characteristics such as mineral constituents, colour, and size of particles and mode of geological formation. Kumutha and Vijai (2013) define laterite as highly weathered material rich in secondary oxides of iron, aluminium or both. Adam and Agip (2003) define laterite as a highly weathered material which contains large but, extremely variable proportion of iron and aluminium oxides, as well as quartz and other minerals. However, Rhardjo, Aung, Leong and Rezam (2004) describe laterite as a product of in-situ weathering in igneous, sedimentary and metamorphic rocks commonly found under unsaturated conditions. He noted that this weathering process primarily involves the continuous chemical alteration of minerals, the release of iron and aluminium oxides, and the removal of bases and silica in the rocks. Ajao, Lawal, Onaolapo and Eniayekan (2012) opines that lateritic soil samples composed of kaolinite and illite clay minerals with some quartz and feldspar.

Kumutha and Vijai (2013) reports that the recognition of laterite as an earth material, with unique properties, dates back to 1807 when Buchanan first encountered a material in India which he called laterite from the Latin word “later” meaning brick. He defined the material as “soft enough to be readily cut into blocks by an iron instrument, but which upon exposure to air quickly becomes as hard as brick, and is reasonably resistant to the action of air and water”. Laterite is either hard or capable of hardening on exposure to wetting and drying. Hardness is an outstanding property of laterite.

Laterite as an ancient material has been used extensively for all wall construction around the world, particularly in developing countries. Approximately 30% of world’s present population still lives in laterite structures Kumutha and Vijai(2013). It is a cheap, environmentally friendly and abundantly available building material in the tropical region. Laterite has other advantages which makes it potentially a very good and appropriate material for construction, especially for the construction of rural structure in the less developed countries.

Kumutha and Vijai(2013) reports that laterite are found in abundance in the tropics and sub tropics, where they generally occur just below the surface of grass lands or forest clearing in regions with rainfall or at lower levels and in valleys. However, Adam and Agip (2003) observed that laterite soil is one of the most important and common materials used in earth work engineering construction especially in the tropics and subtropics where it is in abundance. The colour of laterite soil can vary from red, brown, and violet to black depending on the concentration of iron oxides.

2.3Properties of Lateritic Soil

2.3.1 Particle Size

According to Williamson (2012), “A well graded soil will give a good result in most applications”. The different ranges of particle size within a soil have specific names. The largest particles are called gravel. Sand is the next particle group. Silt is the next group to sand and clay is the smallest particle, however, the unified soil classification system combines clays and silts in a group called fines. The gradation of a soil can be determined by shaking a soil sample through a stack of standard sized sieves. This process is known as gradation analysis. The results of this analysis are displayed using a particle size distribution curve. This curve is constructed by plotting the size of the sieve openings against the percentage of soil mass that passed through that sieve opening. The result of the analysis can be used to determine if a soil is poorly graded, well graded or gap graded.

2.3.2 Specific Gravity

The specific gravity of soil according to Jackson and Dhir (1998) is being defined as the ratio of the mass of solid particles to the mass of the same volume of water. Lateritic soils generally have very high specific gravities of between 2.6 to 3.4. The specific gravity of lateritic soil varies not only with the textures of soils group but also with different fractions. For the same soil, gravel fractions were found to have higher specific gravities than fine fractions due to concentration of iron oxide in gravel fraction, while alumina is concentrated in the silt and clay fraction.

2.3.3 Liquid Limit

Liquid limit is the minimum water content in which a soil begins to flow under a specific small disturbing force. The liquid limits of lateritic soil have been found not to be greater than 60%, while the plasticity index is equal or less than 30%. Therefore, laterite is of flow to medium plasticity.

2.3.4 Density

Ikiensinma (2005) states that maximum dry densities of lateritic soils were found to range between 1842kg/m^{3}to 2322kg/m^3. Higher densities are usually obtained after compaction. Cementing agents in lateritic soil help to bind the finer particles together to form larger aggregates. However, as a result of leaching, these aggregates break down which results to increase in liquid limit. He reported that the removal of cementitious materials give rise to an increase in compressibility by more than 50%. This is mainly due to the destruction of aggregate structure, conversely there is a decrease in the coefficient of consolidation by 20% after leaching.

2.4 Soil Classification System

There are two commonly used classification systems based on particle size distribution and Atterberg limits. They include:

1. American Association of State Highway and Transportation Officials (AASHTO) System.

Originally developed by Hegentogler and Terzaghiin (1929) as the Public Roads Classification System. Although several revisions have been done afterwards. The American Association of State Highway and Transportation Officials (AASHTO) System includes more details on the material properties of the soil such as colour, in situ moisture content, in situ strength etc. this form of classification provides more basic information of the soil than the Unified Soil Classification System (USCS) as in Table 2.1.

2. Unified Soil Classification System (USCS)

This system was originally developed by Casagrande (1948) for the United States Army Corps of Engineers (USACE). It was for the purpose of airfield construction during World War II. Afterwards, it was modified by Professor Casagrande, the U.S. Bureau of Reclamation, and the U.S. Army Corps of Engineers to enable the system to be applicable to Dams, foundations and other construction. Unified Soil Classification System is the most widely used soil classification system among geotechnical engineers.

Four major divisions of soils based on this system include:

(1) Coarse-grained
(2) Organic soils
(3) Fined-grained
(4) Peat

2.5Soil Stabilization

Soil stabilization according to Krishnaiah and Reddy (2008) is the change or alteration of any of the properties of a soil to improve its engineering characteristics and performance. The factors that are affecting stabilization are the type of soil, binder (lime/cement) content, compaction and method of mixing with the soil type being very important.

Soil stabilization according to Adam and Agip (2001) is a process of modifying soil properties by adding another material to improve its strength and durability. The materials that are added are called stabilizers. Soil stabilization involves the alteration of any property of a soil to improve its engineering performance. The modification of the properties of soil-water-air system makes the soil compatible with desired applications in construction.

Adam and Agip (2001) also observe that the concept of soil stabilization is not new since natural stabilizers such as natural oil and plant extracts, animal dung and crushed ant-hill material have been used for many centuries. They noted however that in recent times, more rigorous scientific rather than adhoc methods of soil stabilization have being developed.

Such methods are applied by using Portland cement, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, polymers developed mainly from early techniques for stabilization of earth roads. A broaderclassification of soil stabilization techniques includes the following:

2.5.1 Chemical Stabilization

Chemical Grouting Technique: The National Lime Association {NLA} (2001), has asserted that soil stabilization in chemical grouting occurs when the additive combines with reactive soil elements to generate a long term strength gain through pozzolanic reaction such as that obtained by using lime.

Chemical stabilization consists of adding other materials to the soil or chemicals that alter its properties, either by a physio-chemical reaction between particles and the added materials or by creating a matrix that binds or coats the particles Lemougna, Melo, Kamseu and Tehamba(2011). The binder modifies the soil properties through cementation or linkage of its particles. Both cementation and linkage are as a result of chemical reactions involving the binder and water. They also noted that the physio-chemical reaction can cause the formation of a new material made from a pozzolanic reaction between clay and limestone. However, chemical stabilization involves the use of a wide range of additives in order to achieve a desired result. The most frequently used chemical stabilizers are cement, lime, pozzolanas, gypsum and bitumen.

2.5.1.1 Cement Stabilization

Portland cement is the widely stabilizer used for earth stabilization. Cement has the ability to increase plasticity index and reduce liquid and hence increases the soil workability. The addition of chemical stabilizer's such as lime and cement has effects of speed of flocculation and also the promotion of chemical binding. The chemical binding depends on the stabilizer's type employed (Janz & Johansson, 2002).

Lemougna*et al.*(2011) also pointed out that the main reaction in a soil-cement mixture comes from the hydration of the two anhydrous calcium silicate ($3CaO.SiO_2$(C_3S) and $2CaO.SiO_2$ (C_2S), the major constituent of cement, which form two new compounds: calcium hydroxide (hydrated lime called portlandite) and calcium silicate hydrate (CSH), the main binder of concrete.

The chemical reaction between cement and water is as indicated in equation (2.1).

Cement + $H_2O \rightarrow CSH + Ca(OH)_2$ …………………………………..(2.1)

It was observed that unlike lime, the mineralogy and granulometry of cement treated soils have little influence on the reaction since the cement powder contains in itself everything it needs to react and form cementitious products. Cement will create physical links between particles, increasing the soil strength. Lime needs silica and alumina from clay particles to develop pozzolanic reactions. Generally, the hydration reactions of cements are faster than those of lime, but in both cases, the final strength results from the formation of CSH.

2.5.1.2 Lime Stabilization

According to Arora (2005), lime is produced by burning limestone in kilns. He said the quality of lime obtained depends upon the parent material and the productionprocess.

Basically there are four (4) types of lime according to Arora (2005). These are:

i) Dolomite lime (CaO + MgO)
ii) High Calcium, quick lime (CaO)
iii) Normal, hydrated dolomite lime [$Ca(OH)_2$+ MgO_2].
iv) Hydrated, high Calcium lime [$Ca(OH)_2$]

Various forms of lime have been successfully used as soil stabilizing agents for many years and the most commonly used products are hydrated high-calcium lime, mono hydrated dolomite lime, calcitic quick lime and dolomite quick lime. Hydrated lime is used most often because it is much less caustic than quick lime.

Arora (2005) established the fact that quick lime is more effective as stabilizer than the hydrated lime; but the latter is more safe and convenient to handle. Lime stabilization refers to stabilization of the soils by the addition of burned lime stone products, either calcium oxide or calcium hydroxide.

Lime stabilization occurs when lime is added to reactive soil to generate long-term strength gain through a pozzolanic reaction, this reaction produces stable calcium silicate hydrates and calcium aluminate hydrates as the calcium from the lime reacts with the aluminates and silicates solubilized from the clay (NLA, 2001).When lime reacts with soil, there is exchange of cations in the adsorbed water layer and a decrease in plasticity of the soil occurs, the resulting material is more friable than the original clay, and is therefore, more suitable as sub-grade.

The effect of lime stabilization on soil have been investigated by numerous researchers, because the properties of soil lime mixtures depends upon character of soil, type and period of curing, the method and quality of construction and the proper amount of lime to be used should be investigated before the application of lime stabilization (Gokceoglu, Tonoz & Ulusay, 2004).

Chemical reactions and treatment mechanism: Water absorption is the first activity that occurs when lime (particularly quick lime) is added to soil.

Lime-soil chemical reaction has two stages. The first stage, which is known as immediate or short-term treatment, occurs within a few hours or days after lime is added. Three main chemical reactions, namely, cation exchange, flocculation-agglomeration and carbonation occur at this stage. The second stage requires several months or years to complete and is thus considered the long-term treatment. Pozzolanic reaction is the main reaction at this stage. The drying of wet soil and the increase in soil workability is attributed to the immediate treatment, whereas the increase in soil strength and durability is associated with the long-term treatment (Mallela, Harold, Smith & Consultants, 2004; Kassim, Hamir & Kok, 2005; Geiman, 2005).

The addition of lime to the soil water system produces (Ca^{+2}) and (OH^{-}). In cation exchange, bivalent calcium ions (Ca^{+2}) are replaced by monovalent cations. The Ca^{+2} ions link the soil minerals (having negative charge) together, thereby reducing the repulsion forces and the thickness of the diffused water layer. This layer encapsulates the soil particles, strengthening the bond between the soil particles. The remaining anions (OH^-) in the solution are responsible for the increased alkalinity (Mallela *et al.*, 2004; Geiman, 2005). After the reduction in water layer thickness, the soil particles become closer to each other, causing the soil texture to change. This phenomenon is called flocculation-agglomeration (Geiman, 2005). The silica and alumina that exist in the soil minerals become soluble and free from the soil when pH exceeds 12.4. The reaction between the released soluble silica and alumina and the calcium ions from lime hydration creates cementitious materials such as Calcium Silicate Hydrates (C-S-H) and Calcium Aluminate Hydrates (C-A-H) (Eisazadeh, Kassim and Nur, 2012). These pozzolanic reactions can be clarified as indicated in equations (2.2) and (2.3) (Mallela*et al.*, 2004; Yong & Ouhadi, 2007; Chen & Lin, 2009):

$Ca(OH)_2 + SiO_2 \rightarrow CaO + SiO_2 + H_2O$……………….. (2.2)

$Ca(OH)_2 + Al_2O_3 \rightarrow CaO + Al_2O_3 + H_2O$…………….. (2.3)

Deleterious chemical reactions: Two undesirable (deleterious) chemical reactions probably occur in the lime-treated soil. The first is lime carbonation and the second is the reaction with the sulfate salt existing in the soil. Carbonation is the reaction that occurs between free lime and atmospheric carbon dioxide, as shown in equation (2.4) (Umesha, Dinesh and Sivapullaiah, 2009):

$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$…………………. (2.4)

Gokceoglu *et al.* (2004) investigated the performance of quick lime in powder form on laboratory-scaled models to improve physical, swelling and strength characteristics of the soil. The lime-soil mixture design techniques were employed in the laboratory, and five different types of lime-soil mixture between 2% and 10% by weight were prepared.Engineering properties of the soil determined from natural and lime-treated samples cured for 3, 7, 14 and 28 days were compared.As result of reactions, uniaxial compressive strength increased with about 84% after 28days. However, the result indicated that if curing period is less than 28days, the uniaxial compressive strength values of the lime-treated samples are higher than those of natural samples, achieved at 4% optimum stabilization of lime content and 28days curing time.

When introducing lime into soil for stabilization, Ca^{2+} is partly adsorbed on the surfaces of clay particles in replacement of monovalent cations such as $Na^{+}$and K^{+}. The amount of Ca^{2+} adsorbed depends on the cation exchange capacity of the treated soil. The higher the exchange capacity, the higher the amount of Ca^{2+} absorbed by the soil. All the adsorbed cations are no longer available for pozzolanic reactions. The amount of lime required to satisfy the affinity of soil for lime is called lime fixation point. The lime in excess of lime fixation point is involved in the process of cementing. The reaction between lime, silica and alumina-free contributing to the formation of new mineral such as calcium silicate hydrates, calcium aluminate hydrates and alumino-calcium silicate hydrates, are primarily responsible for the consolidation. These reactions are more or less slow and depend on various factors such as mineralogy, grain sizes of the treated soil, as well as curing time and temperature (Lemougna *et al.,*2011).

2.5.1.3 Bitumen Stabilization

Bitumen stabilization has been described by Ransom (2011) as a chemical method of soil stabilization. There are two ways of stabilization with bitumen as outlined by Adam and Agip (2001). The first way is through a binding process that increases strength particularly in granular soils. Generally, small amount of bitumen 2-6% give the soil cohesion. When these percentages are exceeded, the bitumen tends to act as a lubricant separating the particles and thus reducing the strength. The second way is when the bitumen acts as a water repellent. The two mechanisms usually occur together in any soil but to different degrees, depending on the type of soil. Soils suitable for bituminous stabilization are sandy soils.

2.5.1.4 Gypsum Stabilization

Is a white material consisting of hydrated calcium sulphate used in the early civilization for plaster. It is a traditional material in the Mediterranean and Middle East countries. Ransom (2011) reports that the advantage of gypsum over Portland cement and lime is that it requires a low calcination temperature. Its agricultural and chemical uses is in the production of Portland cement where it retards the setting of the cement and also a good stabilizer for sandy soil.

2.5.1.5 Pozzolana Stabilization

Pozzolanic materials as defined by the American Society of Testing Materials (ASTM) specification C618 –1 (2005) are materials that have siliceous or siliceous-aluminous contents which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. Natural pozzolanas are usually substances of volcanic origin or sedimentary rocks with suitable chemical and mineralogical composition (Lea, 2004). The natural pozzolanas have lost their popularity in view of the availability of more active artificial pozzolanas (Shetty, 2004). Artificial pozzolanas are either calcined clays or byproducts of various industrial and agricultural processes whereby calcination has occurred (Umar, 2014). Others from steel and coal production are pulverized fly ash, electric arc furnace slag, blast furnace slag, silica fume, and others (Anwar, Yagawa & Gaweesh, 2000).

Adam and Agip (2001) defines pozzolanas as fine silica and alumina rich materials which when mixed with hydrated lime produce cementitious materials suitable for stabilization and construction. It is also a porous volcanic ash that hardens when mixed with cement either in air or under water. In their natural state, pozzolanas are found as volcanic ash or pumice. They can also be manufactured from finely ground recycled fired clay bricks and mudstone. They have been used extensively for plaster with excellent results.

Industrial pozzolanas shall not increase the water demand of the cement/lime appreciably, impair the resistance of the mortar or mix to deterioration in any way or reduce the corrosion protection of the reinforcement. These include a wide range of materials from heat-treated clays and shales to ashes derived from burning rice husks as well as slags from various non-ferrous metal-processing industries. In common with natural pozzolanas, it is desirable that they should contain reactive silica and some glass (Lea, 2004).

After the development of natural cement during the latter part of the 18th century, the practice of using pozzolanas declined, but in more recent times, Pozzolanas have been extensively used in Europe, USA and Japan, as an ingredient of Portland cement concrete particularly for marine and hydraulic structures. It has been amply demonstrated that the best pozzolanas in optimum proportions mixed with Portland cement improves many qualities of concrete such as:

i. Lower the heat of hydration and thermal shrinkage;

ii. Increase the water tightness;

iii. Reduce the alkali-aggregate reaction;

iv. Improve resistance to attack by sulphate soils and sea water;

v. Improve extensibility;

vi. Lower susceptibility to dissolution and leaching;

vii. Improve workability;

viii. Lower costs.

In addition to these advantages, contrary to the general opinion, good pozzolanas will not unduly increase water requirement or drying shrinkage (Shetty, 2004).

The chemistry of PBB involves the chemical reaction of the amorphous silica in the powder with lime to form calcium silicate hydrates, which is the very compounds in cement that are primarily responsible for the strength. Equation (2.5), (2.6), (2.7), and (2.8) indicates the reactions that take place when PBB is added as a blend.

$Si + O_2 \rightarrow SiO_2$………………………………………………. (2.5)

$CaO + H_2O \rightarrow Ca(OH)_2$……………………………………… (2.6)

When silicon burned in the presence of oxygen silica will form.

C_3S (Cement) $\rightarrow$ CSH (gel) + $Ca(OH)_2$ ………………………...(2.7)

Hydration of cement will form C-S-H gel and calcium hydroxide.

$SiO_2 + Ca(OH)_2 \rightarrow CSH + SiO_2$ ………………………………..(2.8)

The highly reactive silica reacts with $Ca(OH)_2$ and leads to the formation of C-S-H.

The term 'pozzolanic activity' covers all reactions occurring among the active constituents of pozzolanas, lime and water. The definition, although approximate, is however acceptable from a technical and practical viewpoint. Notwithstanding the difficulty in following the evolution of pozzolanas active phases throughout the hydration process, the progress of pozzolanic reaction is commonly evaluated in terms of diminution of the free lime in the system or increase in the silica + alumina soluble in acid (Lea, 2004).

Pozzolana has two distinct meanings. The first one indicates the pyroclastic rocks, essentially glassy and sometimes zeolitised, which occur either in the neighborhood of Pozzuoli (the ancient Puteoli of the Roman times) or around Rome. The second meaning includes all those inorganic materials, either natural or artificial, which harden in water when mixed with calcium hydroxide (lime) or with materials that can release calcium hydroxide (Portland cement clinker). The term 'pozzolana' will be referring to the latter meaning, definitely wider than the former, and will therefore embrace a large number of very different materials in terms of origin, composition and structure. Pozzolanic cements are by definition mixes of Portland cement and pozzolana which, if dispersed in excess water and kept under certain conditions, eventually give rise to unsaturated calcium hydroxide solutions (Lea, 2004).

2.5.2 Mechanical Stabilization

Mechanical stabilization consists of compacting and compressing the soil particles to increase its resistance and density and also reduce permeability and porosity. Lemougna*et al.* (2011) pointed that the soil is mechanically treated so that maximum air can be eliminated and this contributes to an increase in its density. Compression leads to the redistribution and rearrangement of soil particles thereby eliminating air from the soil voids. Compaction is best achieved when the grain size distribution of a soil is continuous. Mechanical stabilization is widely used in road construction and requires a prior analysis of the soil to determine the optimum water content for better soil compressibility.

2.5.3 Physical Stabilization

According to the opinion of Lemougna*et al.* (2011), physical stabilization consists of modifying the properties of soil by intervening with its texture (granulometry treatment or electric treatments that leads to the drainage of the soil and thus confer new structural properties to it). Physical stabilization may also involve the introduction of synthetic fibers or fibers originating from plants, animals and minerals into the soil. If the particle size distribution of the soil must remain intact, then physical stabilization must be used in preference to other stabilization techniques. Another reason may be if the material is sensitive to movements induced by factors such as water action, thermal expansion etc. These movements can then be countered by a frame made of fibers.

2.6Compressed Earth Blocks/Bricks

Compressed earth block/brick is the modern descendent of the moulded earth block which became widely used around the world. Compressed earth machines were first used to compress earth as early as the 18th century. Architectural purposes came into effect only in 1952 in France by Engineer Raul Ramirez of the CINVA center Columbia, who designed the CINVA-Ram press machine. This was used all over the world especially in developed countries (Heathcote, 2002 and Morel, Pkla & Walker 2007).

Compressed Earth Block (CEB) is one name given to earthen bricks compressed with hand-operated or motorized hydraulic machines. There are hundreds of types of machines. Some of these are designed with simple levers which are easily manufactured in local machine shops. Other presses contain a variety of compression mechanisms such as cams, hand-operated hydraulic assists, toggles and motorized hydraulics. As these presses are more complex and expensive, they have had less frequent use. In many areas of the world, proper materials are available for making CEB, and thus this type of block may be a better choice than any other building material. The choice to use CEB is dependent on several factors, including culture, labour force, and most importantly, the preference of the home owner (Khalil, 2017).

Hand-operated presses have been used for many decades. Before and still today, some people make blocks by beating soil into a wooden mould with a stick. "Rammed earth" is a similar process, in which case a structure is made as one continuous mass of compressed earth (Khalil, 2017).

Modern equipment, with hydraulics driven by diesel, gas or electric motors, may be useful in urban areas or for large multi-house sites. However, using motor-driven equipment for smaller and more rural projects is hard to grasp until you have lived in a remote village situation. People in these situations are often the ones that need the most help with improving their housing, and compressed earth block can be one of the solutions to their building needs. However, one must be aware that significant problems with maintenance, expense of fuel and spare parts, as well as the tools and expertise needed to repair and maintain the presses, have been experienced by many local builders who have tried to use these machines without understanding their proper place in the local economy (Khalil, 2017).

2.6.1 Innovations in Compressed Earth Brick

Over time, innovation in CEB manufacture has included changing the original shape from a solid rectangle to one incorporating holes or grooves in the blocks to allow for the use of steel or bamboo to resist earthquakes. Another innovation was to create interlocking shapes that don't need to be laid in a bed of mortar, and U-shapes or tapered bricks for use in reinforced lintels or arches. Sometimes the press has been used to make bricks which were then fired in a kiln, although once fired they are no longer referred to as CEBs (Khalil, 2017).

The interlocking shapes of these improved bricks can help to reduce the skill level needed for homeowners to build their own homes. In addition, several layers of blocks can be placed in the wall at a time. A supervisor can then check that the wall is straight and plumb before permitting for mortar to be poured inside the hollow blocks to lock them together, thus eliminating the small openings between blocks which would otherwise allow for air infiltration (Khalil, 2017).

2.6.2Advantages of using Compressed Earth Bricks

Advantages of CEB include: uniform building component sizes, use of locally-available materials and reduction of transportation. Uniformly sized building components can result in less waste, faster construction and the possibility of using other pre-made components or modular manufactured building elements. Such modular elements as sheet metal roofing can be easily integrated into a CEB structure. The use of natural, locally-available materials makes good housing available to more people, and keeps money in the local economy rather than spending it to import materials, fuel and replacement parts. The earth used is generally subsoil, leaving topsoil for agriculture. Building with local materials can employ local people, and is more sustainable in times of civil unrest or economic difficulties. People can often continue to build good shelters for themselves regardless of the political situation of the country (Khalil, 2017).

2.6.3 Disadvantages of Compressed Earth Bricks

The CEB does fall short of perfection in a couple respects. The press and other needed equipment (i.e. rototiller and tractor) are not made from locally harvested materials. However, almost all building methods requires the use of some heavy machinery, and to its advantage, the press is designed to be locally manufactured. Also, The Liberator is not designed to make roofing shingles (although these can be made from compressed earth). So, the ecological qualities of the roof cannot be addressed. Soil composition may not be appropriate on some sites as well which would mean appropriate soil would need to be transported from elsewhere (Khalil, 2017).

2.7 Sorptivity

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material (Ganesan, Rajagopal and Thangavel, 2008). It is also a measure of the capacity of the medium to absorb or desorb liquid by capillarity. It expresses the tendency of a material to absorb and transmit water and other liquids by capillarity.

2.7.1 Sorptivity Apparatus and Test Method

The apparatus used include the electric oven for drying of the and a desiccator for cooling after heating. Rods were used to create a gap between the unsealed surface of the specimen and the tray in order to allow free access water contact to the surface. An electric balance was however, used for taking the masses of the specimens at removing from water(Ganesan, Rajagopal and Thangavel, 2008).

2.7.2 Preparation of Test Specimens

At the end of the curing age, the specimens were oven-dried at about 100^0C for three days until a constant weight was attained and then allowed to cool gradually to room temperature for 24 hours. In order to achieve a unidirectional flow, the sides of the specimens were coated with silicone gel. The bottom, instead of the top of the specimen as cast was selected as the exposed surface so as to minimize the potential errors that may arise from the inconsistencies of the top surface roughness (Ganesan, Rajagopal and Thangavel, 2008).

2.7.3 Testing Procedures and Determination of Sorptivity Coefficient

The testing procedures outline in the ASTM C 1585-04 was followed. The specimens were immersed to a depth of about 5mm in water on one surface. The initial mass of the specimens was taken at time 0, and at time intervals of 1, 5, 10, 20, 30 and 60 minutes. The samples were removed from water and excess water blotted off and the samples were weighed. It was then placed back in water and the process repeated at the same selected time intervals. The absorption (I) was determined as the quotient of the change in mass (m_t) and the product of the cross-sectional area (a) of the test specimens and the density of water. However, a value of 0.001g/mm^3 as the density of water was used as recommended by ASTM C 1585-04. Finally, the sorptivity (mm/$s^{0.5}$) was obtained as the slope of the line that is best fit to the absorption (I) plotted against the square root of time ($t^{0.5}$)(Ganesan, Rajagopal and Thangavel, 2008)

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1 Materials

The work and the experiments in this research was based on the evaluation of the properties of compressed earth bricks stabilized with lime and PBB in brick production. The stabilization techniques involve mixing the soil with the lime and PBB.

3.1.1 Experimental Concept

The specimens produced were as follows: -

i. Specimens without stabilizing agent (control): Laterite only.

ii. Specimens stabilized with lime only: Lime and Laterite

iii. Specimens stabilized with lime and PBB only: Lime, PBB and Laterite

Materials used in this work were: Laterite soil, Lime, PBB, Lubricant and Water.

3.1.2 Laterite

The laterite soil in this experiment was obtained from Kofar Kona, a location in Zaria City. By visual inspection, the best sample was selected and ensured that it is free from debris and other inorganic materials. The soil was well graded so that itmeets the maximum particle sizes required. The laterite was reddish-brown belonging to A-2-6 class using AASHTO Soil classification system.The soil sample was transported to the laboratory for preparation and testing.

The laterite was air dried and sieved by shaking through a mesh sieve size of 5mm and the quantity of soil required for producing the brick samples was taken. Preliminary tests were done on the laterite soil to find the chemical composition of the soil and some of its geotechnical properties. Other tests include sieve analysis, moisture content, fineness modulus, specific gravity, Atterberg limit test and bulk density test. The samples were cured by open air drying and subsequent tests were carried out. Plate I shows a sample of the Laterite used for the research.

PLATE I: Sample of laterite

3.1.3 Lime

High quality hydrated lime (Delta lime) by Delta steel company limited, Ovwian Aladja was used in this work. The Lime sample was obtained from Kaduna State water board, Zaria as indicated in Plate II.

PLATE II: Sample of lime

3.1.4Pulverized Burnt Bricks

The Pulverized Burnt Bricks used in this work was obtained from brick sellers at PZ, Zaria and later grounded to powder form before use as in Plate III.

PLATE III: Sample of PBB

3.1.5 Water

Portable drinking water from tap deemed fit for consumption and free from taste, odour, colour and other impurities as specified in BS EN 1008(2002) was used in this work.

3.1.6 Lubricating Oil

Used engine oil was used in the inner surfaces of the mould of the compressed earth machine before each casting to avoid the specimen from sticking to the mould during extrusion.

3.2 Laboratory Tests on Samples of Laterite, Lime and PBB

3.2.1 Chemical Analysis

The chemical analysis was done in the Department of Chemistry, ABU Zaria to determine the chemical constituents and other oxide compositions of the soil sample, lime and PBB. The tests showed the various oxides and their corresponding percentages by weight. Energy Dispersive X-ray Fluorescence (EDXRF) spectrophotometer equipment was used.

3.2.2 Physical Properties Tests of Laterite sample

The tests carried out on the air-dried laterite sample include particle size analysis, specific gravity, moisture content, bulk density and fineness modulus.

3.2.2.1 Particle size analysis

The particle size analysis was conducted to determine the gradation/classification of the sample i.e. the distribution of aggregate particles by size to know the basic information on the engineering properties of the sample and its classification i.e. whether sand, clay, gravel or silt. A sample of laterite weighing 2000g was placed in a set of BS sieves with sizes ranging from 5mm to 0.15mm in descending order. The gradation of the sample involves the use of woven wire mesh sieves of different sizes, mechanical shaker and weighing balance. Each sieve has smaller openings so that particles larger than the size of each sieve are retained on the sieve. This test gave the distribution size and the relative % (percentages) of the particles of each sample. The results of the sieve analysis are plotted as a grain size distribution curve and particle distribution table, which is then analyzed to determine the soil gradation of the particular soil. Thetest was conducted in accordance with BS 1377 (2016) as in Appendix V.

3.2.2.2 Specific gravity determination

The specific gravity of the sample was determined as specified in BS 1377(2016).The weights of an empty glass jar and its plate were taken and recorded. A sample of the laterite of about 55g was poured into the glass jar and the weight was recorded. 120ml of water was added to the laterite and shaken thoroughly before filling the jar to the brim. The glass plate was placed on the jar and the air spaces were eliminated. Thereafter, the body of the jar was cleaned with dry cloth and the mass was recorded. The glass jar was emptied of its content and filled with clean water before the final mass was recorded. The procedure was repeated and the average of the two results was taken as the specific gravity of the sample. The calculation is shown in appendix I.

3.2.2.3 Moisture content

To determine optimum water absorption capacity of the sample**.** Trials mixes were prepared using percentages by mass of water as specifies in BS 1377(2016). The moisture content test was carried out in order to determine the percentage quantity of moisture present in the laterite sample. The mass of an empty container and its lid was taken after which a sample of the laterite was placed in the container and covered with the lid and its mass was taken and recorded again. The container with the laterite sample inside was placed in an oven for 24hours. The specimen was taken out, cooled and the new mass was recorded as calculated in appendix II.

3.2.2.4 Bulk density

This test was to determine the soil weight confined within container of unit volume when compacted under a specified condition as in BS 1377 part 3(2018). A cylinder was filled in three different layers. After each layer, a rammer was used to tamper the laterite 25 times. This was done to compact the loose soil. The top of the cylinder was levelled with the rammer and the bulk density was taken as the mass of aggregate required to fill the container divided by the volume of the container that was used. The calculation for bulk density is as indicated in appendix IV.

3.2.2.5 Atterberg test

The test was conducted on the soil sample to determine the plastic limit (i.e. the water content at which the soil starts to exhibit plastic behaviour), liquid limit (i.e. the water content at which the soil is just about to pass from the plastic state into the liquid state), and plasticity index of the soil sample. This index gives an idea on the plasticity of the soil whether high or low plasticity.The test was carried out according to BS1377, (2016) while the liquid limit was conducted based on Casagrande method. A sample of the laterite soil weighing 200g was passed through a 425micrometer sieve. The sample was mixed with water until a uniform paste was formed. A small quantity of the paste was placed in the Casagrande apparatus and spread to produce a thickness of about 11mm. A groove was created on the paste and the Casagrande handle was rotated and the number of blows was recorded for the different tests. A blow occurred at every two revolutions per seconds and the moisture content at each phase was determined. For the plastic limit test, 200g of the dry soil was mixed with water to form a paste and the portion of the paste was rolled on a surface to form a thread until cracked at about 3mm in diameter. The thread was placed in a container and weighed then put in the oven at 105^0C for 24hours. The moisture was calculated as in appendix II. However, plastic index was calculated by subtracting plastic limit from liquid limit.

3.2.2.6 Fineness modulus

This test was conducted to determine the coarseness or fineness of the sample by using weighing balance and sieves of different sizes. 2000g of laterite sample was weighed and sieved using a sieve range of 5mm to 0.15mm and the weight of aggregate retained on each sieve including the pan was recorded. The cumulative weight of the aggregate retained on each sieve and the pan and the cumulative percentage of aggregate retained was calculated. The cumulative percentage of the aggregate retained was added and divided by hundred. Therefore, this value is known as fineness modulus as calculated in appendix III.

3.3 Samples Preparation and Production

Lime, PBB, water, laterite and engine oil were the materials used in the production of the brick samples. A total of 162 prisms sample of size 150mm x 150mm were produced. These consisted of 30 prisms for different proportion of lime contents only, 99 stabilized cubes and 33 un-stabilized prisms. The brick samples were produced using compressed earth machine in the departmental laboratory which is specially made for the purpose of brick making.

However, all samples were prepared by varying the percentage of PBB only and 5% of lime was used throughout for the stabilization. Moulds of the compressed earth machine were oiled properly so as to prevent the samples from sticking during extrusion. A calculated amount of laterite, lime, PBB and water for the stabilized samples was mixed uniformly and the samples were produced from the compressed earth machine. The samples were cured in the Departmental Laboratory. Different tests were conducted on all the samples at the ages of 7, 14, 21, 28 and 56 days respectively.

It was confirmed by Ayodeji (2015) that the required amount of lime to stabilized laterite soil range between 3% and 14% by dry weight, depending largely on soil content. Based on the above fact and the results of trial mixes, the percentage of lime adopted as stabilizer by weight in this work is as in Table 3.1

Table 3.1: Proportion of Materials in each mix ratio

	Content of Items	
LM	PBB	SL
0%	0%	100%
5%	5%	100%
5%	10%	100%
5%	15%	100%

Source: Ayodeji, (2015)

Note: LM = Lime, SL = Soil, PBB = Pulverised Burnt Bricks

Samples of the Stabilized Compressed Earth Bricks produced in the laboratory are shown in Plate IV.

PLATE IV: Samples of Bricks

3.4 Test for BrickSpecimen

3.4.1 Compressive Strength Test

This test was conducted to determine the development of strength of the specimens and its resistance to axial loading with age as in BS 812 (1985). A total of sixty prisms were produced (forty-five stabilized prisms and fifteen un-stabilized prisms).Three prisms of both stabilized and un-stabilized were subjected to crushing at the age of 7, 14, 21, 28 and 56 days respectively. The prisms were weighed before being crushed with compressive testing machine. This was done by placing each cube between two metal plates and subjecting it to compression. The load at failure was recorded and divided by the cross sectional area of the prisms. This was carried out for three different prisms samples and the average was calculated to obtain the compressive strength.

3.4.2 Abrasion Resistance Test

The purpose of this test was to evaluate or assess the extent of resistance of specimens to surface wear due to friction as in BS 812,(1985).And also to evaluate the extent of wear and tear on the sample as a result of scratch by passersby. This gives an indication of likely behavior of the material to erosion and other environmental conditions.The percentage of the abraded material which is a function of the abrasion resistance was determined. It was conducted for prisms at the age of 28 and 56 days only, being a durability assessment test.

Table 3.2: Samples for Abrasion Test

% of Lime	% of PBB	Curing time (days)	
		28	56
0	0	3	3
5	5	3	3
5	10	3	3
5	15	3	3
		12	12

From Table 3.2, twenty-four prisms were produced for this test which consisted of 18 stabilized prisms and 6 un-stabilized prisms. Three prisms of both stabilized and un-stabilized were weighed before placing 2.5kg loaded wired brush on each prism to scratch the surface. This was done for 60 seconds, each second corresponding to a forward and backward motion. The samples were weighed again and the percentage weight loss was used to calculate the abrasive resistance of the cubes and the average value was taken. The process is as shown in Plate V.

3.4.3 Water Absorption Test

This test was to determine the absorption rate of water of the specimens at different levels as in BS 5628,(1990) in Wenapere, (2009). The test which is also for assessing durability property was done to determine the suitability of the laterite for building construction works.

Table 3.3: Samples for Absorption Test

% of Lime	% of PBB	Curing time (days)	
		28	56
0	0	3	3
5	5	3	3
5	10	3	3
5	15	3	3
		12	12

From table 3.3, twenty-four prismswere produced for this test. These consisted of 18 stabilized prisms and 6 un-stabilized prisms. Three prisms of both stabilized and un-stabilized were subjected to the test at the age of 28 and 56 days. The prisms were placed in an oven and subjected to heat for three days. Therefore, they were cooled before their masses were recorded. The prisms were immersed in water at room temperature of 25^{0}C for 15 seconds with 25mm of water above their surfaces. It was observed that after the 15 seconds duration the 0% lime and PBB prisms (un-stabilized samples) partially dissolved in water.However, the samples were removed from the water and dried with a piece of cloth to remove the surface water before their final masses were recorded as in Plate VI.

PLATE V: Abrasion resistance test

PLATE VI: Water absorption test

3.4.4 Sorptivity Test

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material (Ganesan, Rajagopal and Thangavel, 2008). It is also a measure of the capacity of the medium to absorb or desorb liquid by capillarity. It expresses the tendency of a material to absorb and transmit water and other liquids by capillarity.

The specimens were heated in an oven at 100^0C for three days until a constant weight was attained and then allowed to cool gradually to room temperature for 24 hours. The sides of the specimens were coated with silicone sealant to allow the flow of water on only one surface of the specimens. The specimens were immersed to a depth of about 5mm in water on one surface. The initial mass of the specimens was taken at time 0, and at time intervals of 1, 5, 10, 20, 30 and 60 minutes. The samples were removed from water and excess water blotted off and the samples were weighed. It was then placed back in water and the process repeated at the same selected time intervals.The Sorptivity value of the specimens at 28 and 56 days were calculated. The process is as indicated in Plate VII.

PLATE VII: Sorptivity test

From figures 4.5 and 4.6, from Δ abc on line PQ,

$y = mx + c$ but, when $c = 0$,

$y = mx$

$m = y/x$--- equation 3.1

Therefore, Sorptivity = m = mm/s.

3.5 The Percentages of Lime, PBB and Curing Periods are indicated in Table 3.4.

Table 3.4: Percentages of Lime, PBB and Curing Periods

Samples with 0%Lime, 0% PBB				
A7	A14	A21	A28	A56
A7	A14	A21	A28	A56
A7	A14	A21	A28	A56
Samples with 5% Lime, 5% PBB				
B7	B14	B21	B28	B56
B7	B14	B21	B28	B56
B7	B14	B21	B28	B56
Samples with 5% Lime, 10% PBB				
C7	C14	C21	C28	C56
C7	C14	C21	C28	C56
C7	C14	C21	C28	C56
Samples with 5% Lime, 15% PBB				
D7	D14	D21	D28	D56
D7	D14	D21	D28	D56
D7	D14	D21	D28	D56

3.6Trial Results by Varying Percentages of Lime Contents

Table 3.5: Results Using Different Proportions of Lime Content

% of Lime	% of Soil	Curing time (days)	Ave. wt (kg)	Compressive strength (N/mm^2)
0	100	7	2.8	0.82
0	100	28	2.6	1.07
5	100	7	2.9	1.10
5	100	28	2.7	1.29
10	100	7	2.9	1.08
10	100	28	2.7	1.25
15	100	7	2.8	1.03
15	100	28	2.7	1.20
20	100	7	2.8	0.93
20	100	28	2.7	1.14
25	100	7	2.8	0.91
25	100	28	2.7	1.08

Source: Laboratory Work, 2019

CHAPTER FOUR

4.0 Results and Discussion of Results

4.1 Physical Properties of the Laterite Sample

The physical test conducted on the samples of laterite is presented in Table 4.1.

Table 4.1: Physical properties of Laterite Sample

Properties	Description
Condition of Sample	Air-dried
Specific gravity	2.62
Colour	Reddish-Brown
Bulk Density	1405kg/m^3
Fineness Modulus	1.77
Moisture Content (%)	10.71
AASHTO Classification System	A-2-6

Source: Laboratory work, (2019).

By visual inspection, the laterite soil was observed to be reddish-brown in colour. The specific gravity of the laterite was 2.62 which goes in line with a study by Kweku (2015). The result falls within the range of 2.6 – 2.8 specified for laterite soil with less organic matter in ASTM D 854-2002. The bulk density was determined to be 1405kg/m^3 which is close to the value of 1416kg/m^{3}as obtained by Kweku (2015). The fineness modulus of the laterite was found to be 4.95 which is greater than the 3.98 obtained by Kweku (2015). The natural moisture content was given to be 10.71% which is a little bit greater than that of 9.5% as obtained byAginam, Nwakaire and Nwajuaku, (2015). The laterite soil was found to belong to class A-2-6 of the AASHTO soil classification system.

4.2 Chemical Analysis

The result of the chemical tests conducted on the laterite soil sample, lime and pulverized burnt bricks are shown in Table 4.2.

Table 4.2: Chemical Composition of Experimental Materials

Elements	**Concentration (wt. %) in each material**		
	Laterite	PBB	Lime
Na_2O	0.333	0.000	0.000
MgO	0.356	1.114	0.236
Al_2O_3	28.357	25.203	0.516
SiO_2	39.357	54.453	2.901
P_2O_5	0.657	0.033	0.106
SO_3	-	0.243	0.058
Cl	-	0.037	0.085
K_2O	1.164	2.003	0.100
CaO	0.329	0.840	95.201
TiO_2	12.402	1.937	0.009
Cr_2O_3	-	0.016	0.010
Mn_2O_3	-	0.226	0.002
Fe_2O_3	17.045	13.859	0.238
ZnO	-	0.014	0.000
SrO	-	0.022	0.538

Source: Laboratory work, (2019).

From table 4.2, Aluminium, silicon, titanium and iron oxides were found to be present in the laterite having corresponding weight percentages of 28.357%, 39.357%, 12.402% and 17.045 % respectively. These oxides must be present in laterite soils as specified by Lemougna*et al.*(2011). Aluminium and iron oxides are known to be the oxides that are responsible for the reddish-brown colour in laterite soils. This may be as a result of the seasonal fluctuation of the water table. The composition of MgO in the soil was found to be 0.356% which is less than the 4% maximum requirement according to ASTM C 618-01 (2005). The summation of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) were found to be 84.759%.Aluminium, silicon and iron oxides were also found to be present in the pulverized burnt bricks having corresponding weight percentages of 25.203%, 54.453%, and 13.859% respectively. The summation of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) were found to be 93.515%.Calcium oxide was found to be present in the lime having corresponding weight percentage of about 95.201% of the total concentration. Therefore, the silicon content on Pulverised Burnt Bricks (PBB) was far higher than that of lime which is responsible for improving the hydration of lime.

4.3 Trial Results for Optimization using Lime

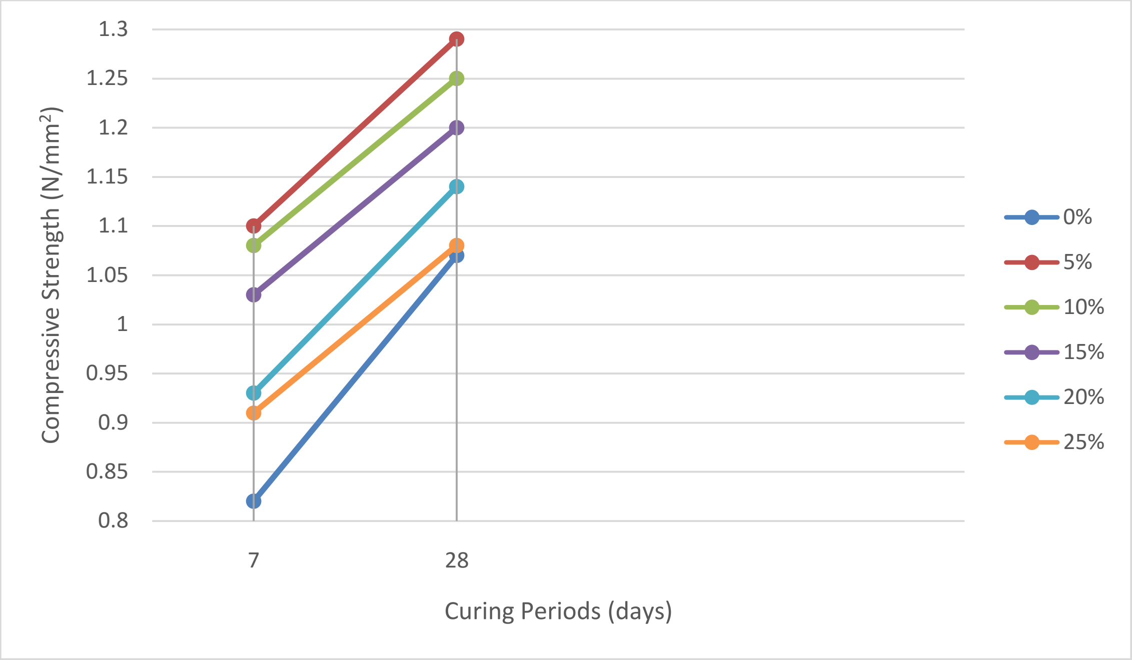


Figure 4.1: Compressive Strength Result Using Different Percentages of Lime

During the course of trial from figure 4.1, control samples gave the least strength values of 0.82B/mm^{2}and 1.07 at 7 and 28 days respectively. Samples produced with 5% lime were observed to have the highest strength of 1.10N/mm^2 and 1.29N/mm^2 at the ages of 7 and 28 days respectively, followed by 10% lime with 1.08N/mm^{2}and 1.25N/mm^2, followed by 15% lime with 1.03N/mm^2 and 1.20N/mm^2, followed by 20% lime with 0.93N/mm^2 and 1.14N/mm^2 and then finally 25% lime with 0.91N/mm^2 and 1.08N/mm^2. It was observed from the result that as quantity of lime increases the strength decreases which may be attributed to the fact that lime has low Plasticity index. Therefore, 5% lime was adopted for this research work.

4.4Average Compressive Strength Test Results

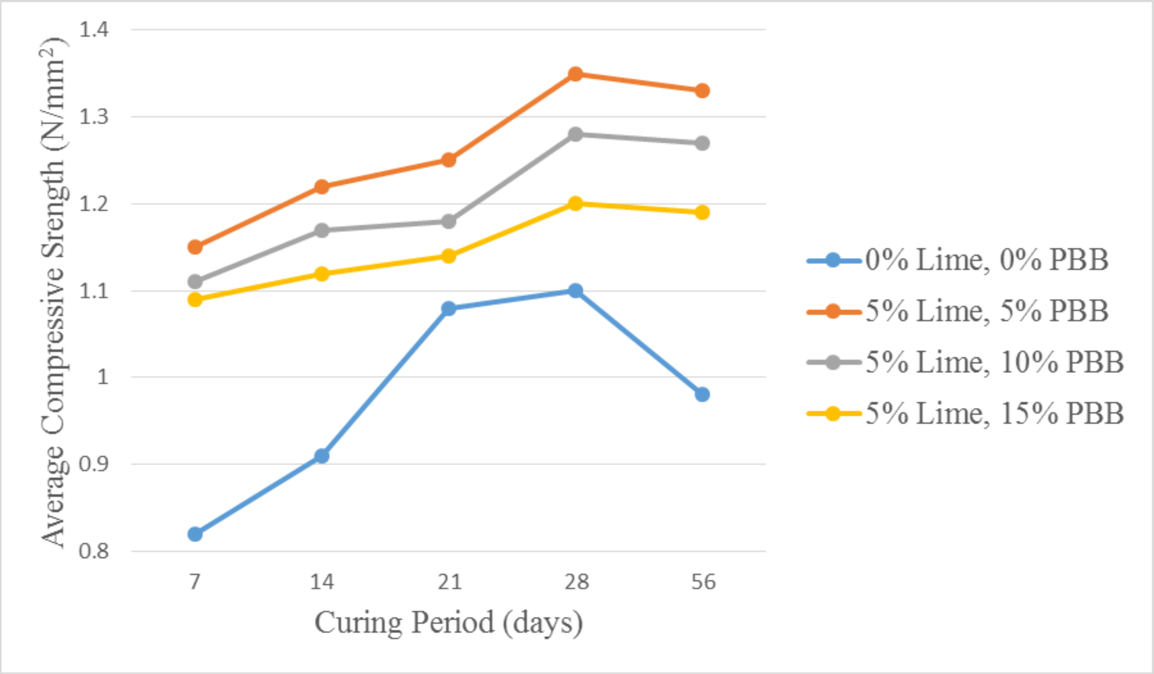


Figure 4.2: Compressive strength results for the control and stabilized samples

It was observed from figure 4.2 that the control samples (0% lime and PBB) gave average strengths of 0.82N/mm^2, 0.91N/mm^2, 1.08N/mm^2 and 1.10N/mm^2 at the ages of 7, 14, 21 and 28 days with a corresponding increase in strength as the age increased. However, at the age of 56 days, control samples gave an average strength of 0.98N/mm^2 indicating weakening of the bricks on total evaporation of mixing water, this was confirmed through weight loss.

Stabilized samples produced with 5% lime and 5% PBB were observed to have the highest average strength of 1.15N/mm^2, 1.22N/mm^2, 1.25N/mm^2 and 1.35N/mm^{2}at the ages of 7, 14, 21 and 28 days respectively. This was followed by samples produced with 5% lime and 10% PBB with average strength of 1.11N/mm^2, 1.17N/mm^2, 1.18N/mm^2 and 1.28N/mm^2. And then followed by the samples produced with 5% lime and 15% PBB with average strength of 1.09N/mm^2, 1.12N/mm^2, 1.14N/mm^2 and 1.20N/mm^2. However, at the age of 56 days, samples produced with 5% lime and 5% PBB gave average strength of 1.33N/mm^{2}followed by those produced with 5% lime and 10% PBB with strength of 1.27N/mm^2 and lastly those produced with 5% lime and 15% PBB with strength of 1.19N/mm^2. The decrease in strength of the samples at the age of 56 days may be attributed to the gradual diminishing of moisture at later age and the excess of silicon oxide in PBB as the percentage of the PBB increases.

4.5Abrasion Resistance Test Results

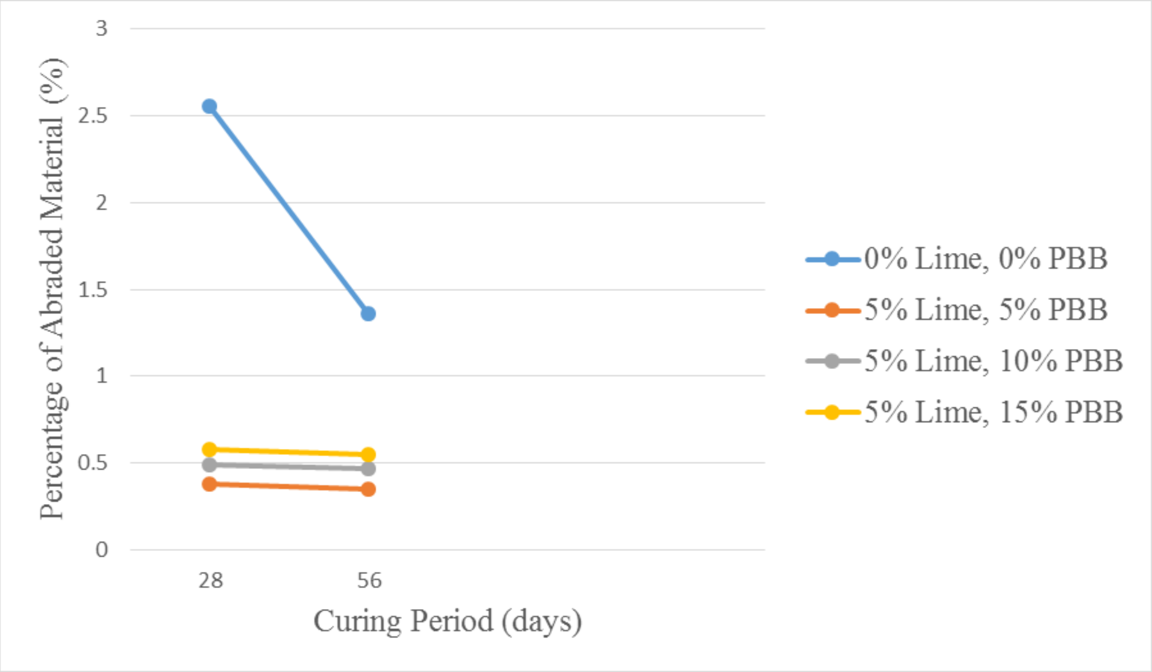


Figure 4.3: Abrasion resistance results for the control and stabilized samples

Figure 4.3 depicts that abrasion resistance increased with age of the samples from 28 to 56 daysand the percentage of PBB added. The increase in percentage weight loss of the control sample was from 2.56% to 1.36%.

The results of the stabilized samples showed an increase in abrasion resistance from 0.38% to 0.35% for 5% PBB, followed by 0.49% to 0.47% for 10% PBB and then 0.58% to 0.55% for 15% PBB. The increase is attributed to the improved cementitious action between the lime, PBB and the laterite resulting in an enhanced bonding strength which holds the particles firm.

4.6Water Absorption Test Results

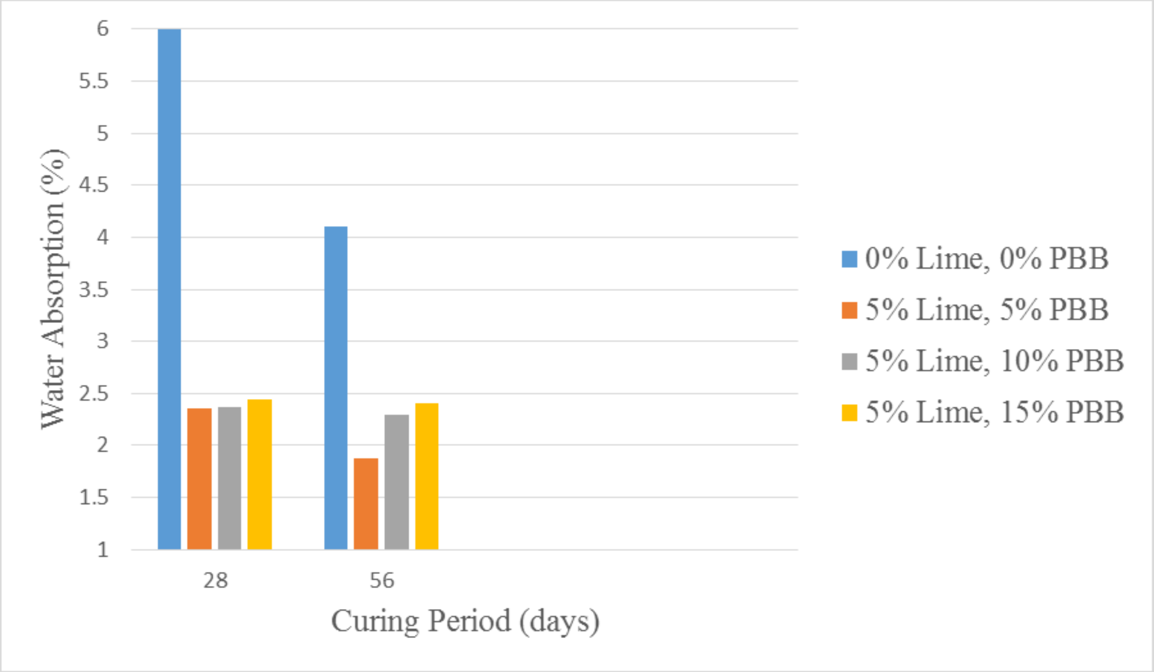
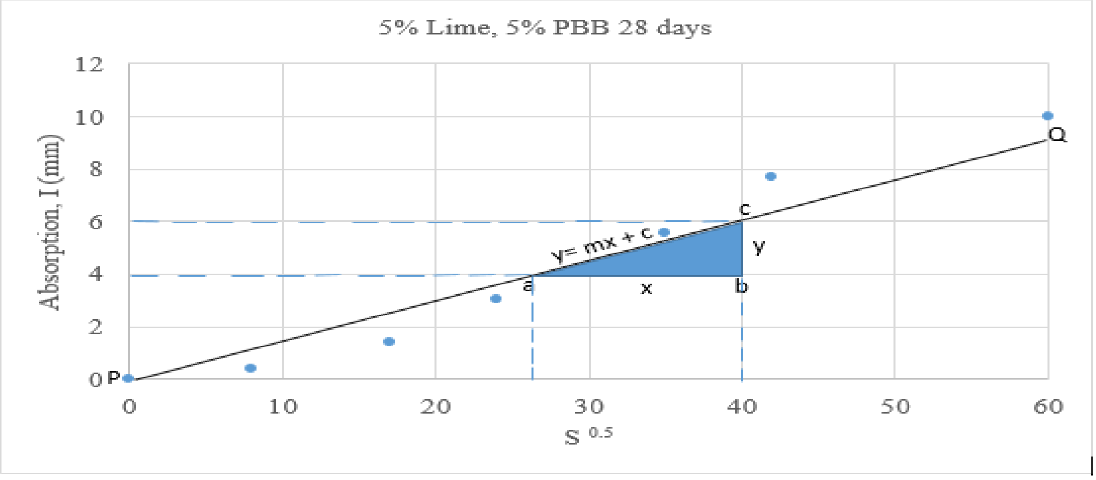
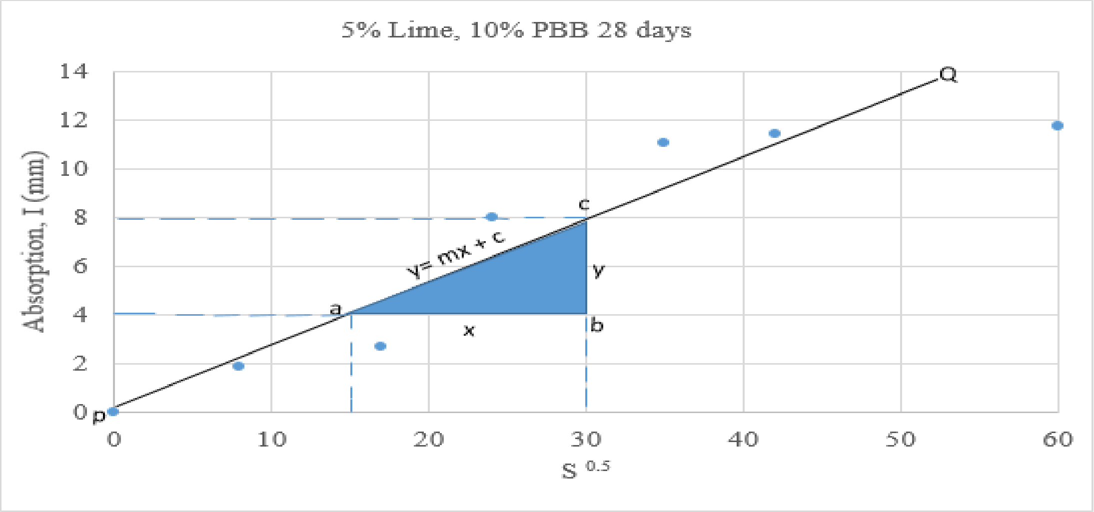


Figure 4.4: Water absorption results for the control and stabilized samples

From figure 4.4, the control samples have percentage absorption rate of 6.00% at 28 days and 4.10% at 56 days. Meanwhile, the result of the stabilized samples shows an absorption rate of 2.35% to 1.88% for 5% PBB, 2.37% to 2.30% for 10% PBB and 2.44% to 2.41% for 15% PBB. The absorption capacities of the samples were observed to increase between 28 and 56 days for all the samples.This is because the samples became dryer and absorb more water and can also be attributed to the fact that the soil sample contains clay particles which have a high water holding capacity.

4.7Sorptivity Test Result of the Samples at 28 days





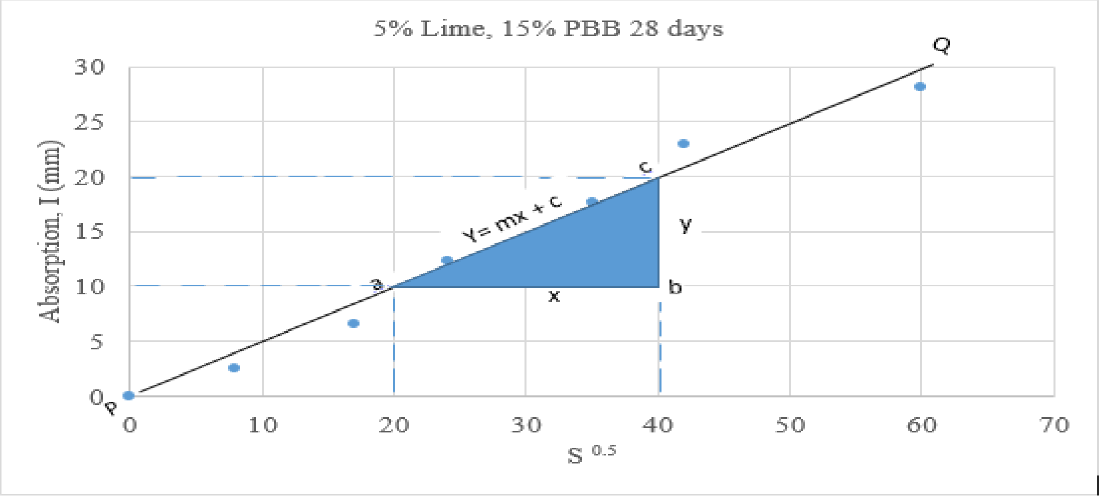
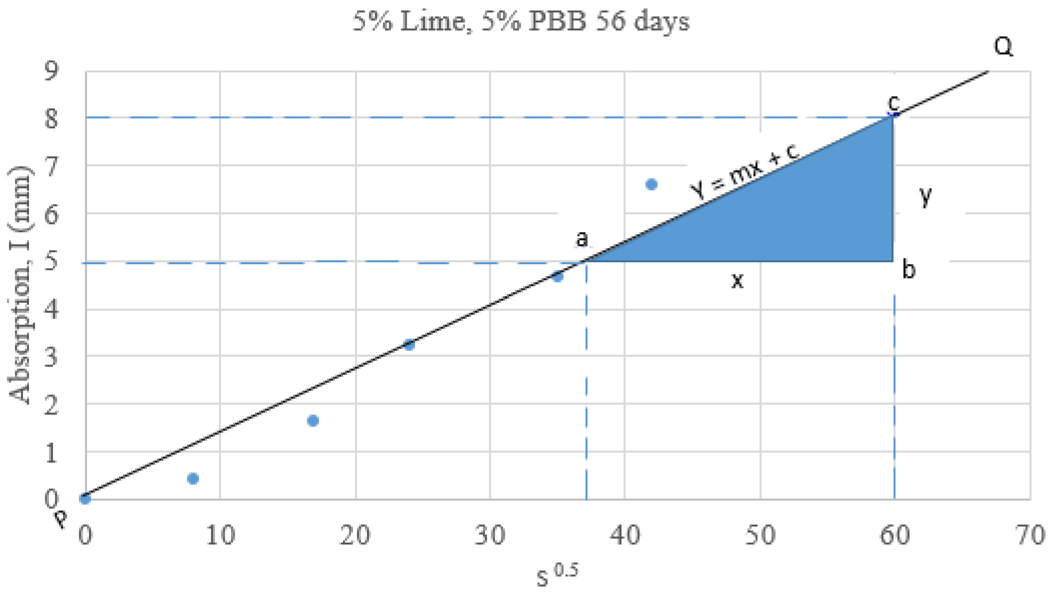
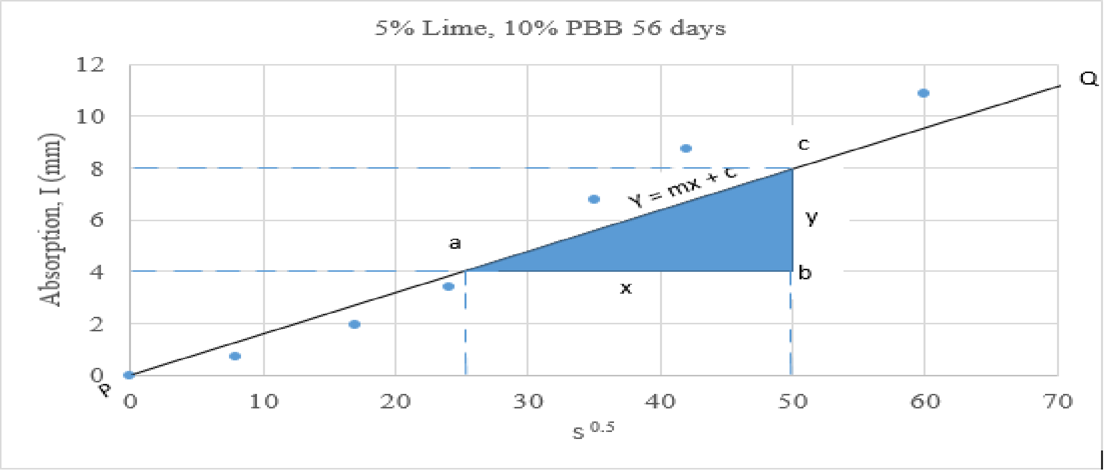


Figure 4.5: Sorptivity test result of the stabilized samples at 28 days

The result shows that samples produced with 5% PBB were observed to have the highest resistance to capillary action of water at 28 days, followed by those produced with 10% PBB and then those produced with 15% PBB. The capillary action of the samples was observed to increase between 60 seconds to 3600 seconds for all the samples. The sorptivity values of the bricks containing Lime and PBB show general increase as the PBB content increases.The sorptivity of the bricks at 56 days are lower than at 28 days which may be as a result of improvement with age.

4.8Sorptivity Test Result of the Samples at 56 days





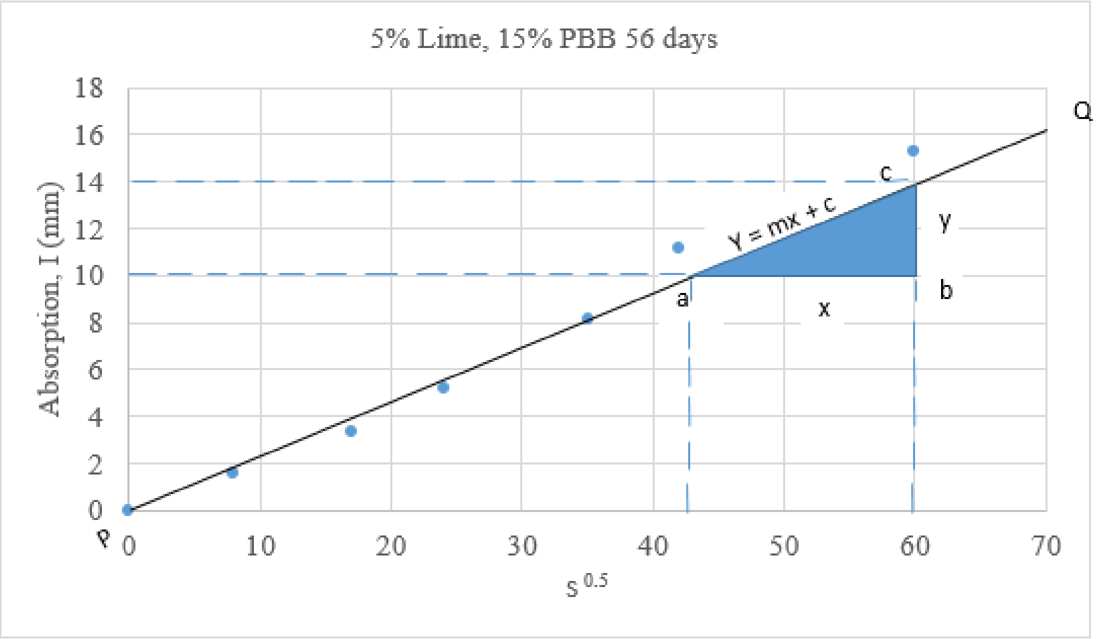


Figure 4.6: Sorptivity test result of the stabilized samples at 56 days

The result shows that samples produced with 5% PBB were also observed to have the highest resistance to capillary action of water at 56 days, followed by those produced with 10% PBB and then those produced with 15% PBB. The capillary action of the samples was also observed to increase between 60 seconds to 3600 seconds for all the samples.The Sorptivity values of the bricks containing Lime and PBB also show general increase as the PBB content increases. The Sorptivity of the bricks at 56 days are lower than at 28 days which may be as a result of improvement with age.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of findings

(i) The laterite soil contained Silica, Alumina, Iron oxide and Titanium oxide at appreciable quantities of 39.357%, 28.357%, 17.045% and 12.402% respectively. This satisfied the condition as specified by Lemougna*et al.* (2011) for a soil to be called laterite soil and the specific gravity of the laterite was obtained to be 2.62.

(ii) Thesoil classification system of the laterite fell under group A-2-6 of theAmerican Association of State Highways and Transportation Officials (AASHTO) which indicates the presence of elastic silt fines, gravels and sand.

(iii) Un-stabilized samples gave average compressive strength values of 0.82N/mm^{2}at 7days, 0.91N/mm^2 at 14days, 1.08N/mm^2 at 21days, 1.10N/mm^2 at 28days and 0.98N/mm^2 at 56days while that of stabilized samples gave average compressive strength values of 1.15N/mm^2 at 7days for 5% PBB, 1.11N/mm^2 at 7days for 10% PBB, 1.09N/mm^2 at 7days for 15% PBB, 1.22N/mm^2 at 14days for 5% PBB, 1.17N/mm^2 at 14days for 10% PBB, 1.12N/mm^2 at 14days for 15% PBB, 1.25N/mm^2 at 21days for 5% PBB, 1.18N/mm^2 at 21days for 10% PBB, 1.14N/mm^2 at 21days for 15% PBB, 1.35N/mm^2 at 28days for 5% PBB, 1.28N/mm^2 at 28days for 10% PBB, 1.20N/mm^2 at 28days for 15% PBB, 1.33N/mm^2 at 56days for 5% PBB, 1.27N/mm^2 at 56days for 10% PBB and 1.19N/mm^2 at 56days for 15% PBB.

(iv) The strength (compressive) of un-stabilized samples (control) increases with age to 1.10N/mm^2 at 28days but reduced to 0.98N/mm^2 at the age of 56days. The strength is likely to stabilized after total evaporation of moisture.

(v) The strength of the samples increases with age to 1.35N/mm^{2}at 28days having higher strength with 5% lime and 5% PBB, but reduced to 1.33N/mm^2 at the age 56days for 5, 10 and 15% PBB stabilization. The reduction in strength is attributed to the gradual diminishing of moisture at later age.

(vi) From the results of stabilized and un-stabilized samples, samplesproduced with stabilization had higher resistance to abrasion of 0.38% for 5% PBB at the age of 28 days and 0.35% for 5% PBB at the age of 56 days respectively.

(vii) Water absorption results show that stabilized samples had the lowest absorption capacity of 1.88% at 56 days for 5% lime and 5% PBB stabilizationand the highest absorption capacity of 2.44% at 28days for 5% lime and 15% PBB stabilization. However, all un-stabilized samples partially dissolved in water.

(viii) From the Sorptivity results, the control samples completely dissolve within seconds however, samples produced with 5% PBB stabilization were observed to have the highest resistance to capillary action of water at both 28 and 56 days respectively.

5.2 Conclusion

Based on the study carried out on the evaluation of the properties of compressed earth bricks stabilized with lime and PBB, the following conclusions were drowned;

i. Al_2O_3, SiO_2, TiO_2 and Fe_2O_3 were found to be present in the laterite with appreciable quantities of 28.357%, 39.357%, 12.402% and 17.045 %

respectively.Al_2O_3, SiO_2, and Fe_2O_3 were also found to be present in PBB with 25.203%, 54.453%, and 13.859% respectively. CaO was found to bein lime having weight percentage of about 95.201% of the total concentration.

ii. Stabilized laterite samples produced with 5% PBB gave the optimum compressive strength of $1.35N/mm^2$ at 28days. Adequate strengths were achieved with 5% lime and 5% PBB stabilization above the control by up to 22.73% improvement, although it has not met with NBRRI standard of $1.65N/mm^2$.

iii. It was observed that 5% PBB stabilization have higher resistance to abrasion of 0.35% at the age of 56 days and the lowest resistance of 0.58% for 15% PBB stabilization at 28 days.

iv. It was concluded that the absorption results showed a great increase in the absorption capacity of the bricks, thus samples produced with 5% PBB stabilization have the lowest absorption capacity of 1.88% at 56 days andthe highest of 2.44% at 28days for 15% PBB stabilization.

v. It was also concluded that the sorptivity results showed a great increase in resisting the capillary action of water, therefore samples produced with 5% PBB stabilization were observed to have the highest resistance to capillary action of water at both 28 and 56 days respectively.

5.3 Recommendations

i. Laterite soil that certifies AASHTO Classification of A-2-6 with 5% lime and 5% PBB could be adopted for non-load bearing wall construction such as partition walls.

ii. In areas where there are different types of laterite soil and in abundance, tests should be carried out to determine the plasticity index value of the different soils before being stabilized with lime and PBB.

iii. PBB made from burnt brick could be used to reduce the formation of Ettringite when lime reacts with water. Since the pozzolanic reaction and formation of Ettringite both depend on reactionwith lime.

5.3.1 Recommendation for further studies

i. Effect of weather and chemical attack on compressed earth bricks stabilized with lime and PBB should be investigated.

ii. More work should be done to determine the long term effect of lime and PBB on strength and durability properties of laterite stabilized with the Lime and PBB.

iii. Various curing methods should be investigated to find the best method for the production of Compressed Earth Bricks stabilized with Lime and PBB.

5.4 Contribution to Knowledge

The research established that:

i. Compressed Earth Bricks Stabilized with Lime and PBB produced Bricks with increase in strength of up to 22.73% compared to those without stabilization.

ii. 5% stabilization with Lime and PBB is the optimum percentage addition for production of Compressed Earth Bricks.

iii. The sorptivity of the bricks with Lime and PBB stabilization at 56 days are lower than that at 28 days which may be as a result of improvement with age.

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APPENDIX I

SPECIFIC GRAVITY TEST ON THE LATERITE SAMPLE

Weight of empty cylinder (a)	91g
Weight of cylinder + sample of laterite (b)	146g
Weight of cylinder + laterite + water (c)	369g
Weight of cylinder + water (d)	335g

Therefore,

$$\text{Specific Gravity} = \frac{b - a}{(d - a) - (c - b)}$$

$$= \frac{146 - 91}{(335 - 91) - (369 - 146)}$$

$$= \frac{55}{(244) - (223)}$$

$$= \frac{55}{21}$$

SG = 2.62

APPENDIX II

PERCENTAGE MOISTURE CONTENT

Weight of container and lid (a) = 60g

Weight of container and lid + moist laterite sample (b) = 122g

Weight of container and lid + oven dried laterite sample (c) = 116g

Moist laterite = b – a

= 122g – 60g

= 62g

Oven dried laterite (d) = c – a

= 116g – 60g

= 56g

Mass of water (e) = 62g – 56g

= 6g

Therefore, percentage moisture content = $\frac{\text{Mass of water x 100}}{\text{Mass of oven dried laterite}}$

= 6 x 100 / 56

= 10.71%

APPENDIX III

FINENESS MODULUS

$$\text{Fineness modulus} = \frac{\text{Summation of percentage weight passing}}{100}$$

$$\text{Fineness modulus} = \frac{72.25+49.50+26.75+20.00+5.75+2.25+0}{100}$$

$$\text{Fineness modulus} = \frac{176.5}{100}$$

Fineness modulus = 1.77%

APPENDIX IV

BULK DENSITY

Weight of empty container = 0.695kg

Gross weight = Mass of compacted laterite = 2.1kg

Net weight = Gross weight – weight of empty container

= 2.1 – 0.695 = 1.405kg

Volume of the container = 0.001m^3

$$\text{Therefore, bulk density} = \frac{\text{Net weight}}{\text{Volume of the container}}$$

$$\text{Bulk density} = \frac{1.405}{0.001}$$

Bulk density = 1405kg/m^3

APPENDIX V

PARTICLE SIZE DISTRIBUTION

Sieve Sizes (mm)	Weight Retained (g)	Weight Passing (g)	Percentage Weight Passing (%)	Percentage Weight Retained (%)	Cumulative Percentage Retained (%)
5	555	1445	72.25	27.75	27.75
2.36	455	990	49.50	22.75	50.50
1.00	455	535	26.75	22.75	73.25
0.6	135	400	20.00	6.75	80.00
0.3	285	115	5.75	14.25	94.25
0.15	70	45	2.25	3.5	97.75
Pan	45	0	0	2.25	100

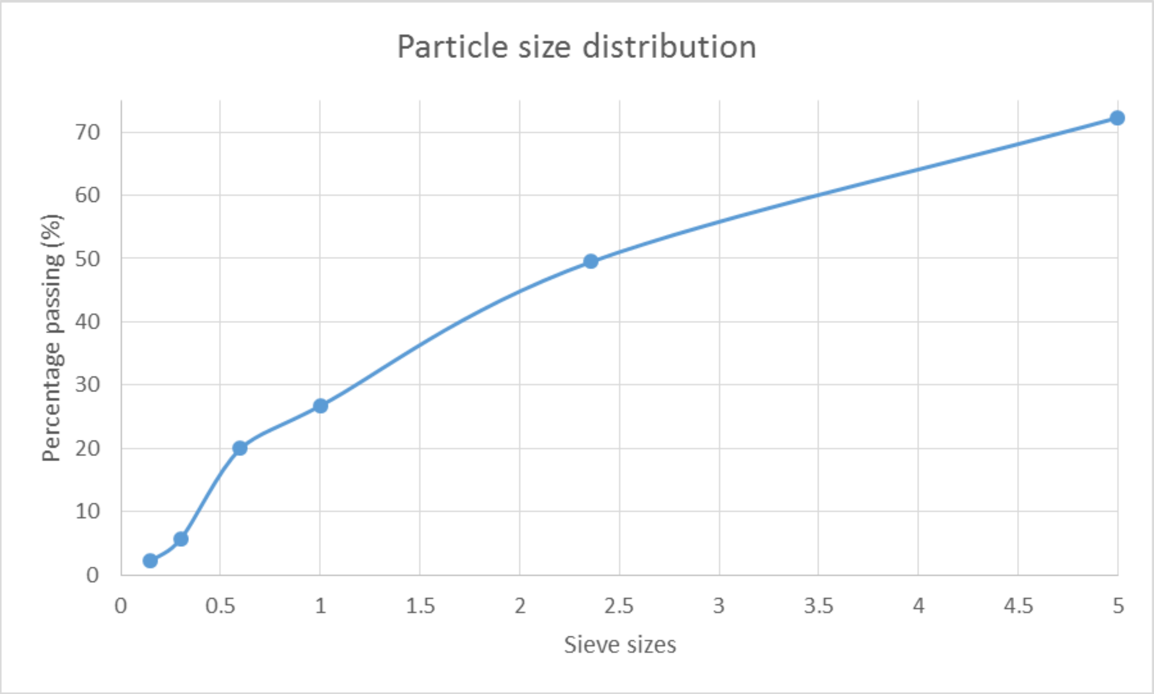

Figure 4.7: Typical Particle Size Gradation

APPENDIX VI

TEST RESULTS FOR UN-STABILIZED LATERITE SAMPLES

Table I: Compressive strength results for un-stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Ave. wt. of samples (kg)	Ave. failure loads (KN)	Compr. strength (N/mm^2)
0	0	7	2.8	17.13	0.82
0	0	14	2.9	19.23	0.91
0	0	21	2.6	22.62	1.08
0	0	28	2.4	23.25	1.10
0	0	56	2.5	20.53	0.98

Table II: Abrasion resistance test results for un-stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Av. wt. before test (g)	Av.wt. after test (g)	Wt. loss (g)	% loss
0	0	28	2400	2340	60	2.56
0	0	56	2600	2565	35	1.36

Table III: Water absorption test results for un-stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Av. Wt. b/4 test (g)	Av. Wt. after test (g)	Difference (g)	Absorption (%)
0	0	28	2330	2469	139	6.0
0	0	56	2200	2290	90	4.1

APPENDIX VII

TEST RESULT FOR STABILIZED SAMPLES

Table I: Compressive strength result for stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Av. Wt. of samples (kg)	Av. Failure loads (KN)	Compr. Strength (N/mm^2)
5	5	7	2.8	24.10	1.15
5	10	7	3.0	23.50	1.11
5	15	7	2.7	22.85	1.09
5	5	14	2.7	25.54	1.22
5	10	14	2.8	24.66	1.17
5	15	14	2.9	23.65	1.12
5	5	21	2.8	26.27	1.25
5	10	21	2.8	24.85	1.18
5	15	21	2.8	24.00	1.14
5	5	28	2.7	28.27	1.35
5	10	28	2.6	26.90	1.28
5	15	28	2.6	25.20	1.20
5	5	56	2.427.95	1.33	
5	10	56	2.6	26.75	1.27
5	15	56	2.624.99	1.19	

Table II: Abrasion resistance test results for stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Av. wt. before test (g)	Av. wt. after test (g)	Wt. loss (g)	% loss
5	5	28	2600	259010	0.38	
5	10	28	2552	253913	0.49	
5	15	28	2572	2557	15	0.58
5	5	56	2400	2391	09	0.35
5	10	56	2552 2540	12	0.47	
5	15	56	2572	2558	14	0.55

Table III: Water absorption test results for stabilized brick samples

Lime (%)	PBB (%)	Curing time (days)	Av. Wt. b/4 test (g)	Av. Wt. after test (g)	Difference (g)	Absorption (%)
5	5	28	2511	2570	59	2.35
5	10	28	2536	2596	60	2.37
5	15	28	2525	2590	65	2.44
5	5	56	2400	2445	45	1.88
5	10	56	2512	2570	58	2.30
5	15	56	2654	2718	64	2.41

Table IV: Sorptivity test results for stabilized samples (5% lime & 5% PBB 28 days)

Test Time (s)	$S^{0.5}$	Mass (g)	Δmass (g)	I= Δmass/Area x Density (mm)	Sorptivity (mm/s)
0	0	2275.010		0	
60	8	2277.22	2.210.125		
300	17	2283.10	8.090.458		
600	24	2292.03	17.020.963		1.4×10^{-1}
1200	35	2306.27	31.261.769		
1800	42	2318.16	43.152.441		
3600	60	2331.25	56.243.182		

Table V: Sorptivity test results for stabilized samples (5% lime & 10% PBB 28 days)

Test Time (s)	$S^{0.5}$ (g)	Mass (g)	Δmass (mm)	I= Δmass/Area x Density (mm/s)	Sorptivity
0	0	2028.00	00		
60	8	2038.50	10.500.594		
300	17	2043.14	15.140.857		
600	24	2073.08	45.082.551		2.7×10^{-1}
1200	35	2090.13	62.13	3.515	
1800	42	2092.22	64.22	3.634	
3600	60	2094.18	66.18	3.744	

Table VI: Sorptivity test results for stabilized samples (5% lime & 15% PBB 28 days)

Test Time (s)	$S^{0.5}$	Mass (g)	Δmass (g)	I= Δmass/Area x Density (mm)	Sorptivity (mm/s)
0	0	2030.1500			
60	8	2044.02	13.870.785		
300	17	2067.05	36.902.088		
600	24	2099.29	69.143.912		5.0×10^{-1}
1200	35	2129.16	99.015.602		
1800	42	2159.07	128.927.294		
3600	60	2188.19	158.048.942		

Table VII: Sorptivity test results for stabilized samples (5% lime & 5% PBB 56 days)

Test Time (s)	$S^{0.5}$	Mass (g)	Δmass (g)	I= Δmass/Area x Density (mm)	Sorptivity (mm/s)
0	0	2400.08	0	0	1.3×10^{-1}
60	8	2402.43	2.35	0.133	
300	17	2409.28	9.20	0.521	
600	24	2418.24	18.16	1.027	
1200	35	2426.12	26.10	1.477	
1800	42	2437.18	37.16	2.103	
3600	60	2445.20	45.18	2.556	

Table VIII: Sorptivity test results for stabilized samples (5% lime & 10% PBB 56 days)

Test Time (s)	$S^{0.5}$	Mass (g)	Δmass (g)	I= Δmass/Area x Density (mm)	Sorptivity (mm/s)
0	0	2400.02	0	0	1.6×10^{-1}
60	8	2404.20	4.18	0.237	
300	17	2411.14	11.12	0.629	
600	24	2419.06	19.04	1.077	
1200	35	2438.25	38.17	2.160	
1800	42	2449.29	49.21	2.784	
3600	60	2461.04	60.96	3.449	

Table IX: Sorptivity test results for stabilized samples (5% lime & 15% PBB 56 days)

Test Time (s)	$S^{0.5}$	Mass (g)	Δmass (g)	I= Δmass/Area x Density (mm)	Sorptivity (mm/s)
0	0	2400.41	0	0	2.2×10^{-1}
60	8	2409.11	8.7	0.492	
300	17	2419.32	18.91	1.070	
600	24	2429.43	29.02	1.642	
1200	35	2446.36	45.95	2.600	
1800	42	2463.19	62.78	3.552	
3600	60	2486.24	85.83	4.856	