EFFECTS OF THREE BINDING MEDIA ON MOISTURE MOVEMENT IN COMPRESSED EARTH BRICKS

BY

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DECLARATION

I declare that the work in this thesis entitled “EFFECTS OF THREE BINDING MEDIA ON MOISTURE MOVEMENT IN COMPRESSED EARTH BRICKS” has been carried out by me in the department of building. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other Institution.

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Sign Date

CERTIFICATION

This thesis entitled "EFFECTS OF THREE BINDING MEDIA ON MOISTURE MOVEMENT IN COMPRESSED EARTH BRICKS" by AMINU ALHAJI GADO meets the regulations governing the award of the degree of M.Sc CONSTRUCTION TECHNOLOGY of the Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This thesis is dedicated to my Mother and my entire family.

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In the name of Allah the most beneficent the most merciful whom gave me the opportunity to witness this time in the history of my studies and in this program in particular. I would like to show my appreciation to my able supervisors in person of Dr. D. Dahiru and Malam I.M. Khalil and others like Prof. M.M Garba and Malam Jamilu whom gave me attention, tolerance and understanding during the course of my research work. I would also like to extend my appreciation to the entire staff of the Department by sparing their time in impacting the knowledge to us during this study period.

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ABSTRACT

The major problem associated with cassava starch stabilized bricks is the high rate of water absorption. The effect of high rate of water absorption make the bricks to be soluble in water and limits its use for only internal partition walls not out doors. This study therefore evaluates the effects of three binding media on compressed stabilized earth bricks. The three binding media are Makuba, Cassava Starch and Cement. The research entails a laboratory investigation in which three sets of compressed earth bricks were produced which sum up to a total of 107 bricks cured by open air dry method. The control (CO) and the addition of three binding media in the laterite mix were fixed at binder combination (C1) and binder combination (C2). The brick samples were tested for permeability, Sorptivity, water absorption, adsorption, compressive strength, abrasion resistance and density for the curing periods of 7, 14, 28 and 56 days. The results show that permeability of C2 has the minimum absorption rate of 7.90% at 56days. The Sorptivity of C2 had the least water rise of 5% at 10min. It was observed that the average water absorption of the test samples was 2.77% for C2 at 56days which conformed to ASTM C 62 (2010) Water Absorption test of brick samples. The compressive strength of C1 and C2 had increased the strength with 2.29 and 1.69 N/mm^2 respectively. The setting time results confirmed that makuba has a significant effect on accelerating the setting time of cement while cassava starch decelerate the setting time of cement. This research was able to assess the effects of the three binding media on moisture movement in brick samples and the high rate of water absorption was reduced and the bricks produced are suitable for outdoors used. It is recommended therefore

that for walls exposed to moisture such as external walls and walls of bathrooms and kitchen the C2 binder combination should be incorporated.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the modern brick construction practices, agricultural by-products are largely used as raw materials in laterite brick production. These have many benefits to the environment and bring about economic impact because of the cost of waste disposal which is increasing due to strict environment regulations. Waste utilization has been a common step taken in most countries in the world.Soil construction methods are used in 20%of urban buildings in Nigeria while this figure exceeds 90% in rural areas. Buildings are constructed entirely, or partially of soil, depending on location, climate, available skills, cost, building use and local tradition (Agib et al, 2001).

Laterite which is derived from the Latin word "later"meaning brick, was first used by Buchanan in 1807 for describing a red iron-rich material found in southern parts of India. The soil colour can vary from red, brown, and violet to black, depending on the concentration of iron oxides(Agib et al, 2001).Laterites are highly weathered soils which contain large, though extremely variable, proportions of iron and aluminium oxides, as well as quartz and other minerals. They are found in abundance in the tropics and subtropics, where they generally occur just below the surface of grasslands or forest clearings in regions with high rainfall (Starry, 2007).Laterite is defined by Encarta English Dictionary as red tropical soil: a reddish mixture of clayey iron and aluminium oxides and hydroxides formed by weathering of basalt under humid, tropical conditions. Fermor (1981) classified various forms of laterite soils on the basis of the relative contents of the constituents (Fe, Al, Ti, Mn) in relation to Silica. A chemical

definition based on the Silica Sesquioxides (S-S) ratio ($SiO_2/Al_2O_3+Fe_2O_3$) has been proposed, the conclusion being an s-s ratio 1.33 implies a true laterite; an s-s ratio between 1.33 and 2.0 refers to a lateritic soil; and an s-s ratio above 2.0 indicates a non-lateritic typically weathered soil. (Fermor, 1981).In comparison with another building material, compressed stabilized earth bricks (CSEB) offered a number of advantages. It increases the utilization of local materials and reduces the transportation cost as the production is in situ, makes quality housing available to more people. In addition, faster and easier construction methods result in less skilled labor requirements(Adam, 2001).CSEBs have good strength, insulation and thermal properties, less carbon emission and embodied energy in the production phase. It createsextremely low level of waste easily dispose off and cause no direct environmental pollution during the whole life cycle. Earth bricks also have the ability to absorb atmospheric moisture which results to healthy environment in the interior of buildings for its occupants (Ganguli, 2011).

Soil stabilization means modifying soil properties by adding another material to improve its durability and strength. Soil stabilization has been used widely since the 1920s mainlyfor road construction. When a soil is successfully stabilized one or more of thefollowing effects 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, the soil shrinkage and expansion will be reduced, (Adam, 2001).Stabilizer for CSEB is playing an important role in creating bonding between soil-stabilizers mixes. One of the main functions of the stabilizing medium is to reduce the swelling properties of the soil through forming a rigid framework with the soil mass, enhancing its strength and durability (Khalil, 2005).Stabilized Earth bricks technology offers an

environmentally sound masonry system. The product has a wide application in construction and is manufactured by compacting earth (laterite/sub-soil) mixed with a stabilizer such as cement or lime e.t.c. (Practicalaction, 2009). The use of stabilizers in building and civil engineering construction will go a long way in reducing environmental pollution. Some of the advantages of using earth as a building material includes:Quality of Stabilized Earth Brick (SEB)which allows users to produce uniform bricks of greater strength than typical fired blocks that provide better thermal insulation. Also the total cost of building a structure with CSEB is 20%-30% cheaper than building with fired bricks because far less mortar is required, structures do not have to be plastered, and bricks can be made on site so transportation costs are minimized. Also CSEBs are environmentally friendly because they are cured in the sun; the need for fuel wood is eliminated, helping curb deforestation rates. Moreover, the bricks have an appealing aesthetic with an elegant profile and uniform size that doesn't require plastering. (Practical Action, 2009). There is availability of Cassava in parts of Nigeria such as Nasarawa, Cross River, Akwa Ibom, Rivers, Delta, Ogun, Ondo, Oyo, Enugu, Abia, Imo and Kaduna (Phillip, 2004).

The utilization of such product will boost the economic base of the farmers by increase in production. The production of starch requires less energy compared to cement production.(Panjul, 2011).

Moreover, Locus bean pod (makuba) which is a Waste Agricultural Biomes (WAB) and obtained from the fruit of the African locus bean tree (parkia biglobosa) which is a material resource that can extensively be used in adequate proportion as a soil stabilizer for the production of soil blocks to build houses. Although many people look down on soil blocks today, it is however one of the

oldest building materials. It has been used for centuries in all parts of the world, before the advent of modern building materials like concrete but its usage can now be promoted by adding stabilizers (Bashir, 2012).

Cement is a binder, a substance that sets and hardens independently, and can bind other materials together (Gartner et al., 2011).

Moisture movement occurs when it moves from one state or one point to another, (Joseph *et al, 1994).*Moisture movements include; Moisture downhill, warm air holds more moisture than cool air does. Openings in the building shall include intentional openings, such as doors and windows, and unintentional openings, such as cracks and missing components, such as brick, sealant, etc (Heinz, 2001).

1.2 Statement of Research Problem

One of the drawbacks using earth alone as a material for construction is the lack of durability properties which is related to its compressive strength because most soil in their natural condition lack the strength, dimensional stability and durability required for building materials. The technique to enhance natural durability and strength of soil is defined as soil stabilization. Research works have shown that stabilizing laterite with agricultural waste such as the locus bean pod (*Makuba*) and cassava starch as the agricultural renewable material the properties of soil can be improved, the energy efficiency will be achieved with less technical knowhow (Phillips, 2004). Moreover, Bitumen, lime and cement have been in use for stabilizing laterite soil for building construction work. More recently by other materials like rice husk ash, cassava starch, locus bean pod (*Makuba*) have been introduced for the stabilization of laterite soil. Also Research works have specified certain percentage of these materials in soil with improvement in strength and other properties gained. Macuba and Cassava starch are readily available and abundant agricultural by-product and a renewable material that is less expensive than other stabilizers (Khalil, 2005).Previous researches have shown that the use of makuba and cassava starch in stabilizing laterite for brick production have capacity of improving the brick strength. However, the rate of water absorption was only reduced substantially. In a research carried out by Khalil, (2005) it was observed that cassava starch stabilized bricks have improved strength and wearing resistance and can therefore be used for internal walls, rather cannot be used for environment exposed to moisture. Bashir(2012) noted that makuba stabilized bricks have improved brick strength and lower absorption rate.

Moreover, Peter(2011) reported from a research on makuba stabilized bricks that the bricks have increased in strength and the rate of water absorption reduced substantially but not completely impeded. Yusuf (2014) reported that bricks should be protected from moisture and suitable for internal walls while the use of makuba stabilized bricks outdoors may be substantial. In view of the above, this research is looking into the possibility of utilizing the three binding media as agricultural waste, renewable material and industrial product in stabilizing laterite for brick production, with view of the rate of water absorption.

1.3 Justification for the Study

With the availability of macuba as agricultural wasteand cassava starch as renewable materialin most part of the country, there is need to assess their properties with respect to the production of earth bricks.This would help to reduce the over dependence on conventional building materials, and contribute in reducing pollution arising from agricultural and industrial waste in the environment (Panjul, 2011). Moreover, National Building Road Research

Institute (NBRRI) has established that cement content in compressed stabilized earth bricks above 5% is uneconomical (Agbede and Joel, 2008).

Therefore,in the modern brick construction practices, agricultural by-products are largely used as raw materials in laterite brick construction as an attempt for reducing the harmful impact of agricultural waste in the environment, which is detrimental to the human health.

This research looked into the feasibility of using the three binding media as stabilizer for laterite earth bricks production which perhaps solves the problem of limiting the use of stabilized bricks for internal walls alone but also for external walls in the environment that are exposed to moisture.This is of great importance to the low income earners living in the buildings that requires mud rendering during every rainy season. The binding media are; cement, cassava starch and makuba. Bashir(2012) recommended that makuba should be combined with cement or other pozzolans to observe possible improvements in the properties of soils. Yusuf (2014) recommended that makuba should be incorporated with other stabilizers to achieve the best with respect to moisture movement.

1.4 Aim and Objectives of the Study

1.4.1 Aim

This research is aimed at investigating the relationshipbetween the three binding media with respect to moisture movements in compressed stabilized earth bricks with a view to determining the area of application for each binder.

1.4.2 Objectives

1.To determine the physical properties of raw materials (Cassava and Makuba)

2.To establish an appropriate mix ratio of the binders

3.To assess the physical and mechanical properties of the brick samples produced

4.To determinethe relationship between the moisture movement of the brick samples

5. To established permeability characteristics of the bricks samples produced

1.5Research Methodology

The methodology adopted for this research work entails a review of journals, textbooks, published and unpublished research works, seminars, past projects, internet materials, etc so as to articulate existing knowledge on compressed stabilized earth bricks.Laboratory tests were carried out in conformity with relevant British standards. The bricks were tested for compressive strength, abrasion resistance, density, permeability, sorptivity, water absorption and adsorption at replacement combinationC0, C1, C2of cement, makuba and cassava starch as stabilizers. The curing period of 7, 14, 28 and 56days.All tests were conducted based on BS 1377: (1990).For the purpose of this research work however, soil stabilization techniques inferred by Adam and Agib (2001) is adopted.

1.6 Scope and Limitation

1.6.1 Scope

This research focus onmoisture movements and strength properties of compressed stabilized earth bricks. With respect to moisture movement only water absorption, adsorption, permeabilityand sorptivity tests was considered.

1.6.2 Limitations

1. **Only laterite soil from Sabon Gari Local Government area of Kaduna State was used.**
2. **Only cassava starchfrom Sabon Gari Local Government and Makuba from Gwarmai village,Kano State was used.**

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil and Soil Properties

2.1.1 Soil

“Soil is the layer of earth formed on the surface by weathering and the influence of all other environmental factors. The mineral and organic substances of soil are pervaded with air, water and life forms. Natural soil originates through the combined interaction of parent material (basis rock), climate, water, relief, topography, flora, and fauna. The conditions at each location produce different soil types with characteristic profiles and specific physical and chemical properties. Along with air, water, and sunlight, soil is the basis of life for plants and animals, including humans. Soil is used as a production base for agriculture and forest plantations. Soil is affected by human interventions, by being moved and removed, altered, and destroyed, such as by construction and industrial action(Aey, 1991).

The Geologist regards soil as the material in the relatively thin surface zone within which roots occur and all the rest of the crust is grouped under the term “rock” irrespective of its hardness. To the Engineer, soil is the ungraded or uncemented deposits of mineral and/or organic particles or fragments covering a large portion of the earth crust Tawfiq(2004). To the soil scientist, or pedologist, the word "soil" conveys a somewhat different meaning, but no generally accepted definition exists Jenny (1994). Hilgard (1914) defined soil as "the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment, as well as other conditions of growth." This is one of the many definitions that consider soil primarily as a means of plant production. Ramann (1928) writes: "The soil is the upper weathering layer of the solid earth

crust." This definition is scientific in the sense that no reference is made to crop production or to any other utilitarian motive.Jopte (1936), a representative of the Russian school of soil science, objects to Ramann's formulation on the grounds that it does not distinguish between soil and loose rock material. According to Jopte, the soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth, which differs from the parent material below in morphology, physical properties and constitution, chemical properties and composition, and biological characteristics.

2.1.2 Soil forming processes

There are five key processes by which soil is formed, they are:

2.1.2.1 Leaching

Leaching is the removal of soluable components of the soil column. As water washes down through the soil it can carry away bases such as calcium, held as exchangeable ions in clay-humus complexes, as well as acidification through the substitution of hydrogen ions (Jenny, 1994).

2.1.2.2 Eluviation

Here soil particles held in suspension, such as clay, are removed (eg. washed away).

2.1.2.3 Illuviation

Here soil particles held in suspension, such as clay, are accumulated (eg. deposited).

2.1.2.4 Podsolisation

Podsolisation occurs when strongly acid soil solutions cause the breakdown of clay minerals. As a result silica, aluminium and iron form complexes with organic substances in the soil. These minerals are removed from the surface zone of the soil and can accumulate in distinct dark sub-surface layers - very evident on inspection. Upland heaths and moors often contain podsols.

2.1.2.5 Gleying

Gleying occurs in waterlogged, anaerobic conditions when iron compounds are reduced and either removed from the soil, or segregated out as mottles or concretions in the soil. Marshy wetlands often contain gleyed soils. It is important to realise also that soil types are closely related to the shape of the landscape - or its 'topography'. Soil scientists use this to help them create soil maps. An experienced eye can determine changes in underlying soil types when walking through a landscape and observing changes in topography (and often vegetation too) (Jenny, 1994).

2.1.3 Weathering processes

One important influence on the formation of soils is weathering. There are two main categories of weathering, both having different effects:

2.1.5 **Physical weathering**

2.1.5.1 Freezing and Thawing: **Here, the expansive force of water pushes the soil structures apart. Water expands considerably when frozen and this expansion literally pushes the soil apart, breaking it down. When the ice thaws the soil can slump back again. The overall process is rather like a very slow 'churning'. Freeze-thawing can literally grind mountains down over time.**

2.1.5.2 ***Heating and Cooling***

Here soils subjected to extremes of temperature are affected as they expand and contract. The effect is less pronounced that that of freezing and thawing but over time this can become significant.

2.1.5.3 ***Wetting and Drying***

Soils that are wetted up may be prone to swelling. Clay minerals in particular exhibit this property. The soils that have thus expanded then shrink when the soils dry out. These seasonal effects are termed shrinkage and swelling. Many household claims for subsidence are based upon such shrinkage and swelling of clays under foundations.

2.1.5.4 **Grinding or Rubbing**

Most obvious on the beach, grinding of particles against each other leads to particle disintegration. This is why beach pebbles become smooth. Abrasion similarly breaks down the soil particles.

2.1.5.5 ***Organisms***

The effect of organisms, plants and animals, living in the soil cannot be overstated. Soil is home for a wide range of organisms. If plants can push through concrete - soil presents little obstacle! Worms churn their way through soil, mixing and aerating it all through their lives and there can be thousands of worms in a field.

2.1.5.6 ***Unloading***

When pressure is placed upon soil it becomes compressed. Never mind tractors, imagine the weight of a glacier! When ice melts a huge weight is lifted and the soils may react accordingly by uplifting and expanding(http://www.soil-net.com, 2001).

2.1.6Chemical weathering

2.1.6.1 Solution

Certain solid components in the soil can be dissolved in soil water. In this way underground caverns can form in limestone karst landscapes. The name Karst comes from the Krass plateau in Slovenia where there are some of the most magnificent cave systems anywhere in the world - valley sized caves!

*2.1.6.2 **Hydrolysis***

Certain compounds in the soil can react to elements in the water.

*2.1.6.2 **Carbonation***

Soil compounds can react with carbonic acid.

2.1.6.3 **Hydration**

Water in the soil can act to change the chemical structure of the soil components.

*2.1.6.4 **Oxidation***

Oxygen in the soil can act to change the chemical structure of the soil components.

*2.1.6.5 **Reduction***

A lack of oxygen in the soil can act to change the chemical structure of the soil components (http://www.soil-net.com, 2001).

2.2 Soil classification according to particle size

“Soil characteristics and climatic conditions of an area must be evaluated before manufacturing soil building blocks. A dry climate, for example, needs different soil blocks from those used in temperate, rainy or tropical areas. All soils are not suitable for every building need. The basic material, however, required to manufacture compressed stabilized earth building blocks is a soil containing a minimum quantity of silt and clay so as to facilitate cohesion. Soils are variable and complex materials, whose properties can be modified to improve performance in building construction by the addition of various stabilizers. All soils consist of disintegrated rock, decomposed organic matter and soluble mineral salts. Soil types are graded according to particle size using a system of classification widely used in civil engineering. This classification system, based on soil fractions shows that there are 4 principal soil fractions - gravel, sand, silt and clay”.

Table 2.0 Size ranges of particles

Name of fraction		Diameter size ranges of particles (mm)
Gravel	Coarse gravel	20.000 - 60.000
	Medium gravel	6.000 - 20.000
	Fine gravel	2.000 - 6.000
Sand	Coarse sand	0.600 - 2.000
	Medium sand	0.200 - 0.600
	Fine sand	0.060 - 0.200
Silt	Coarse silt	0.020 - 0.060

	Medium silt	0.006 - 0.020
	Fine silt	0.002 - 0.006
Clay	Clay	less than 0.002

Source: Wang (2010)

From the table the mediumsand which from 0.200- 0.600mm was the type of soil used in stabilization while for the silt the British Standard have specified that the amount of silt in soil should not exceed 8%, and the fine silt is the most common in soil. The clay fraction carry the highest percentage in soil and is always less than 0.002mm.

2.3 Soil Structure

All the effects of soil forming processes, weathering, translocation leaching and so on leave the soil with a particular 'structure'. Soil structure refers to the shape, size and degree of development of the aggregation, if any, of the primary soil particles into naturally or artificially formed structural units and to their spatial arrangement. In describing soil structure, we refer to soil 'peds' and soil fragments or 'clods'.

Soil peds are natural, relatively permanent aggregates, separated from each other by voids or natural surfaces of weakness. Peds persist through cycles of wetting and drying. Soil Fragments and Clods are artificial structural units, formed at or near the surface by cultivation or frost action, and are not peds.

2.4 Soil Profile

The soil profile is one of the most important concepts in soil science. It is a key to understanding the processes that have taken in soil development and is the means of determining the types of soil that occur and is the basis for their classification. The soil profile is defined as a vertical section of the soil from the ground surface downwards to where the soil meets the underlying rock. The soil profile can be as little as 10 cm thick in immature soils and as deep as several metres in tropical areas where the climate is conducive to rapid alteration of the underlying rock to form soil. In temperate areas, the soil profile is often around a metre deep and in arid areas somewhat shallower than this (Panshali, 2011).

2.5 Soil Functions

Soil has always been important for the foundation platform of buildings, roads and other communications and never more so. There is an ever increasing need to expand the number of dwellings and the supporting communication network. The problem with this is that buildings and engineering structures such as roads 'seal' the soil and negates the use of land for other purposes in the future. The nature of the soil, be it sandy, silty or clayey, has an important influence on the foundations to the structures and the measures that need to be taken to ensure stability to the structures (Panshali, 2011).

2.6 Laterite Soil

Among the various soil types that occur in the tropics and sub-tropics, laterite are of special interest in conjunction with building construction. These are highly weathered soils, which contain large, though extremely variable, proportions of iron and aluminium oxides, as well as quartz and other minerals. They are found

abundantly in tropics and sub-tropics, where they generally occur just below the surface of wide grasslands or forest clearing in regions with high rainfall. The colour can vary from ochre through red, brown, violet and black, depending largely on the concentration of iron oxides (Ajayi, (1985).

The special characteristics of laterites, by which they differ from other soils, are;

***2.6.1* Soft occurrences tends to harden on exposure to air, which is why blocks have**

traditionally (eg in India) been cut in situ, allowed to harden and then used for masonry wall construction (hence the name was derived from "later", the latin word for "brick")

***2.6.2* The darker the laterite, the harder, heavier and more resistant to moisture it is.**

***2.6.3* Some laterites are found to have pozzolanic reaction when mixed with lime**

(which can be explained by the high clay content) producing hard and durable building materials (e.g stabilized blocks) (Ajayi, 1985).

2.7Soil Stabilization

Modifying soil properties by adding another material to improve its durability is called soil stabilization (Adam and Agib 2001). Olaoye (2004) also defined soil stabilization as the alteration of any property of a soil in order to improve its engineering performance. Soil stabilization has been widely used since the 1920s

mainly for road construction. Successful stabilization of soil results in one or more of the following;

1. **Increase in strength and cohesion of the soil**
2. **Reduction in permeability of the soil**
3. **Making of the soil water repellant**
4. **Increase in the durability of soil or**
5. **Reduction in shrinkage and expansion of the soil in dry and wet conditions**

The art of soil stabilization is not new. Kulkarni (1973) noted that Indians have stabilized soils from pre-historic times up to 600 BC. These stabilized soils were used for constructing mud walls, for fabricating bricks, for applying a waterproof plaster to walls and sometimes for preparing statutes of gods and goddesses and also for applying waterproof plaster to these idols. Adam and Agib (2001) also observed 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 been introduced, developed mainly from early techniques devised mainly for stabilization of earth roads (Ramson, 2005).

2.8Soil Stabilizers

A number of stabilization methods have been identified by various authors. However some of the stabilization methods such as the chemical stabilization involve the use of a wide range of additives in order to achieve a desired result. Adam and Agib (2001) noted that stabilizers in use include manufactured ones such as Portland cement, lime, bitumen, gypsum, alkalis, sodium chloride, calcium chloride, polymers and the natural ones agricultural and industrial wastes. Other natural stabilizer earlier mentioned include natural oil and plant extracts, animal dung and crushed ant-hill materials, bird droppings and animal blood have been used for the manufacture of compressed stabilized earth building blocks. The waste materials generally consist of nitrogenous organic compounds which help to bind together soil grains. Cassava starch has also been scientifically established by Khalil (2005) to impart stabilization characteristics to a wide range of soil types.

2.9 **Stabilization Techniques**

Various researchers have classified soil stabilization Techniques into a number of methods. For instance Spence and cook (1983) classified soil stabilization into three methods namely;

1. **Stabilization by Mechanical compaction**
2. **Stabilization by addition of binders and**
3. **Stabilization by addition of water proof**

Houben and Guiland (1994) on the other hand classified soil stabilization into;

1. **Mechanical stabilization**
2. **Physical stabilization and**
3. **Chemical stabilization.**

2.9.1 Mechanical stabilization

Adam and Agib (2001) noted that mechanical stabilization involves tamping or compacting the soil by using a heavy weight to bring about a reduction in the air void volume, thus leading to an increase in the density of the soil. The main effects of compaction on the soil are to increase its strength and reduce its permeability. The degree of compaction possible, however, is affected greatly by the type of soil used, the moisture content during compaction and the compression effort applied. Best results can be obtained by mixing the correct proportions of sand and clay in a soil. More recent developments for roads and embankment construction have led to compacting soil with vibrating rollers and tampers. Tampers and block-making presses are also used for single storey constructions. The major drawback of mechanically compressed stabilized earth blocks is their lack of durability especially in places of moderate to high rainfall. Manual stabilisation or compaction methods vary from foot treading to hand tamping equipment, with compacting pressures varying between 0.05 to about 4MN/m^2. Mechanical equipment may achieve compacting pressures of several thousand MN/m^2.Olaoye (2004) averred that the mechanical compaction is the most economical means of soil stabilization.

2.9.2 Cement Stabilization

“Ordinary Portland cement hydrates when water is added; the reaction produces a cementitious gel that is independent of the soil. This gel is made up of calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The cementation process results in deposition between the soil particles of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel. Penetration of the gel throughout the soil hydration process is dependent on time, temperature and cement type. The lime released during hydration of the cement reacts further with the clay fraction forming additional cementitious bonds(Adam and Agib 2001).

Soil-cement mixes should be compacted immediately after mixing in order not to break down the newly created gel and therefore reduce strengthening. The basic function of cementation is to make the soil water-resistant by reducing swelling and increasing its compressive strength. With respect to the general processes of cementation, penetration and binding mentioned above, many factors must be considered. Processes may also vary between different types of soils. Cement is considered a good stabiliser for granular soils but unsatisfactory for clays. Generally cement can be used with any soil type, but with clays it is uneconomical because more cement is required. The range of cement content needed for good stabilization is between 3% and 18% by weight according to soil type” (Adam and Agib 2001).

It has also been established that there is relationship between linear shrinkage and cement content need for stabilization. Table 2.1 shows that cement to soil

ratio ranges between 5.56% and 8.33% for measured shrinkage variation of between 15mm to 60mm.

Table 2.1 – Relationship between cement to soil ratio for Shrinkage

Measured Shrinkage (mm)	Cement to soil ratio
Under 15	1:18 parts (5.56%)
15-30	1:16 parts (6.25%)
30-45	1:14 parts (7.14%)
45-60	1:12 parts (8.3%)

Source: Adam and Agib (2001).

Adam and Agib also noted that for a given shrinkage, the cement to soil ratio is a function of compaction effort exerted. For example, a CINVA Ram machine exerts a compaction pressure of about 2MN/m^2, by increasing this pressure to about 10MN/m^2 the cement content can be reduced to between 4% and 6% for soil with shrinkage of up to 25mm. Over this shrinkage value, 6% to 8% cement would need to be used for effective stabilization.

2.9.3 Lime Stabilization

Adam and Agib (2001) further reported that by adding lime to the soil for stabilization, four basic reactions are believed to occur: cation exchange, flocculation and agglomeration, carbonation, and pozzolanic reactions. The pozzolanic reaction is believed to be the most important and it occurs between lime and certain clay minerals wto form a variety of cementitious compounds which bind the soil particles together. Lime can also reduce the degree to which the clay absorbs water, and so can make the soil less sensitive to changes in moisture content and improve its workability. Lime is a suitable stabilizer for clay soils. Lime is more widely available than Portland cement in Sudan (and

other developing countries) and is produced locally in traditional kilns. However, some improvements still need to be made in its production and processing.

The advantages that lime has over Portland cement are that it requires less fuel to manufacture and requires relatively simple equipment to make. It is therefore more suitable for village scale production and use.

It has been reported that when lime is used as a stabiliser instead of cement, the quantity needs to be doubled. However Adam and Agib (2001) show that such doubling is not necessary if a sufficiently high compacting effort is applied on a high clay content soil. The reduction in the volume of air voids brings the lime and soil particles into closer contact and the stabilising reactions can take place more easily. Tests show that wet compressive strengths of between 3MN/m^2 and 3.5MN/m^2 may be achieved with compacting efforts in the range of 8 to 14MN/m^2. Blocks made from Sudanese black cotton soils are tested using wide range of compaction pressures. A 6% lime content is used for stabilizing black cotton soil from Sudan with a silt and clay content of 58% and a linear shrinkage of 11%.

2.9.4 Bitumen Stabilization

Bitumen stabilization has been described by Ujene (1999) as a chemical method of soil stabilization. Adam and Agib (2001) identified two ways by which bitumen can stabilize soils. The first way is through a binding process that increases strength particularly in granular soils. Generally, small amounts of bitumen (2% to 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. Clay need large amount for a good result. The main disadvantages of bituminous materials as stabilizers are;

i. they are not traditional building materials in most developing countries,

ii. they are expensive to import,

iii. cost of preparation (i.e. heating, storing and mixing) is high,

iv heat can have adverse effect on their binding properties especially in hot countries

2.9.5 Gypsum Stabilization

Gypsum is used in the early civilization for building mainly for plaster and mortar. It is a traditional material in the Mediterranean and Middle East countries. The advantage that gypsum has over Portland cement and lime is that it requires a low calcination temperature (about 1/7th of that needed for cement and 1/5th of that needed for lime).Besides its agricultural and chemical uses, one of the main uses of gypsum is in the production of Portland cement where it retards the setting of the cement. Gypsum is a good stabiliser for sandy soils (Kawalski et al, 2007).

2.10Soil Compaction

"Soil compaction is defined as the method of mechanically increasing the density of soil. In construction, this is a significant part of the building process. If performed improperly, settlement of the soil could occur and result in unnecessary maintenance costs or structure failure. Almost all types of building sites and construction projects utilize mechanical compaction techniques. The reasons for compaction includes

1. Prevents soil settlement and frost damage.

2. **Provides stability.**
3. **Reduces water seepage, contraction and swelling.**
4. **Reduces settling of soil.**

We have four basic types of compaction which are

1. **Vibration.**
2. **Impact.**
3. **Kneading.**
4. **Pressure.**

These different types of efforts are found in the two principle type of compaction force which are the

1. Static Force: is simply the deadweight of the machine, applying downward force on the soil surface, compressing the soil particles. The only way to change the effective compaction force is by adding or subtracting the weight of the machine. Static compaction is confined to upper soil layers and is limited to any appreciable depth. Kneading and pressure are two examples of static compaction.

2. Vibratory Force: uses a mechanism, usually engine-driven, to create a downward force in addition to the machine's static weight. The vibrating mechanism is usually a rotating eccentric weight or piston/spring combination (in rammers). The compactors deliver a rapid sequence of blows (impacts) to the surface, thereby affecting the top layers as well as deeper layers. Vibration moves through the material, setting particles in motion and moving them closer together for the highest density possible. Based on the materials being compacted, a certain amount of force must be used to overcome the cohesive nature of particular particles (Khalil (2005).

2.11Stabilized Earth Bricks

Brick making remains an important industry in many rural and peri-urban areas, but the income it provides can be a very marginal one. Often there are large numbers of producers and the quality of bricks produced can vary greatly. Stabilized Earth Brick technology (also known as Stabilized Compressed Earth Block (SCEB)) allows producers to easily manufacture higher quality bricks and as a result receive a higher income for themselves (http://www.earth-auroville.com, 2009)

2.12Compressed Earth Bricks

At the inception in 1976 of Habitat for Humanity International, a major provider of housing for the world's poor, one of the first decisions made by the board of directors was to use locally-available materials as much as possible. This choice is the basis of a more sustainable building system, which is empowering to the people of the community, and better for the environment (Rigassi, 1995). In my experience teaching in Africa and elsewhere we have often used Compressed Earth Block.

Rigassi, (1995) also described Compressed Earth Block (CEB) as 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, so that in many countries they have seen widespread use. 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, labor force, and most importantly, the preference of the homeowner. Hand-operated presses have been used for many decades. Before that, and still today, some people make the blocks by beating soil into a wooden mold with a stick. "Rammed earth" is a similar process, in which case a structure is made as one continuous mass.
Modern equipment, with hydraulics driven by diesel, gas or electric motors, may be useful in urban areas or for large multi-house sites (Rigassi, 1995).

2.12.1 Physical characteristics of compressed earth brick (CEBs)

Research is currently underway at Texas University (2011) to determine the physicalcharacteristics of compressed earth blocks. The testing procedures for defining these coefficients are based on Uniform Building Code Sections 21.906 - 21.911. A review of the literature indicates that there is considerable knowledge about the soils needed to make good CEBs, but little is known about the physical characteristics of the compressed earth blocks when used in walls, either as a veneer or as solid or multi-Wythe walls. Proper placement of movement control joints in walls made with these materials will help to improve their service performance and durability. Soil mix designs, combining sand, silt and clay, to make blocks that can pass the modulus of rupture and compressive strength requirements of the earthen building codes, are pretty well understood. The following coefficients will serve as a point of departure for design professionals to use when locating movement control joints in their structures to accommodate the stresses walls may have applied to them so cracks do not occur. The

coefficients shown here are conservative in their values to accommodate a wide range of soils and manufacturingProcesses (British Standards Institution, 1990).

2.12.2 The environmental advantages of building with stabilized compressed earth bricks

Earth building using Anyway's new line of products has much to offer those who place value upon environmental sustainability. It enables us to incorporate the land we live on into our buildings, saves energy both in the process of creating the building materials and in importing them to the building site, creates more efficient thermal and acoustic isolation, and adapts itself to the local environment in which we live.

In the last years has arisen a global movement that emphasizes the need to use advanced technologies in the building process which protect and preserve the world we live in. Anyway's innovative technology enables the use and recycling of local readily available materials while creating strong and easy to use earth blocks. (www.google.com, 2014).

2.13 Cost and Energy Efficient in Production

The cost of an Earth Block wall system is about 40% cheaper than conventional systems. Earth Blocks are made on-site, saving in transportation costs and fuel consumption while requiring little energy in the block making process.

2.14Cost and Energy Efficient through the Lifespan of the Building

Earth Block building creates incredible energy savings for the owner throughout the life of the building. The thermal mass quality of Earth Blocks alone can offer the owner savings of up to 14% on cooling and heating costs. When the owner's home energy requirements are reduced this much, the community saves as well (Heinz, 1981).

2.15 Portland Cement

Cement is define as any material that has adhesive and cohesive properties that makes it possible to find fragment materials together so as to produce a continuous compact mass of masonry (Garba, 2004). Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. It consist of a mixture of oxides of calcium, silicon and aluminium. Portland cement and similar materials are made by heating limestone (a source of calcium) with clay, and grinding this product (clinker) with a source of sulphate (most commonly gypsum) (Garba, 2004).

Ordinary Portland cement (OPC) is the most common use cement today out of many others.It is fine, grey powder that can be mixed with sand, gravel and water to produce a strong and long lasting mortar or concrete (Roland and Kiran, 1993). Portland cement are the most produced and used cement types in the construction industry (Garba, 2004).

As the Cassava peel ash content is increased from 0% to 40%, the initial setting time was found to increase from 95 minutes to 140 minutes and the final setting time increased from 155 minutes to 230 minutes (Ogunbode, 2012).

2.16 Cassava Starch Production

Starch is one of the most abundant substances in nature, a renewable and almost unlimited resource. Starch is produced from grain or root crops. It is mainly used

as food, but is also readily converted chemically, physically, and biologically into many useful products to date, starch is used to produce such diverse products as food, paper, textiles, adhesives, beverages, confectionery, pharmaceuticals, and building materials. Cassava starch has many remarkable characteristics, including high paste viscosity, high paste clarity, and high freeze-thaw stability, which are advantageous to many industries (IITA, 2005).

Cassava starch is produced primarily by the wet milling of fresh cassava roots but in some countries such as Thailand it is produced from dry cassava chips. Starch is the main constituent of cassava. About 25% starch may be obtained from mature, good quality tubers. About 60 % starch may be obtained from dry cassava chips and about 10 % dry pulp may be obtained per 100 kg of cassava roots. Fresh tubers are processed during season and dry chips during the off-season in some countries. Extraction of starch from fresh cassava roots can be divided into five main stages: preparation (peeling and washing), rasping/pulping/grating, purification (starch washing), dewatering and drying, and finishing (milling and packaging).

Cassava starch has a variety of uses. Dextrin pre-gelled cassava starch are used for adhesive while starch and hydrolysates are used for pharmaceuticals and seasoning, (Kormawa and Akoroda, 2003). The starch was also observed to find application in the Textile for sizing and dying to increase brightness and weight of cloth (Tonukari, 2004). Tonukari further asserted that cassava starch is also an important raw material for powder in the cosmetics industries. In detergent soap manufacture, starch is used to get better recovery and to improve the shelf life of detergents. While in the rubber and foam industries, starch is employed for getting better foaming and color.

The construction industry is not an exception in the application of cassava starch. Cassava starch has several other numerous uses such as an additive in cement to improve the setting time, and it is used to improve the viscosity of drilling mud in oil wells. It is also used to seal the walls of bore holes and prevent fluid loss (Khalil, 2005).

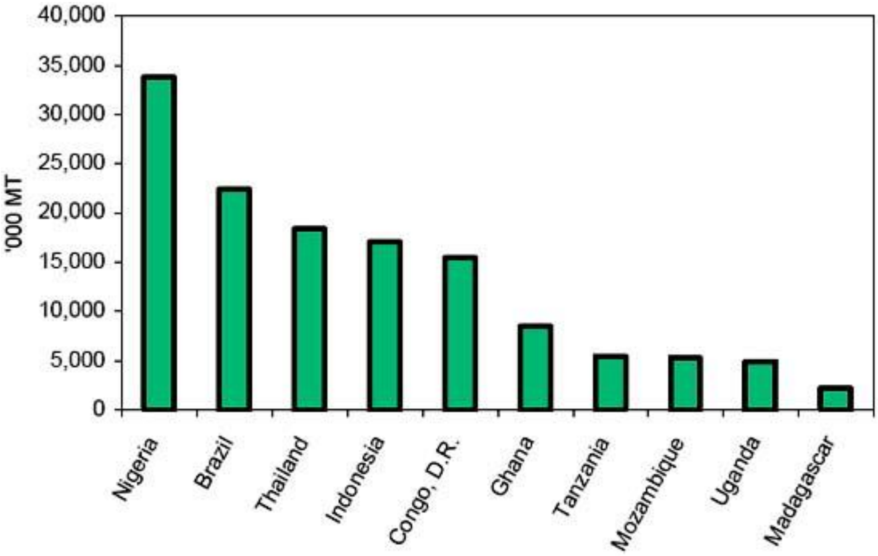
“In Nigeria, cassava is one of the basic starchy foods. It has many names given to it by the many ethnic groups in Nigeria. Example, the Hausa calls it Rogo, the Yoruba calls it Ege while the Igbo calls it Akpu. In Nigeria it is not normally grown alone because it takes a longer time before it matures. For this it is grown together with other crops examples are maize, melon, and many others. Nigerian cassava production is by far the largest in the world; a third more than production in Brazil and almost double the production of Indonesia and Thailand. Cassava production in other African countries, the Democratic Republic of the Congo, Ghana, Madagascar, Mozambique, Tanzania and Uganda appears small in comparison to Nigeria’s substantial output (Adebowale, 2004).

2.16.1 Modified starches

For those characteristics, which are unattainable with native starch, modified starch can be used for other industrial applications through a series of techniques, chemical, physical, and enzymatic modification. Thus, modified starch is native starch that has been changed in its physical and/or chemical properties. Modifications may involve altering the form of the granule or changing the shape and composition of the constituent amylase and amyl pectin molecules. Modifications are therefore carried out on the native starch to confer it with properties needed for specific uses. Some of these modified starches, their methods of modification and desirable properties are shown in Table 6. When a starch is modified chemically or physically, the properties of the native starch is altered. Various modifications give the starch properties that make it useful in many industries such as food, pharmaceutical, textile, petroleum, and paper pulp industries. The different ways of modifying native starch consist in altering one or more of the following properties: paste temperature, solids/viscosity ratio, starch paste resistance to reduction of viscosity by acids, heat and or mechanical agitation (shear), retro gradation tendencies, ionic and hydrophilic nature. Modifying starch is important to provide the following properties: thickening, gelatinization, adhesiveness and/or film-formation, to improve water retention, enhance palatability and sheen and to remove or add opacity(Abdulfatah, 2010).

The reasons why native starch is modified are:

i. **To modify cooking characteristics (gelatinization).**
ii. **To reduce retro gradation.**
iii. **To reduce paste's tendency to gelatinize.**
iv. **To increase paste's stability when cooled or frozen.**
v. **To increase transparency of pastes and gels.**
vi. **To improve texture of pastes and gels.**
vii. **To improve adhesiveness between different surfaces, such as in paper applications.**



Source: Field work (2004).

Figure 2.1: Leading World Producers of Cassava

Nigerian cassava production is by far the largest in the world350000 million tones; a third more than production in Brazil and almost double the production of Indonesia and Thailand. Cassava production in other African countries, the Democratic Republic of Congo, Ghana, Madagascar, Mozambique, Tanzania and Uganda appears small in comparison to Nigeria's substantial output (Adebowale, 2004).

2.16.2-Geographical-distribution

Native : Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Democratic Republic of Congo, Gambia, Ghana, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Sao Tome et Principe, Senegal, Sierra Leone, Sudan, Togo, Uganda

Exotic : Antigua and Barbuda, Barbados, Cuba, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, St Lucia, St Vincent and the Grenadines, Trinidad and Tobago, Virgin Islands (US) (Nelson, http://www.habitat.org, 2002).

2.16.3 Functional uses of makuba

Food: Seeds are fermented to make daddawa, a black, strong-smelling, tasty food high in protein. Dried fermented seeds keep for more than a year in traditional earthenware pots without refrigeration, and small amounts are crumbled during cooking into traditional soups and stews that are usually eaten with sorghum- or millet-based dumplings and porridges. Because of the savoury taste and the high protein and fat values of the seed, it is sometimes described as a meat or cheese substitute, but it is not usually eaten in large amounts. The fat in the beans is nutritionally useful (approximately 60% is unsaturated). Seeds are used as a coffee substitute. Seeds are embedded in a mealy pulp sometimes called dozim, that is high in energy value. It contains up to 29% crude protein and up to 60% saccharose, is rich in vitamin C and high in oil content. The pulp is eaten raw or made into a refreshing drink and is used as a sweetener. For storage, it is pressed into a cake. The fruit provides emergency food during severe droughts. Young pods are sometimes roasted on embers and eaten. Leaves are edible but not commonly eaten. The leaves are mixed with cereal flour and eaten or fermented into balls and used in sauces. Fodder: Whole pods are eaten by domestic stock, including cattle. The young seedlings are nutritious and heavily browsed by livestock. An important attribute of P. biglobosa trees is that most of their leaves remain green throughout the dry season and branches are lopped and used as fodder. Seeds are rich in calcium, sodium, potassium and phosphorus (Nelson, http://www.habitat.org, 2002).

2.17Moisture Content Movement

Burnt clay units exhibit little movement with changes in moisture content. Movement is normally not more than 1 mm in every 10 m of length and rarely

more than 2 mm in every 10 m of length. This movement is reversible(Heinz, 1981).

2.17.1 Thermal movement in earth bricks

‘’ Masonry walls on building exteriors are subjected to both reversible and non-reversiblemovements. Movements include expansion and contraction that are the result of changes intemperature and moisture content. Movements caused by changes in temperature are generallyconsidered to be reversible, while those caused by moisture absorption in clay masonry units and shrinkage of concrete masonry units are typically not reversible (Joseph et al,1994).

Most building materials, masonry walls of earth, whether of sun dried adobe bricks,rammed earth, or compressed earth blocks, respond to changes in moisture and temperature.

2.18 Movement of water under saturated conditions

Poiseuille’s law forms the basis for a number of different equations which have been developed for determining the hydraulic conductivity of the soil for knowledge of

its pore-size distribution. Pore size is of outstanding significance, as its fourth power is

proportional to the rate of saturated flow. This indicates that saturated flow under otherwise identical conditions decreases as the pore size decreases. Generally the rate of

flow in soils of various textures is in the following sequence (Hall, 1977).

2.19 Moisture movement under unsaturated conditions

As drainage proceeds in a soil and the larger pores are emptied of water the contribution of the hydraulic head or the gravitational component to total potential becomes progressively less important and the contribution of the matric potential ψm becomes more important. The effect of pressure is generally negligible because of the continuous nature of the air space. The solute potential (osmotic potential) ψs does not affect the potential gradient unless there is unusual concentration of slat at some point in the soil. The negligible effect of solute potential is due to the fact that both solutes and water are moving. Thus, in moisture moment under unsaturated conditions, the potential ψ (Equation 7.28) is the sum of the matric potential ψm and, to some extent the gravitational potential ψg. In horizontal movement, only ψm applies. Under conditions of downward movement, capillary and gravitational potentials act together. In upward capillary movement ψm and ψg oppose one another (Vos,1969).

2.20 Permeability

Permeability is a soil property indicating the ease with which water will flow through the soil. Permeability depends on the particle size distribution of the soil grains void ratio of the soil shapes and arrangement of pores degree of saturation properties of the pore fluid (especially viscosity) (Samarasinghe, 1982).

2.20.1 Laboratory methods typically used for measuring the permeability coefficient:

i. Variable-head (falling-head) test
ii. The constant-head test (ASTM D 2434)
iii. The capillary method
iv. Back calculation from the consolidation test

Generally, soils which contain 10% or more particles passing the No. 200 sieve are tested using the *falling-head* method. The *constant-head* method is limited to disturbed granular soils containing not more than 10% passing the No.200 sieve (Samarasinghe, 1982).

2.21 Sorptivity

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used of the test fluid. The cylinders after casting were immersed in water for 90 days curing. The specimen size 100mm dia x 50 mm height after drying in oven at temperature of 100 + 10 °C were drowned in water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating. The quantity of water absorbed in time period of 30 minutes was measured by weighting the specimen on a top pan balance weighting upto 0.1 mg. surface water on the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 seconds. Sorptivity (S) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (Claisse, 1997).

2.22Difference between Absorption and Adsorption

Absorption is the process in which a fluid is dissolved by a liquid or a solid (absorbent). Adsorption is the process in which atoms, ions or molecules from a substance (it could be gas, liquid or dissolved solid) adhere to a surface of the adsorbent. Adsorption is a surface-based process where a film of adsorbate is created on the surface while absorption involves the entire volume of the

absorbing substance.Adsorption and absorption are both sorption processes, Absorption occurs when atoms pass through or enter a bulky material. During absorption, the molecules are entirely dissolved or diffused in the absorbent to form a solution. Once dissolved, the molecules cannot be separated easily from the absorbent (Yanful, 1989).

2.22.1 Uses of Absorption and Adsorption

i. **Absorption**: The common commercial uses of absorption cycle are absorption chillers for space cooling applications, ice production, cold storage, turbine inlet cooling. High efficiency operation, environmentally friendly refrigerants, clean-burning fuels and few moving parts that require maintenance make absorption a very good choice for consumers. The process of gas absorption by a liquid is used in hydrogenation of oils and carbonation of beverages

ii. **Adsorption**: Some of the industrial applications for adsorption are air-conditioning, adsorption chillers, synthetic resin and water purification. An adsorption chiller does not require moving parts and hence is quiet. In pharmaceutical industry applications, adsorption is used as a means to prolong neurological exposure to specific drugs or parts thereof. Adsorption of molecules onto polymer surfaces is used in various applications such as in the development of non-stick coatings and in various biomedical devices.

2.23 Mechanism of Moisture Movement During Drying

2.23.1 Diffusion theory of drying

In the general form of the curve for the rate of drying of a solid there are two and sometimes three distinct sections. During the constant-rate period, moisture vaporises into the air stream and the controlling factor is the transfer coefficient

for diffusion across the gas film. It is important to understand how the moisture moves to the drying surface during the falling-rate period, and two models have been used to describe the physical nature of this process, the diffusion theory and the capillary theory. In the diffusion theory, the rate of movement of water to the air interface is governed by rate equations similar to those for heat transfer, whilst in the capillary theory the forces controlling the movement of water are capillary in origin, arising from the minute pore spaces between the individual particles(Vos,1969).

2.23.2 Capillary movement of moisture in drying

Water can flow from region of high concentrations to those of low concentrations as a results of capillary action rather than by diffusion if the pore size of granular materials are suitable . The capillary theory assumes that a packed bed of nonporous spheres contains a void space between the spheres called pores. As water is evaporated, capillary forces are set up by the interfacial tension between the water and solid. These forces provide the driving force for moving the water through the pores to the drying surface (Vos,1969).

CHAPTER THREE

Materials and Methods

3.1 Preamble

The experiment carried out in this research work was based on assessing the effects of three binding media, strength characteristics and moisture movement of compressed earth bricks. The experiment consist of the physical properties of laterite soil and mechanical properties of the brick samples produced.Three levels of stabilization are C0, C1 and C2. Makuba and cassava starch paste

content by weight were adopted as the mixing water from the trial test result. The experiment was conducted in the laboratory of Building, Ahmadu Bello University, Zaria.

3.1.1 Materials

The materials used for this study for the production of three binding media stabilized bricks are laterite, cement, makuba, cassava starch and water.

3.1.2 Soil sample

The soil type used in these experiments was laterite obtained from Sabon Gari local Government, Kaduna State. The laterite sample was sieved through the 4.76mm standard sieve size and particles retained are weighed.

3.1.2 Cement

The cement used in this research work was ordinary Portland cement which was obtained in samaru market in its powdered form and it is 50kg per bag.

3.1.3 Cassava starch

The starch used in this research work is artificially produced, which was obtained in its soluble state and air dried to be in powder form.

3.1.4 Starch source

The starch was obtained from the Sabon-gari, Sabon-gari Local Government Area of Kaduna State, Nigeria. It was manually processed in wet form and it was air dried and tested.

3.1.5 Makuba

The makuba used in this research work is naturally produced, obtained from locus bean tree. The seeds and the pods were removed and the peels were used only throughout the experiment.

3.1.6 Makuba Source

The makuba was obtained from Gwarmai area of Kano State, Nigeria.

3.1.7 Water

The water used in the experiments was portable drinking water from tap deemed fit for human consumption.

3.2 METHODS

3.2.1 Quantity of Mixing Water

Mass of water for a brick at 12% OMC = 300g

Number of bricks produced = 108 (from appendix)

Mass of water = 300g X 108 = 32,400g

Mass of water per level of concentration = 32,400g/3 = 10,800g

3.2.2 Production of Brick Samples

3.2.2.1 Trial brick production

The experiment begun with determining the optimum mixing water for the production of bricks. The trial bricks samples were produce using mixing water adopted from the literature. The mix design for all the combinations used starch-makuba/water slurry as the mixing water.(150 x 300 x 80) mm rectangular bricks

were used for the trial mix. Eight (8) different replacement combinations were tested for compressive strength at 7days,and 24 bricks were produced to obtain the best among the combinations as shown in the figure 3.1 below. The compressive strength of 0.68N/mm^2, 1.03 N/mm^2 and 1.08N/mm^2 were recorded for C0, C2 and C1 respectively. Impressive results were obtained with the mixing water used. Therefore, the mixing water was adopted for this research due to 1.08 N/mm^2 as higher compressive strengthobtained at 7days. Therefore, prior to low strength obtained at C0 replacement there is need for the three binding media to increase the compressive strength and improve other significant properties of brick samples for the final mix.

3.2.3 Main brick production

A total of 108 bricks of 140 x 140 x 80 mm were produced to study the physical and mechanical properties of each brick samples. The materials were weighed, batched thoroughly and hand-mixed to obtained homogenous sample specimen. Lubricant was applied to the interior of the mould to prevent bricks from sticking to the mould, and the sample was compressed with the NBRRI manual compressive machine at 10 presses and the fresh brick sample was leveled. All brick samples were cured for the period of (7, 14, 28 and 56 days). Three mixes were prepared which include: the control and two others with the binder ratio. Binders and water was measured in percentages by weight of laterite used. The bricks were kept under room temperature in the laboratory to be air-dried.

Physical Properties of Laterite;

3.3.4 Field settling test

Aim: Determination of the percentage of silt in the soil.

Materials: water, soil sample and sodium chloride.

Apparatus: Measuring Cylinder (250ml), stirrer, metric rule and weighing balance.

Procedure: this test was conducted according to BS 812: Part 2 (1975):, which stipulated a maximum limit of silt in soil to be not more than 8% as shown in table 4.1.1.

1% prepared salt solution (sodium chloride) was poured into the 250ml measuring cylinder to the 50ml mark was reached. The mixture was vigorously shaken and left to settle in the measuring cylinder for 3 hours.

The thickness of visible silt layer formed at the surface was measured and the depth of the sample excluding the silt layer was also measured.

The ratio of the depth of silt layer to that of sample in percentage obtained was compared to the 8% specified by BS 812: Part 2 (1975).

Significance: Excess quantity of silt and impurities adversely affect the quality of soils and might also reduce the bond between soil particles and stabilizer. Thus, it is important to ensure the cleanliness of the soil as well as the proportion of the different particle sizes which agreed general.The result of this test are presented in Table 4.1.1

3.2.5 Sieve analysis

Procedure: Conducted in accordance with BS 410: 1976.

Sieve analysis involves passing a representative sample of the dry materials through a stack of nest of sieves in accordance with BS 410: 1976 with the largest mesh first. Sieving can be performed manually by shaking each sieve separately for at least two minutes or mechanically by the use of a sieve shaker for three to four minutes per stack of sieves.

Sieving was done manually and the weights of materials retained on each sieve and receiver was recorded.

Significance: This test is used to predict the size distribution and the relative percentages of the particles of each sample.

3.2.5 Specific gravity

Procedure: Conducted in accordance with BS 1377: 1990.

A Pycnometer (glass bottle with conical brass top of mass 525g) was used for this test. Some of the sample was placed in the bottle and weighed. Some water was added into the sample and stirred intimately to release entrapped air. The conical brass was tightly screwed and topped with water through the small opening at the top. The outside of the Pycnometer was wiped dry and weighed. The Pycnometer was emptied, rinsed, refilled with water and weighed after wiping dry again. The specific gravity of the soil was then determined.

The specific gravity is given by:

$Sg = [B – A]/ [D – A) – (C – B)]\ g/m^3$.

Where: A= Empty weight of cylinder, B= empty weight of cylinder + sample, C = Cylinder + Sample + Water, D = Cylinder + water only.

Significance: this is the measure of the material volume excluding pores. A specific gravity test is important because it is dependent on the specific gravities of the individual constituent mineral elements and on the amount of voids present. This indicates the gravity of the material without the need for crushing value tests.

3.2.6 Moisture content

Aim: Determination of water absorption capacity of soil

Materials: Soil sample and water.

Apparatus: **Beaker, weighing balance, oven and tray.**

Procedure: **as specified in BS 1377: 1990.**

A quantity of the sample was placed in a beaker of known weight and weighed. The beaker containing the sample was then flooded with water and kept for 24 hours. The soaked sample was the removed from water strained to remove surface water and then weighed. The sample was replaced into a crucible tray and put into an oven set at 105^{o}C and left for 24 hours. The sample was removed and allowed to cool off before weighing. The ratio of decrease in mass of the dry sample expressed as a percentage is termed adsorption.

Significance: Moisture content may influence the bond between the additive and soil particles. The actual water absorption of soil has to be deducted from the total water required of the mix to obtain the effective mixing water, which control compaction.

The results of this test are presented in table 4.1.3.

Plate ii Moisture content test

3.2.7 Density determination test

Procedure: Conducted in accordance with BS 1377: 1990, using the formula; $\rho = \frac{M}{V}$

Actual weights of soil, cement, cassava starch and makuba were determined using a 100kg Weighing Balance. The volume of the container used was determined by measuring the length, width and the height of the container.

The densities of the laterite soil, cement, cassava starch and makuba are presented in table 4.1.4

3.2.8 Mix proportion

Procedure: This test was conducted in accordance with BS1377: 1990: Part 4.

Significance: To determine suitable amount of water (OMC), which is soil dependent for maximum density in compaction related tests.The result of this test are presented in appendix N.

3.2.9 Setting time test of cement, makuba and cassava starch

Aim: To Determine the Setting Time of Cement, cassava starch and makuba Paste,

Materials:Cement, cassava starch, makuba and Water

Apparatus: Vicat Apparatus, Needle, Rod, gauging trowel, plunger, initial and final setting time needles

Procedure: To determine initial and final setting time of cement in conformance with IS: 4031 part 5(1988). To do so there is need for vicat apparatus conforming to IS: 551(1976), balance, whose permissible variation at a load of 1000g should be +1.0g, gauging trowel conforming to IS: 10086 – (1982).

I. Prepare a cement paste of standard consistency.

II. Start a stop watch, the moment water is added to the cement.

III. Fill the vicat mould completerly with the cement paste guage as above, the mould resting on a non – porous plate and smooth off the surface of the paste making it level with the top of the mould. The cement block prepared in the mould is the test block.

A. **Initial setting time: initial setting time was expressed as the time elapsed since the mixing water was added to cement until the last reading. Initial setting time of Portland cement is said to be minimum of 45 minutes.**

B. **Final setting time: the needle was replaced with a $1mm^2$ needle fitted with metal annular attachment and allowed to gently come in contact with the surface of the cement paste. This was done at intervals of 15mins.the final setting time was gotten when the needle made an impression on the surface of the paste. Final setting time of Portland cement should not exceed 10 hrs. this procedure was done to % replacement of (90% OPC,5m,5s), (90%,10m,5s), (95%, 5m) and (95% OPC, 5s)**

Significance: The setting times of cement depend on the type of cement. The setting time should neither be too slow nor too fast, are the setting times highly variable property of cement. The initial setting time should be long enough to enable mixing, transporting, placing and compaction of mortar to be completed before final setting starts. The minimum setting time as given in B.S 12 is: initial setting times not less than 45 minutes and final setting time not more than 10 hours.

The result of this test are presented in appendix C & D

3.2.10 Soundness test

Aim: To determine the soundness of cement

Materials: Cement, cassava starch, makuba andwater

Apparatus:Le Chatelier's Apparatus, brass cylinder, needles, mould, glass plate, trowel, heater.

Procedure: Le chatelier's mould was placed on a small glass plate and filled with each of the cement paste of standard consistency. The pastes were leveled up and covered with another glass plate and the whole assembly immersed in water at room temperature of about 28^o c for 24 hours. The gap between the indicators of the mould was measured and the whole assembly was immersed in the water bath and heated to the boiling point temperature of 100^o for one hour thirty minutes after which the moulds were removed from the water bath and allowed to cool for hours. The vertical gap in space between the indicators of the mould and the sample were re-measured after cooling and the values earlier recorded were subtracted from the current values. This is in conformance to IS: 4031 part 1 (1988), cement is said to be sound when the expansion is below 10 mm.

Significance: Sound cement is one whose paste (mixture of cement and water) sets and hardens without cracking or disintegration. To guard against unsoundness, cement should be thoroughly mixed and ground.

The result of this test are presented in appendix E

3.2.11 Consistency test

Aim: To determine amount of water for producing starch paste of standard consistence.

Materials: Cassava starch and water

Apparatus: Measuring cylinder (200ml), water heater, beakers (250ml) plastic tray, scoop, spatula and a bucket.

Procedure: Paste production involves mixing starch powder with an amount of cold water first, and hot makuba water at about 90^{0}C is then added to the cold slurry to produce starch paste thus:

(1)-a 200g (powder) + 100g (cold water) = thick slurry

-b 600g (hot water) + thick slurry = non-uniform, whitish paste

(2)-a 200g (powder) + 200g (cold water) = light slurry

-b 600g (hot water) + light slurry = uniform, whitish paste

Significance: This test is necessary in order to ascertain the quantity of cold and hot water required to produce cassava starch paste of standard consistence i.e. paste clarity and uniform viscosity. The result of this test is presented in table 4.5.

3.3Mechanical Properties of Brick Samples

3.3.1 Abrasion resistance test

Procedure: For this test 18 specimens were prepared.

After 28 and 56 days curing abrasion resistance test was conducted using method of abrasion coefficient. The brick samples were subjected to mechanical erosion by brushing for 25 circles in backward and forward motion for about 60 seconds with a 1.2kg mass attachéd to the brush.

Significance: One of the applications of stabilization is in dust and erosion control.

This test is important in assessing the level of resistance of stabilized soil to surface wear, i.e. particle loss from surfaces of specimens.The result of this test are presented in appendix P

3.3.2 Water absorption test

1. **Procedure: Conducted in conformance with ASTM C 62 (2010) Water Absorption test of brick samples.**

This test was conducted on the same number of specimens used for abrasion resistance test. It was done by taking the time in which the control brick (CO) has taken to reach its saturation point and immersed all the remaining bricks for the same period of time. This procedure was adopted because laterite bricks can dissolve in water when immersed for 24 hours.The resistance to permeability is another important property of stabilization. Thus, this test is important in determining the water absorption rate of the stabilized soil at the different replacement.The result of this test are presented in table 4.2.5 and 4.2.6

3.3.3 Compressive strength test

Procedure: Conducted in accordance with BS 6073 part 1 (1981).For the purpose of this test 36 specimens, 3 for each hydration period were used.Strength is one of the most important purposes of soil stabilization. Hence it is very important to ascertain the strength of the various soil types at the different replacement and at different ages of curing in order to determine the effect of cement, makuba and cassava starch on strength increase with age.The result of this test are presented in figure 4.9

3.3.4 Sorptivity test

Material: Specimens (from compressed brick machine), sealant (abro 2000), stones and water.

Apparatus: metal plates, stopwatch and weighing balance, pan and container.

Procedure: For the purpose of this test 18 specimens, 3 for each hydration period were used.

Durability is a function of the pore structure and the nature of the stabilized bond, hence capillary absorption and other properties are used to establish durability index.The result of this test are presented in figure 4.7 & 4.8

Plate VSorptivity test

3.3.5 Permeability test

Material: specimen and water

Apparatus: Funnel, measuring cylinder, glue and stopwatch.

Procedure: as described in appendix with 18 specimens, 3 for each hydration period.

Significance: permeability refers to the ease with which water can flow through a soil.

The result of this test are presented in appendix 4.5 & 4.6

Plate Vi Permeability test

3.3.6 Adsorption test

Material: Sample specimens (from compressed brick machine), calcium carbide and water.

Apparatus: Speedy L2000D, digital scale, beaker, brush,

Procedure: as described in appendix with 18 specimens, 3 for each hydration period. The result of this test are presented in table 4.2.7

CHAPTER FOUR

ANALYSIS, PRESENTATION & DISCUSSION OF RESEARCH FINDINGS

4.1 Properties of MaterialsTest Results

Table 4.1Field Settling Test Result

Sample	% CLAY	% SILT
A	92.21	7.79
B	93.20	6.80
C	92.14	7.86

AV	92.52	7.48

Source: Laboratory work, (2014)

4.1 Field Fettling Test Result

Figure 4.1 Shows the result of the field-settling test. The silt test of the laterite sampleindicates reasonable silt and clay content of 7.48% and 92.52% respectively. This conformed to BS 1377 (1990) standard which state that a maximum limit of silt in soil to be not more than 8%.

Particle Size Distribution

Fig: 4.1 It was observed that the percentage of laterite passing through the 4.75mm sieve was 96.8%. However, most of the laterite was retained on 2.36mm sieves. 86 g of the total weight passed through the sieve 600µm and 44 g retained on the 300µm sieve. Generally, the more the content of laterite less than 600µm, the less is its suitability for making bricks.

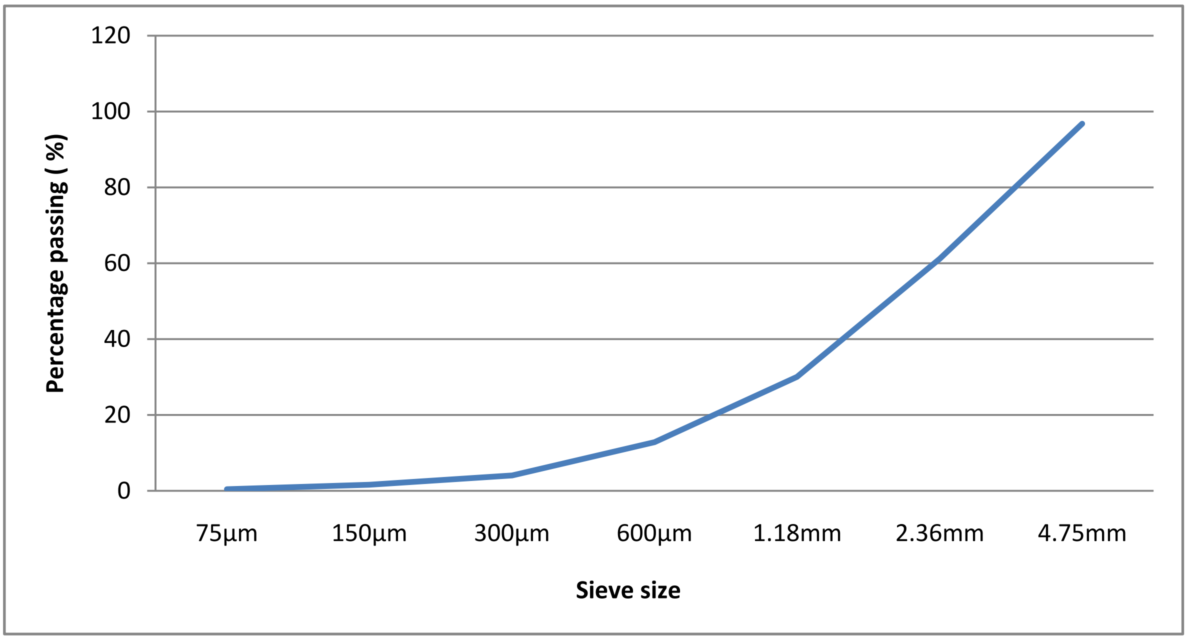


Figure: 4.1Particle Size Distribution

Source: (Laboratory work, 2014)

Table 4.2Specific Gravity of Materials

Materials (kg)	Specific gravity
Portland cement	2.38

Laterite	2.16
Makuba	1.08
Cassava starch	1.42

Source: Laboratory work, (2014)

Table 4.2 shows the specific gravity of materials used. The specific gravity of Portland Cement and laterite was found to be 2.38kg and 2.16kg respectively as against 3.15kg of the British Standard. makuba and cassava starch was found to be 1.08kg and 1.42kg respectively.

Table: 4.3 Moisture Content of Materials

Sample	Cement (%)	Cassava (%)	Makuba (%)	Laterite (%)
1	01	08	13.4	18
2	02	11.4	14.2	19.6
3	1.8	10.6	11.8	17.4
Avm	1.6	1013.13		18.33

Source: Laboratory work, (2014)

Table 4.3 shows the moisture content of materials. Laterite was found with the highest moisture content. The moisture content is used in determining added water in mixes to achieve maximum compaction at or near optimum moisture content (OMC).

Table 4.4Density of Materials

PARAMETER	MAKUBA	CASSAVA STARCH	LATERITE SOIL
Weight(Kg)	0.60	0.27	4.81
Volume(m^3)0.001	0.000422	0.003375	
Density (kg/m^3)600639.81	1425.18		

Source: Laboratory work, (2014)

Table 4.4 shows the density of the materials. The density of the binders was observed to be

600 kg/m^3 and 639.81 kg/m^3 for makuba and cassava starch respectively. Laterite was found to have the highest density of 1425.18 kg/m$^{3.}$

Table: 4.2Paste Consistency Test

Test No.	**1**	**2**	**3**	**4**
Wp (g)	**200**	**200**	**200**	**200**
Wc (g)	**100**	**200**	**240**	**240**
Cm (g)	**TS**	**LS**	**LS**	**LS**
Wh (g)	**600**	**600**	**800**	**1000**
Ps	**UTN**	**UTU**	**CTU**	**CWU**

Where; Wp = weight of powder Wc = weight of cold water

%l = percentage loss in weight Wl = weight loss

UTN = unclear, thick and uniform paste TS = thick slurry

UTU = unclear, thick and uniform paste PS = paste

CTU = clear, thick and uniform Wh = weight of hot water

CWU = clear, watery and uniform LS = light slurry

4.2.1 Paste consistency result

Trial mixes were attempted in order to produce cassava starch paste. Cold water was used to prepare slurry; hot water was then added to the slurry which swelled up to form a paste. The quality of the paste produced depends on the quantity of the cold and hot water. Fourmixes were prepared and was carried out using 200g of starch powder throughout by weight. A consistent paste i.e. a clear, thick and uniform paste of standard viscosity was obtained using 20% cold water and 65% hot water by weight. 200g of starch powder mixed with 240g of cold water to form slurry and then 800g of hot water at about 90^o c added to the slurry which

produced the required paste of standard consistence.

4.3Result of Mechanical Properties of the Brick Samples

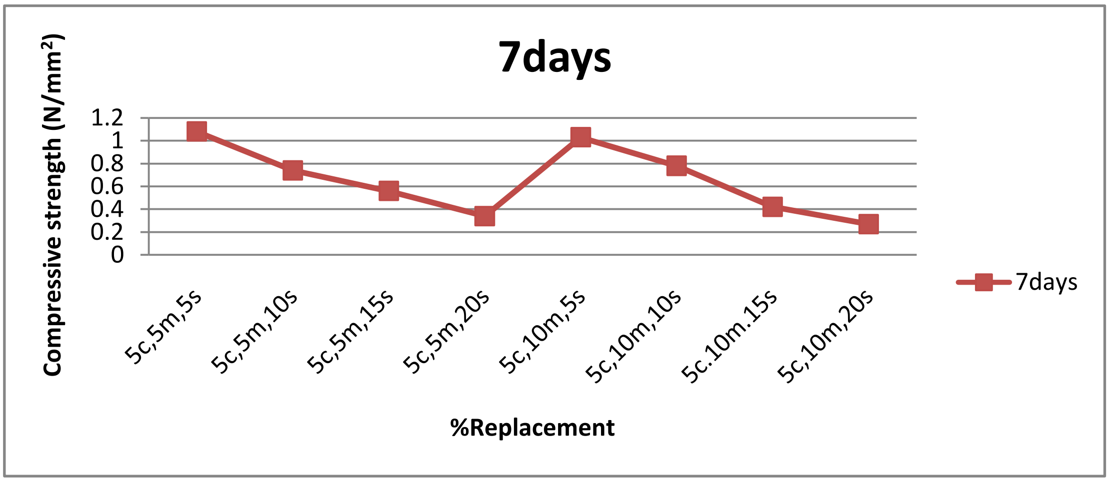


Figure 4.2 Effects of three binding media on compressive strength for trial test at 7days
Source: Laboratory work, (2014)

C0= Control , (5c,5m,5s)= C1 Replacement, (5c,10m,5s)= C2 Replacement
Where; C = cement, M = makuba, S = cassava starch
Eight (8) different replacement combinations were tested for the trial test. This was carried out to obtain the best result among the different combinations.

The compressive strength of 0.68N/mm^2, 1.03 N/mm^2 and 1.08N/mm^2 were recorded for C0 replacement, 5c,10m,5s and 5c,5m,5s replacement level respectively. Impressive results were obtainedwith the mixing water used. Therefore, the mixing water was adopted for this research due

to 1.08 N/mm^2 as the highest compressive strengthobtained at 7days

Table 4.5 Setting Time Test Result

Level (%)	Initial setting time (min)	final setting time (min)
C0110	210	
C1 25	75	
C2 15	55	
OPC/5m		15
35		
OPC/5s		135

255			

Source: Laboratory work, (2014)
N.B: C0 =replacement, C1 = (5c, 5m, 5s) replacement, C2 = (5c, 10m, 5s) replacement

Table 4.5 shows the setting time of cement produced with makuba and cassava starch. The results confirmed that makuba has a significant effect on accelerating the setting time of cement as it sets earlier than the control. while for the cassava starch it decelerate the setting time of cement as it sets later than the control. Moreover, the hydration process slows down causing setting time to increase with respect to cassava starch and the slow hydration means low rate of heat development . This is of great importance in mass concrete construction.

Table 4.6 Soundness of Cement

Sample	Initial length L_1 (mm)	Final length L_2 (mm)	Soundness $(L_2 - L_1)$ (mm)
OPC	0	1	1
OPC/5m, 5s	8	10	2
OPC/10m, 5s	9	10	1

Source: Laboratory work, (2014)

Table 4.6 shows the soundness of cement produced with makuba and cassava starch. It was found that the cement produced was sound having a soundness of 1mm at control level and 2mm at C1 replacement and 1mm at C2 replacement respectively and this conforms to IS: 4031 part 1 (1988), which state that a cement is said to be sound when the expansion is below 10 mm

Table 4.7 Average Density of Stabilized Bricks

Sample	7days(kg/m^3)	14days(kg/m^3)	28days(kg/m^3)

56days(kg/m^3)				
C026702640		2640	2510	
C12780		2560	2500	2340
C2	2786	2720	2580	2386

Source: Laboratory work, (2014)

Fig: 4.7show the average density of brick samples at different curing days. There was no uniform change in the average density of the brick samples and this is as a result of compaction of the specimen with the manual brick machine.

a) **Abrasion Test Result**

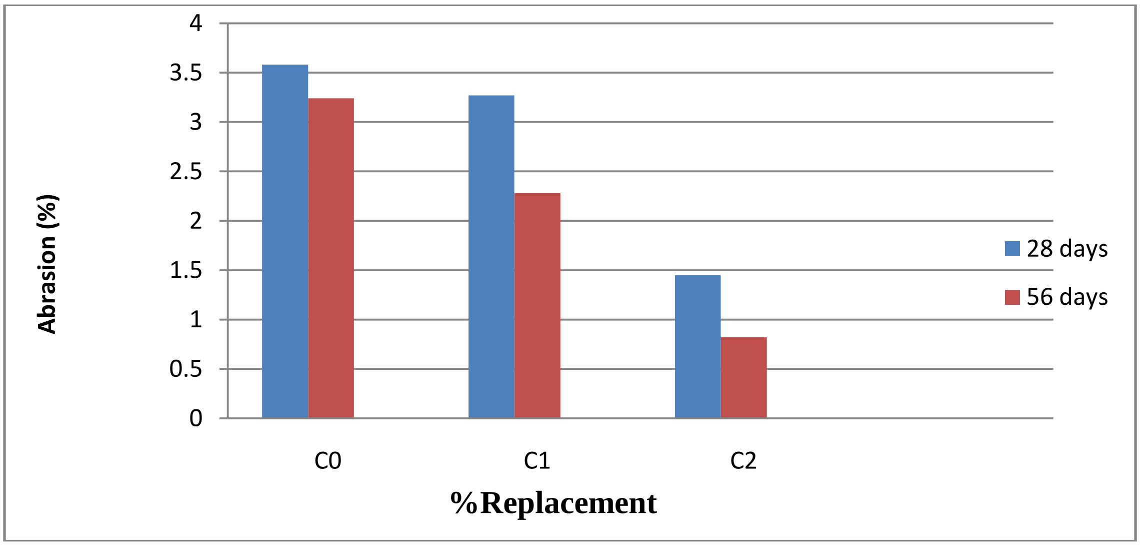


Figure 4.3Effects of Three Binding Media on Abrasion
Source: Laboratory work, (2014)

Figure: 4.3 show the abrasion resistance of the brick samples stabilized with three binding media at 28days and 56days. At C0replacement the percentage wear was found to be 3.58% at 28days while at 56days it was 3.24%. At C1 it was obtained as 3.27% and 2.28% at 28 and 56days respectively. While at C2 replacement the percentage wear was found to be 1.45% and 0.82% at 28 and 56days respectively. The minimum resistance of the total brick samples to

abrasion occurred at C2 at 56th day of curing with percentage loss in weight of 0.82% while the maximum loss in weight occurred at C0 replacement with 3.58% and 3.24% at 28 and 56days respectively. This may be due to the fact that bricks with more coarse particles at the surfaces tend to be brushed out easier than those with finer particles at the surfaces which might have resulted to more loss in weight.

Table 4.8 Water Absorption Test Result at 28 days

Level	Average initial Weight W_1 (kg)	Average final weight W_2 (kg)	Water absorption % $(W_2 – W_1 / W_1)$ x100%
C0	2.47	2.93	18.62
C1	2.48	2.61	5.24
C2	2.69	2.79	3.70

Source: Laboratory work, (2014)

Table 4.8 above shows the water absorption test of three binding media stabilized brick at 28days. It was observed that at C2, the average water absorption of the test samples was 3.7%. This conformed to the requirement of ASTM C 62 (2010) Water Absorption which states that, cold water absorption of any single brick of a random sample of five brick does not exceed 8%. While at C0 and C1 the average water absorption of test samples were 18.62%. This does not conformed

to the requirement of ASTM C 62 (2010) Water Absorption which states that, cold water absorption of any single brick of a random sample of five brick should not exceed 8%.

The C2 replacement has the least water absorption due to the high content of makuba in the sample while as for the CO this could be as a result of zero stabilizing agents in the sample.

Table 4.9 Water Absorption Test Result at 56 days

Level	Average initial Weight W_1 (kg)	Average final weight W_2 (kg)	Water absorption % $(W_2 – W_1 / W_1)$ x100%
C0	2.66	2.98	12.03
C1	2.64	2.72	3.03
C2	2.53	2.60	2.77

Source: Laboratory work, 2014)

Table 4.9 shows the water absorption test of three binding media stabilized brick at 56days. It was observed that at C2 and C1 replacement, the average water absorption of the test samples was 2.77% and 3.03% respectively. This conformed to the requirement of ASTM C 62 (2010) Water Absorption alternate which states that, cold water absorption of any single

brick of a random sample of five brick does not exceed 8%. Only at C0 level the average water absorption of test samples was 12.03%. This does not conform to the requirement of ASTM C 62 (2010) Water Absorption alternate. This may be due to the absent of any stabilizing agent in the sample, since binder was confirmed to be responsible reducing the rate of water absorption in brick samples.

a) Water Adsorption Test Result

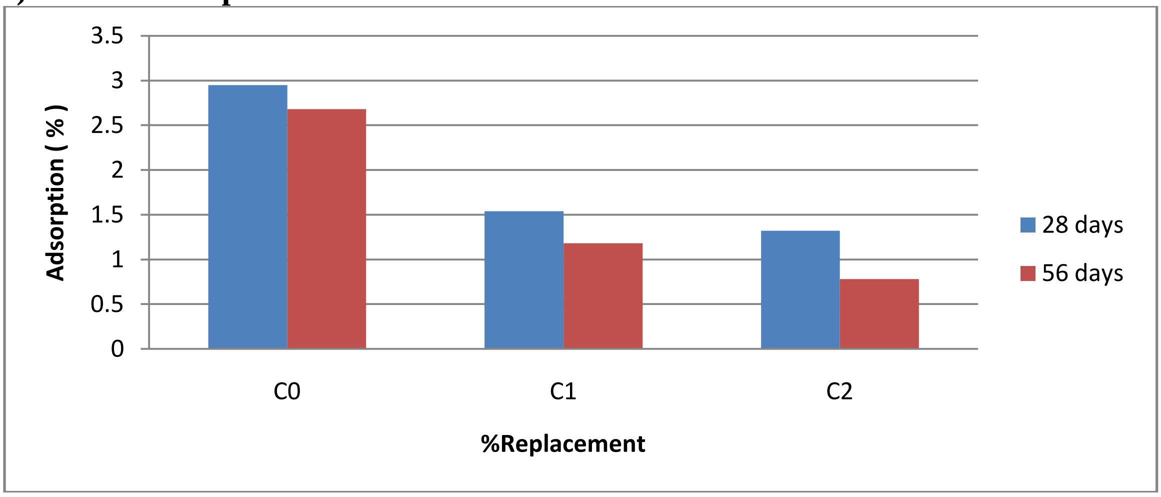


Fig: 4.4 Effects of Three Binding Media on Water Adsorption of CO, C1 and C2 replacement

Source: (Laboratory work, 2014)

From figure 4.4 it was observed that the loss of moisture in the control C0 is high with the adsorption rate of 2.95% and 2.68% at 28 and 56days respectively. While its lower in C2 with the adsorption rate of 0.72% at 56days.

b) Permeability Test Result

Fig: 4.5 shows that the permeability at the 28^{th} day of curing for one hour thirty minutes was maximum at C0 level with the highest absorption rate of 38%, then followed by C1 with the absorption rate of 16%, then lastly C2 having the

minimum absorption rate of 11% as it is indicated in appendix. The absorption rate is higher in 0%, then C1 and C2 respectively. Therefore, the absorption rate of stabilized brick increased with the increase in curing period or ages.

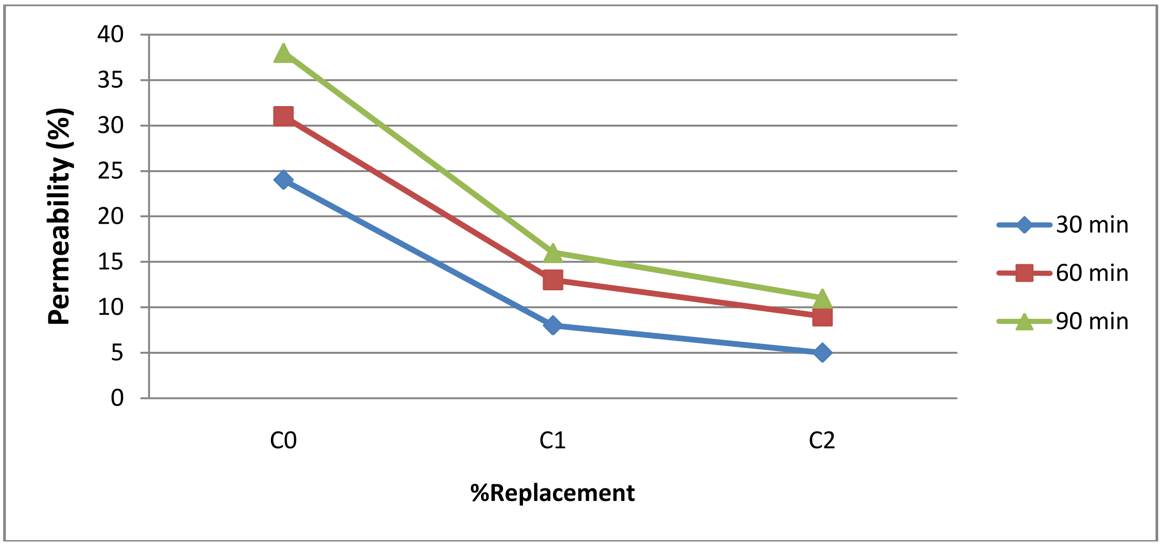


Fig: 4.5   Effects of Three Binding Media on Permeability at 28 days
Source: (Laboratory work, 2014)

Permeability Test Result at 56 days

Fig: 4.6 shows that the permeability at the 56th day of curing for one hour thirty minutes was maximum at C0 level with the highest absorption rate of 30%, then followed by C1with the absorption rate of 19% , then lastly C2 having the least absorption rate of 7.90% as it is indicated in appendix G. The absorption rate is higher in C0, then C1 and C2 respectively. Therefore, the absorption rate of laterite brick decreases as makuba content and cement increased.

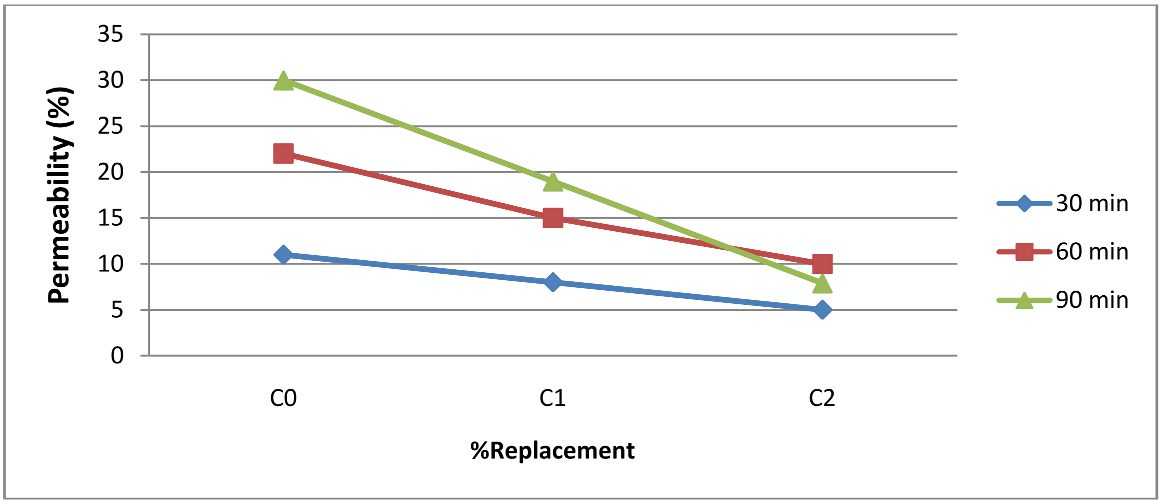


Figure: 4.6 Effects of Three Binding Media on Permeability
Source: (Laboratory work, 2014)

c) SorptivityTest Result at 28days

The figure 4.8 shows the rate of water rise taken at the intervals of 5min, each specimen was weighed at interval of 5min to determine the rate of water rise in each level and to determine the specimen with highest water rise and the one with lower water rise. At 1min, C0 has the highest water absorption rate among the different levels with 42%, then followed by C1 with 15% and C2 with 11% as indicated in the appendix Q respectively. At 5 and 10min, C0 level has eroded and this occurs due to the high absorption rate and lack of binding agents. After the eroding of C0, C1 has the highest absorption rate of 22%. C2level was found to have the least water rise of 30% at 10min which is not more than 8% of absorption stated by ASTM C 62 (2010) Water Absorption of brick samples.

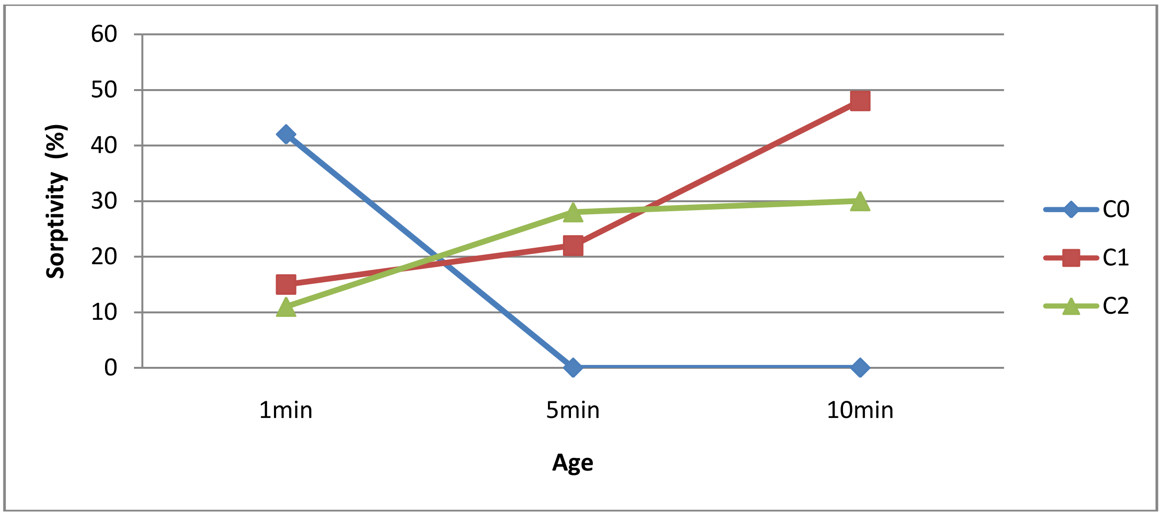


Figure: 4.7 Effects of three binding media on Sorptivity
Source: (Laboratory work, 2014)

Sorptivity Test Result at 56days

The figure 4.8 shows the rate of water rise taken at the intervals of 5min. At 1min, C0 replacement has the highest water absorption rate among the different levels with 14%, then followed by C1 with 22% and C2 with 5% as indicated in the appendix respectively. At 5min, C0 level has collapsed and this occurs due to the high absorption rate and lack of binding agents. At all the time intervals C2 replacement was found to have the least water rise of 5% at 10min.

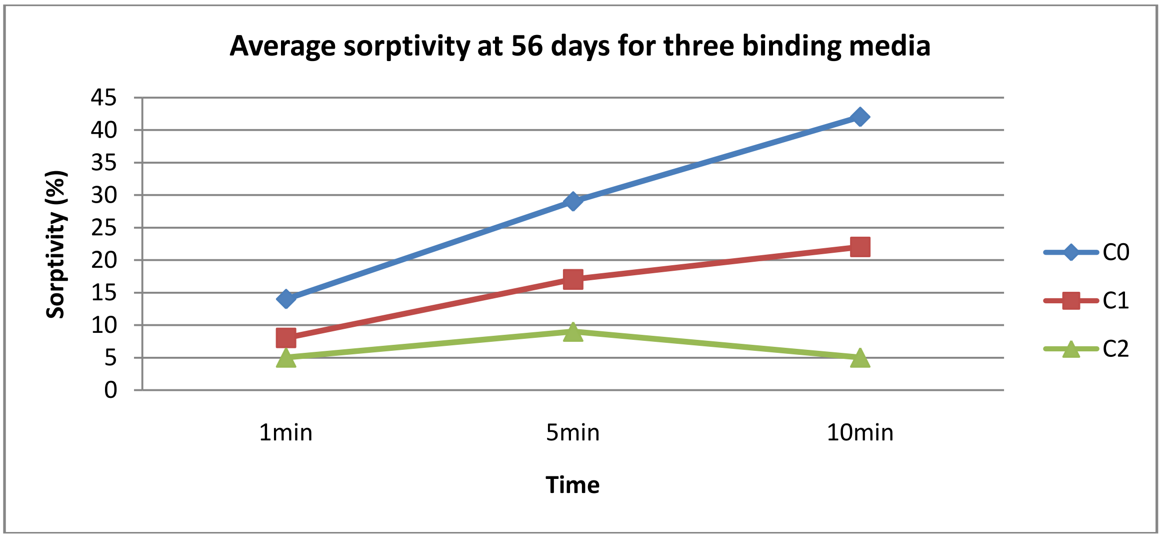


Figure: 4.8 Effect of Three Binding Media on Sorptivity at 56days
Source: (Laboratory work, 2014)

d) Compressive Strength Test Result

The Compressive strength test was conducted on 36 specimens of bricks at different level and ages. The maximum average compressive strength of 2.29N/mm^2 was attained at C1 level and 1.68N/mm^2 at C2 level respectively at the 56th day of curing which both are more than the NBBRI Standard of 1.65N/mm^2. The least strength of 0.56N/mm^2 occurred at C0 level of 7 days.

This could be as a result of zero content of stabilizing agent which improves the strength property of bricks. As the higher starch content is increased, the rate of hydration produced low strengths at all ages. Moreover, the lower the starch content when combine with makuba in the specimen the higher the strength.

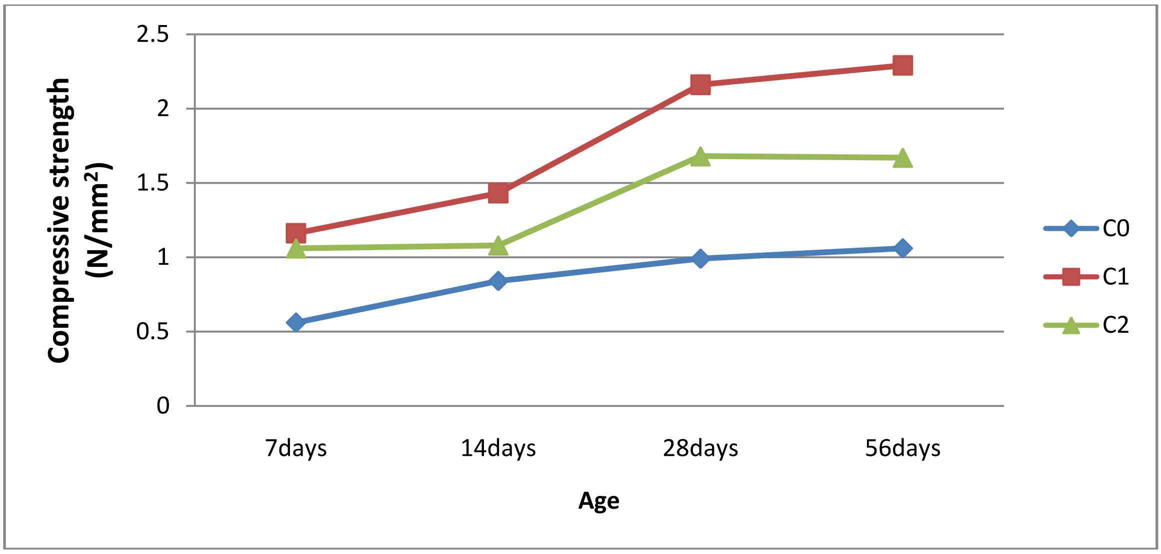


Figure: 4.9 Compressive Strength of CO, C1 and C2 replacement AgainstAge
Source: (Laboratory work, 2014)

Table4.10 RelationshipsBetween the Moisture Movementsof the Brick Samples

Sample	Water Absorption (%)	Water Adsorption (%)	Permeability (%)	Sorptivity (%)
C0	12.03	2.68	30	42
C1	3.03	1.18	11	22
C2	2.77	0.72	7.90	05

Source: Laboratory work (2014)

Thetable shows the relationships of three binding media with the different moisture movement test parameters. The control CO has high rate of water absorption of 12.03% relative to C1 and C2 replacement which have the lower rates of water absorption of 3.03% and 2.77% at 56days respectively. For the water adsorption the control CO had 2.68% loss of water from the interior of the brick sample to the surface, relative to C1 and C2replacement which had lowerwater loss of 1.18% and 0.72% at 56days respectively. Also for the permeability test, the C1 and C2 replacement had lower water absorption rate of 11% and 7.90% relative to the control CO which had the highest water absorption rate of 30% at 56days. Also, for the Sorptivity test the C1 and C2 replacement had the lower water absorption rate of 22g and5gfor 10 min which was relative to the control CO which had higher absorption rate of 42g at 56days.

Hence, it can be deducted that the C2 replacement for water absorption, Sorptivity and permeability test have the least rate of water absorption which isconformed to ASTM C 62 (2010) water absorption test which stated that cold water absorption of any single brick of a random sample of five brick should not exceed 8%.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Findings

1 **It was observed that the average water absorption of the test samples was 5.24% and 3.7 % for C1 and C2 at 28days and also 3.03% and 2.77%was observed for C1 and C2 replacement at 56days. Only 18.62% and 12.03% for C0 replacement at 28 and 56days were obtained.**

2. **At 28 and 56days C2 replacement had lower permeability rate of 11% and 7.90% respectively**
3. **The C2 replacement has exhibited resistance to Sorptivity, and was found to haveleast water rise of 22% and 5%at 28 and 56days respectively for 10min**
4. **The maximum compressive strength at C1 and C2 replacement were achieved as 2.29N/mm^2 and 1.69 N/mm^2 respectively, at the age of 56days relative to the control which was obtained as 1.16N/mm^2.**
5. **The results confirmed that C2 replacement has a significant effect on increasing the rate of setting time.**
6. **At C2 and C1 replacement the percentage wear was obtained as 1.45% and 3.27 at 28days respectively while at 56days the percentage wear was achieved as 0.82% and 2.28% for C2 and C1 replacement respectively.**

5.2 Conclusions

Based on the result of the study the following conclusions were drawn:

1. **The three binding media in laterite with respect to moisture movement responded positively to water absorption, adsorption, permeability and Sorptivity test. The C2 replacement had the least absorption rate which conformed to ASTM C 62 (2010) water absorption test for laterite bricks.**
2. **The inclusion of makuba into cement accelerates the rate of setting time of the paste while Introduction of cassava starch into cementdecelerates the rate of setting time of the specimen.**
3. **The bricks stabilized with three binding media are of sound quality and conformed to IS: 4013 (part-1) - 1988, because the cement is said to be sound when the expansion is below 10 mm.**
4. **The three binding media improved the strength development of laterite brick**
5. **The brick samples responded positively to abrasionresistance**
6. **The C2 specimen can be used well outdoors which are exposed to moisture while the C1 specimen can be used for interior partition walls which are protected against moisture.**

5.3 **Recommendations**

1.**The three binding media has the potential to be used as stabilizing agent**

2.**High percentage of makuba should be combined with other pozzolans to observe possible improvements of water repellent property of earth bricks.**

3.**The percentage of cement may be reduced with increase in the percentages of makuba and cassava in the combination to assess other properties of bricks**

4.**Cement as a conventional material should be combined with other agricultural by-products to assess other water repellent properties of earth bricks**

5. **Different curing methods should be used and tested with a view of finding the best curing method for providing high water repellant property of earth bricks.**

6. Further research on the chemical constituents of makuba should be carried out to determine the elements or compounds responsible for the water repellant property and the strong bond with the functional groups of laterite soil.

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APPENDIX A

Abrasion resistance test results for 28 days

Level	Wb	Wa	Wl	%L
C0	2630	2545	85	3.34
C1	2649	2635	14	0.53
C2	2470	2450	20	0.81

Source: (Experimental work, 2014)

APPENDIX B

Abrasion resistance test results for 56 days

Level	Wb	Wa	Wl	%L
CO	2880	2812	68	2.41
C1	2250	2242	08	0.35
C2	2730	2718	12	0.44

Source: (Experimental work , 2014)

APPENDIX C

Setting time test using vicat apparatus

Sample 1: 100% OPC	Sample 2: OPC/ 5% Starch	Sample 3: OPC / 10% Makuba
9:25	11:23	11:30
9:35	11:33	11:35
9:45	11:43	11:40

9:55	**11:47 Initial setting time (25 min)**	**11:45 Initial setting time (15 min)**
10:05		
10:15	**11:52**	**11:50**
10:25	**11:57**	**11:55**
10:35	**12:02**	**12:00**
10:45	**12:07**	**12:05**
10:55	**12:12**	**12:10**
11:05	**12:17**	**12:15**
11:15 Initial setting time (1 hr 50 min)	**12:27**	**12:20 Final setting time (55 min)**
	12:32	
11:35	**12:37 Final setting time (1 hr 15 min)**	
12:55		
01:15		
01:35		
01:55		
02:15		
02:35 Final setting time (4 hr 10 min)		

Source: (Laboratory work, 2014)

APPENDIX D

Setting time of cement

OPC/ % 5 Makuba	OPC/ % 5 Cassava starch
10:27	11:26
10:32	11:41
10:37	11:56
10:42 Initial setting of cement (15 min)	12:11
10:47	12:26
10:52	12:56
10:57	01:26
11:02 Final setting time of cement (35 min)	01:41 Initial setting time (2hrs 15 min)
	02:41
	03:41 Final setting time (4 hrs 15 min)

Source: (Laboratory work, 2014)

APPENDIX E

Soundness of cement

Level (%)	Initial length L_1 (mm)	Final length L_2 (mm)	Soundness $(L_2 – L_1)$ (mm)
C0	0	1	1
C1	8	10	2

C2	9	10	1

Source: (Laboratory work, 2014)

APPENDIX G

Specific gravity

		Cement		Makuba		Cassava starch		Laterite	
		1	2	1	2	1	2	1	2
P	A	280	280	280	280	280	280	215	215
PS	B	375	320	320	322	300	311	254	259
PSW	C	570	578	560	567	520	522	483	488
PW	D	550	551	540	541	540	546	458	463
S/g	g/m^3	570	578	2.0g	2.63	0.5	0.68	2.78	2.32
Ms	g/m^3	2.382.32			0.59			2.55	

Where: A = Weight of Pycnometer, B = Weight of pycnometer + sample, C = Weight of pycnometer + sample + water, D = Weight of pycnometer + water and S/g = Specific Gravity.

APPENDIX H

Quantity of makuba determination

Level (%)	Mass per brick (g)	Number of bricks	Total mass (g)
C0	-	36	36
C1	125	36	4500
C2	250	36	9000
Total Quantity	375	108	13536

Source: (Laboratory work, 2014)

APPENDIX I

Compressive strength

Levels	7 Days	14 Days	28 Days	56 days
%	(N/mm^2)	(N/mm^2)	(N/mm^2)	
C0	2.61	2.08	(N/mm^2)	
C1	1.83	0.78	2.70	0.56
C2	1.83	1.13	1.83	1.16
			2.78	1.06

Source: (Laboratory work, 2014)

APPENDIX J

7 Days compressive strenght

Level (%)	Average Compressive Strength (N/mm^2)
C0	0.56
C1	1.16
C2	1.06

Source: (Laboratory work, 2014)

APPENDIX K

14 Days compressive strenght

Level (%)	Average Compressive Strength (N/mm^2)
C0	0.84
C1	1.45
C2	1.1.08

Source: (Laboratory work, 2014)

APPENDIX L

28 Days compressive strenght

Level (%)	Average Compressive Strength (N/mm^2)
C0	0.99
C1	2.16
C2	1.68

APPENDIX N

Mix proportion

SAMPLE	C0	C1	C2

LATERITE	2500g	2143.69g	2012.50g
CEMENT	0	125g	125g
MAKUBA	0	118.75g	237.50g
CASSAVA ST	0	112.81g	125g
TOTAL	2500g	2500g	2500g

Source: (Laboratory work, 2014)

APPENDIX O

Table: 4.1.2 Sieve analysis

BS Sieve Sizes	Material retained (g)	Material passing (g)	Percentage passing (%)
4.76mm	16	484	96.8
2.36mm	178	306	61.2
1.18mm	156	150	30
600µm	86	64	12.8
300µm	44	20	4.0
150µm	12	8	1.6
75µm	6	2	0.4
Total	498		

Source: (Laboratory work, 2014)

APPENDIX P

Abrasion resistance test result

Level	28 days %L (g)	56 days %L (g)
C0	3.58	3.24
C1	3.27	2.28
C2	1.45	0.82

Where: Wa = weight before abration, Wa = weight after abration, Wl = loss in weight, %L = percentage loss in weight

APPENDIX Q

Sorptivity test result at 28 days

LEVEL	Wb	Wa	
%	(g/min)	(g/min)	
	1 min	5 min	10 min
C0	14	Clp	Clp
C1	15	22	22
C2	11	28	9

Where: Wb= weight before, Wa= weight after CLP= collapse
Source: (Laboratory work, 2014)

APPENDIX R

Sorptivity test result at 56 days

LEVEL	Wb	Wa	
%	(g/min)	(g/min)	
1 min	5 min	10 min	
C0	14	29	42
C1	8	17	28
C2	5	9	13

Where: Wb= weight before, Wa= weight after CLP= collapse
Source: (Laboratory work, 2014)

APPENDIX S

Permeability test result at 28 days for 90 mins

LEVEL	A W F (g)	AWA(g)	AWR (g)	A (mm^2)
T (mins)	AWA			
%	(g/min)	(g/min)	(g/min)	
C0	50	12	38	
C1	50	16	34	1
C250	11	39		1

Where: AWF= amount of water in the funnel, AWA= amount of water absorbed, AWR= amount of water retained, A= area, T = time
Source: (Laboratory work, 2014)

APPENDIX T

Permeability test result at 56 days for 90 mins

LEVEL	AW F (g)	AWA(g)	AWR (g)	A (mm^2)
T (mins)(				
C0	50	20 30 2.2		
C1	50	19 31		
C2	50	9	41	1

Where: AWF= amount of water in the funnel, AWA= amount of water absorbed, AWR= amount of water retained, A= area, T = time
Source: (Laboratory work, 2014)


Plate iii Preparing starch paste and makuba


Plate Vi Weighing of Materials

Plate V   Batching and mixing of laterite with 3 binding media

Plate VI   Moulding of Bricks

Plate VII De-moulding of Bricks

Plate Viii Leveling of Bricks