AN EVALUATION OF THE CHARACTERISTICS OF STABILIZED POURED LATERITE BEAMS REINFORCED WITH POLYPROPYLENE ROPE

BY

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(M.Sc/ENV-DES/2667/2011-2012)

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA

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DEPARTMENT OF BUILDING

FACULTY OF ENVIRONMENTAL DESIGN

AHMADU BELLO UNIVERSITY, ZARIA

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APRIL, 2015

Abstract

This research investigated the characteristics of cement stabilized poured laterite beams reinforced with polypropylene ropes. It was carried out with a view to first establish the suitability of laterite for cement stabilized poured earth construction and secondly, the possibilities for strengthening poured laterite elements with 3.75mm diameter Polypropylene (PP) rope as reinforcement. The laterite, cement and Polypropylene rope used were sourced from within Zaria. The laterite was air dried for seven days, sieved with 4.75mm BS sieve size and bagged. Physical test result showed that the laterite had a specific gravity of 2.59 with a plastic index (P.I) of 13% indicating low plasticity. Chemical test showed that the oxide of iron had the highest value of 59.09% weight responsible for the laterite reddish brown colour. The mixes were prepared by proportioning for 0%, 10% and 15% cement stabilization with the 0% cement stabilization acting as the control. A total of 171 specimens consisting of 108 cubes, 27 cylinders and 36 beams were produced. Specimens were tested at 7, 14 and 28 days except for all beams and all control (0%) which were tested on 14 and 28 days. Test for the hardened stabilized laterite included compressive strength (wet and dry), tensile strength, flexural strength (for reinforced and non reinforced PP beams), abrasion, water absorption and tension test for the PP rope were performed. Tensile strength test of the PP rope indicated a value of 75.13N/mm^2 as the ultimate tensile strength (UTS). Results showed that specimens containing 15% cement stabilization had the highest 28 days average test result in tensile strength with 0.29N/mm^2, abrasion resistance with 1.37%, wet compressive strength with 0.87N/mm^2, flexural strength without PP reinforcement having 1.16N/mm^2, flexural strength with PP reinforcement having 0.93N/mm^2 and water absorption with a result of 24%. On the other hand, 0% cement stabilization (control) recorded the highest average dry compressive strength of 1.75N/mm^2 at 28 days. Polypropylene rope reinforcement failed to improve flexural strength of beams. It was concluded that poor bonding or anchorage was a contributory factor in the poor performance of 3.75mm diameter polypropylene reinforced poured laterite beams. Also, 15% cement specimens performed best in six tests out of a total of seven. Based on the research, it was recommended that poured laterite containing 15% cement stabilization could be used for construction of non-load bearing internal walls as it will reduce the overdependence on cement and granite usage thereby conserving the scarce natural resources as well as reducing pollution (noise, air, land, etc).

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Declaration

I declare that the work in this thesis entitled "An Evaluation of the Characteristics of Stabilized Poured Laterite Beams Reinforced with Polypropylene Rope" 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.

SACKEY, Kweku Anthony Nnamdi	_____	_____
Name of Student	Signature	Date

Certification

This project entitled **AN EVALUATION OF THE CHARACTERISTICS OF STABILIZED POURED LATERITE BEAMS REINFORCED WITH POLYPROPYLENE ROPE** by Kweku Anthony Nnamdi SACKEY meets the regulations governing the award of the degree of Master of Science in Construction Technology of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof Mohammed Magaji Garba Chairman, Supervisory Committee	_____ (Signature)	_____ Date
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Dr Dikko Kado Head of Department	_____ (Signature)	_____ Date
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I will use this medium to remember all those who are late, who in one way or the other influenced me positively such as Mr. Hassan of blessed memory. May their gentle souls rest in peace, Amen.

Abstract

This research investigated the characteristics of cement stabilized poured laterite beams reinforced with polypropylene ropes. It was carried out with a view to first establish the suitability of laterite for cement stabilized poured earth construction and secondly, the possibilities for strengthening poured laterite elements with 3.75mm diameter Polypropylene (PP) rope as reinforcement. The laterite, cement and Polypropylene rope used were sourced from within Zaria. The laterite was air dried for seven days, sieved with 4.75mm BS sieve size and bagged. Physical test result showed that the laterite had a specific gravity of 2.59 with a plastic index (P.I) of 13% indicating low plasticity. Chemical test showed that the oxide of iron had the highest value of 59.09% weight responsible for the laterite reddish brown colour. The mixes were prepared by proportioning for 0%, 10% and 15% cement stabilization with the 0% cement stabilization acting as the control. A total of 171 specimens consisting of 108 cubes, 27 cylinders and 36 beams were produced. Specimens were tested at 7, 14 and 28 days except for all beams and all control (0%) which were tested on 14 and 28 days. Test for the hardened stabilized laterite included compressive strength (wet and dry), tensile strength, flexural strength (for reinforced and non reinforced PP beams), abrasion, water absorption and tension test for the PP rope were performed. Tensile strength test of the PP rope indicated a value of 75.13N/mm^2 as the ultimate tensile strength (UTS). Results showed that specimens containing 15% cement stabilization had the highest 28 days average test result in tensile strength with 0.29N/mm^2, abrasion resistance with 1.37%, wet compressive strength with 0.87N/mm^2, flexural strength without PP reinforcement having 1.16N/mm^2, flexural strength with PP reinforcement having 0.93N/mm^2 and water absorption with a result of 24%. On the other hand, 0% cement stabilization (control) recorded the highest average dry compressive strength of 1.75N/mm^2 at 28 days. Polypropylene rope reinforcement failed to improve flexural strength of beams. It was concluded that poor bonding or anchorage was a contributory factor in the poor performance of 3.75mm diameter polypropylene reinforced poured laterite beams. Also, 15% cement specimens performed best in six tests out of a total of seven. Based on the research, it was recommended that poured laterite containing 15% cement stabilization could be used for construction of non-load bearing internal walls as it will reduce the overdependence on cement and granite usage thereby conserving the scarce natural resources as well as reducing pollution (noise, air, land, etc).

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List of Symbols and Abbreviations

BS	British standard
ACI	American Concrete Institute
Kg	Kilogrammes
N/mm^2	Newton per millimeter squared
KN	Kilo Newton
PP	Poly propylene
W/S	Water solid ratio
m^3	Meter cube
%	Percentage
NBRRI	Nigerian Building and Road Research Institute
NIS	Nigerian Industrial Standard
%	Percentage
°C	Degree centrigade
mm	Millimetre
et al.	And others
µm	Micrometre
AASHTO	American Association of State Highway Transportation Officials
UTS	Ultimate Tensile Strength

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Concrete is a widely used construction material for building and civil engineering construction. Mehta and Monteiro (2005) emphasized that concrete is the most widely used man made construction material in the world. Also, Garba (2004) maintained that concrete, a relatively new construction material when compared to steel is now used widely in building and civil engineering construction. But, what exactly is concrete? Punmia, Ashok and Arun (2006) defined concrete as a product obtained artificially by hardening of the mixture of cement, sand, gravel and water in predetermined proportions. It is also a material having a variety of strengths (Bill, John and Ray, 2007). Victor (2005) however, defined concrete as a composite inert material comprising of a binder course (e.g cement), mineral filler (body) or aggregate and water. In summary, concrete is an artificial stone consisting of graded and granular materials bound together by cementitous materials and water.

Though, concrete in its final form is hard, strong, durable and weather resistant which makes it an excellent construction material, some of the activities leading to its final production negatively affects the ecosystem. The extraction of limestone to produce cement has lead to the degradation of the ground surface resulting in erosion, leaching, uneven topography, etc. Cement production has increased the carbondioxide (CO_2) level in the atmosphere depleting the ozone layer. Micheal (2000) said the production of cement is linked to global warming and estimates that it contributes as much as 8% at present. Dust emissions are present at cement producing factories resulting in air pollution and destruction of agricultural lands. The effect of extracting granite (coarse aggregate) from rocks has encouraged air pollution, noise pollution and above all,

the degradation and destruction of the ecosystem. The mentioned problems call for more researches in the development of substitute(s) for concrete, for use in the construction of affordable housing.

Raheem, Bello and Makinde (2012) emphasized that housing is acknowledged throughout the world as one of the most important needs of humans. The need to construct low – cost houses to meet up the ever increasing demands of people who intend to own their own properties puts pressure on the policy makers charged with the responsibility of providing cheap and affordable shelter. Daniel (2009) described Nigeria as a developing nation experiencing an increase in population especially in the urbanised and developing parts of the country. Adesoji (2011) also stated that a published UN Report on Nigeria indicated that the annual urban population growth rate was put at 5.8 percent while the national population growth rate was 2.8 percent. It can be seen that the high population growth in urban areas has lead to overcrowding, inadequate dwellings, degrading of public infrastructure and homelessness.

To reduce the problem of inadequate housing, fast building construction techniques and cheap construction building materials need to be adopted for the execution of numerous housing projects in the shortest possible time and at reasonable cost. One of such techniques is the poured earth method of construction were earth (laterite) in stabilized form (soil - cement) is mixed with water and poured to construct walls.

Laterite is an ancient building material that has an existence as old as that of mankind. Patrick *et al* (2011) described laterite as a red iron rich material found throughout the world in regions with high rainfall. Bello *et al* (2010) defined laterite as a product of weathering which produces red or reddish-brown particles found below hardened ferruginous crust. For centuries gone by, earth

(laterite) has been a versatile building material in the construction of houses, roads, bridges, temples, etc. It had also been a source of iron ore for smelting industries in India many centuries ago. Graeme (2008) stated that earth buildings are seen in almost all parts of Africa including the developed nations as well. Most parts of Africa have laterite deposits due to the available factors that encourage its formation. Traditional houses seen in many parts of rural Africa and some urban houses are made using laterite.

Laterite is a 100% eco-friendly building material which is neither manufactured nor transported (Birgit *et al*, 2010). Laterite construction is economically the most efficient means to house the largest number of people with the least demand of resources (Yaser, 2009). Though, as earlier stated, it is assumed that laterite is used for housing only in poor rural areas, there are instances where this material is used for building and civil engineering constructions in urban centres as well. Furthermore, laterite is used in making bricks which can be sundried or burnt. Bricks made from laterite and used in constructing homes are normally found in most rural and urban areas of Africa thereby asserting its versatility as an excellent building material. The use of laterite will help in sustaining the earth's scarce resources and reducing environmental pollution.

Laterite can be improved upon and used as a building material for various types of structures by adding stabilizers, the result of which is stabilized laterite. Some commonly used stabilizers include; straw, dung, lime, cement and a combination of lime and pozzolana. Yaser (2009) emphasized that the stabilization of laterite improves the durability and resistance to abrasion and water damage. Stabilizers and other additives can also reduce swelling, shrinkages, cracking and increase strength (Birgit *et al*, 2010).

Poured laterite construction method involves the construction of formwork for the proposed wall into which the slurry (mixture of laterite, cement and water) would be poured and allowed to cure for some days before the formwork is removed. This method of wall construction as can be observed has the potential of being used to execute numerous housing projects in the shortest possible time. Pour method also enhances the versatility of the wall construction, though, it is limited by the size and shape of the formwork. The monolithic nature of the wall ensures that the whole structure acts as one in the transfer of loads from the roof to the foundation. The solid wall constructed by pour method is less prone to cracks from settlement when compared with walls made of blocks (Carter, 2013). Graeme (2008) emphasized that this technique uses a small amount of cement in the slurry to assist with durability and shrinkage control.

Considering the high cost of steel reinforcement, synthetic rope such as Polypropylene (PP) can be used in place of the steel bars to provide the necessary strength and reduce shrinkage cracks. According to the American Concrete Institute (ACI, 2006), synthetic ropes or fiber reinforced polymer are suitable reinforcement for concrete because they thermally expand and contract at a rate very close to that of concrete. Another important benefit of PP from the view of ACI (2006) is its improved durability and resistance to rust. PP is resistant to chemical attack such as from cement and its light weight and flexible nature enables it to be handled with ease (Alan, 2009).

1.2 Statement of Research Problem

One of the major problems affecting housing delivery in Nigeria today and in the world all over is the affordability of building materials. Most of the materials used in the construction of structures are normally out of the reach of the average Nigerian. Ajanlekoko (2001) attributed the phenomenal rise in population, number and size of our cities over the past few years as the

cause of acute shortage of dwelling units which has resulted in over crowding, high rents and poor urban living conditions. Daniel (2009) pointed out that since the population of Nigeria especially in urban areas is on the increase, housing issues will remain one of the primary social focus in Nigeria for many years to come.

Sandcrete blocks are used for wall construction which can be seen in commercial, residential and industrial buildings. The high cost of cement and fine aggregate has made the price of sandcrete blocks very expensive (James, 2009) and not forgetting the high cost of steel reinforcement used in concrete. Laterite blocks, a suitable substitute for sandcrete blocks when compacted (compressed) have been found to have high compressive strength as a result of the induced high density (Ajao *et al*, 2012). Structures constructed with laterite blocks have been shown to be as durable as their concrete counterpart even with very little cement content. Most buildings constructed with laterite blocks require no wall plaster which economizes construction and maintenance. Researches have shown Polypropylene (PP) ropes to be very durable and resistant to some aggressive environments. However, very little information is available on the subject of poured earth with PP rope as reinforcement. This subject has only been recently introduced and might take quite some time before becoming generally acceptable. There is the need to determine some physical properties such as compressive strength (dry and wet), abrasion resistance, water absorption, flexural strength, etc on the suitability of poured earth using laterite and cement as the stabilizer (binder). The flexural strength of the PP reinforced poured laterite beams will need to be evaluated to determine its suitability as a structural member. Strength, availability and durability are factors which any building material must satisfy before it is accepted as a material for construction (Hababou, 1983 as quoted by Jamilu, 2010).

1.3 Justification of the Study

The result from this research would provide some basic information about the potentials of stabilized poured laterite and PP rope. This will reduce the cost of construction as a result of the availability and affordability of PP ropes and laterite which is present in almost all parts of Nigeria. An increase in the speed of construction using poured earth method will also be achieved. The use of PP reinforcement in structural members will aid strength and control of shrinkage cracks. In addition, the need for aggregate (fine and coarse) and cement will be reduced as noise, dust and carbondioxde encountered when producing both aggregates and cement will be eliminated to an extent. This can encourage the creation of guidelines that standardize and support the use of poured earth method using laterite.

1.4 Aim and Objectives

1.4.1 Aim

The aim of this research is to evaluate the characteristics of cement stabilized poured laterite reinforced with polypropylene (PP) rope with a view to establish its suitability for construction purposes.

1.4.2 Objectives

The specific objectives of this research are;

(i) To determine the physical properties of laterite soil such as; bulk density, specific gravity, particle size distribution, atterberg and moisture content.

(ii) To determine an appropriate mix proportion for stabilized poured laterite.

(iii) To evaluate the mechanical properties of the hardened poured laterite specimens such as; compressive strength, tensile strength, water absorption capacity and abrasion resistance.

(iv) To determine the flexural strength of poured laterite beams reinforced with polypropylene ropes.

(v) To derive some mechanical properties of the PP rope through tension test.

1.5 Research Methodology

The method adopted is summarized as follows;

1.5.1 Literature review

Relevant literature relating to this research were reviewed from various textbooks, past projects, journals, government gazette, internet materials etc.

1.5.2 Materials and method

1.5.2.1 Materials

(i) Water

(ii) Laterite

(iii) Cement

(iv) Polypropylene rope (pp)

(v) Plywood

(vi) Nails

(vii) Used engine oil

1.5.2.2 Method

1. First stage

Tests such as specific gravity bulk density, particle size distribution, atterberg, moisture content were conducted on the air dried laterite sample selected for this experiment. It was followed by

trial tests to establish the mix proportion of water, cement and laterite needed for the mix. From the mix, the degree or extent of its workability was assessed.

2. Second stage

Samples made up of cubes, cylinders and beams were produced. One hundred and eight cubes (100mm x 100mm x 100mm), twenty seven cylinders (100mm x 200mm) and thirty six beams (500mm x 100mm x 100mm) with half of them having PP ropes as reinforcement and the other half having no reinforcement were cast and cured through open air drying. All specimens were tested at seven days, fourteen days and twenty eight days respectively except for beams that were tested on the fourteen and twenty eight day. Cement which is the stabilizer was added at 0%, 10% and 15% for the various specimen. Test such as compressive strength test (dry and wet), abrasions resistance, tensile split test, water absorption and flexural strength were carried out on the specimens.

1.5.3 Analysis of results

The result gotten from this research were analyzed using percentages and arithmetic mean. The result were presented in graphs and tables.

1.6 Scope and Limitation

1.6.1 Scope

The study was confined to some parameters such as compressive, tensile, abrasion and water absorption test. This was to determine the extent to which the poured laterite samples could withstand varying conditions when used in construction. Flexural test was conducted on the PP reinforced laterite beams to access their failure rate when subjected to loading

1.6.2 Limitations

Due to the differences in lateritic formations and mineral constituents, the result gotten from this research will only be applicable to laterite specimen (cubes, cylinders and beams) produced from lateritic soils in Shika or any other laterite or soil samples with similar characteristics.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil

The term “Soil” was originally derived from the Latin word Solum. It is the loose unconsolidated inorganic material produced by the breakdown of rocks from the earth’s crust (Venkatramaiah, 2008). Rebecca (2013) defines soil as the organic and inorganic materials of the earth’s crust were plant’s growth takes place. Also, Iwena (2000) added that the soil is the topmost layer of the earth’s crust which serves as a home for plant’s roots and animals. Soil is the combination of all organic and inorganic materials which are found in the zone overlying the rock crust (Murthy, 2007). Finally Earl (2014) describes soil as the mixture of mineral matter; organic matter, water and air.

2.2 Soil Formation

A geological cycle constantly taking place on the earth’s surface leads to the creation of new soils. This cycle has to be continuous and must take place from time to time to produce sand, silt, clay and gravels. Since the formation of new soils involves the weathering of the parent rock, it implies that without the presence of the parent material, there will be no soil formation (Murthy, 2007). Soils are formed through processes such as weathering, transportation and deposition (Alam, 2002).

2.2.1 Weathering

Iwena (2000) defined weathering as the breaking down of rocks gradually into smaller pieces through physical, chemical and biological agencies. This occurs in the form of disintegration (physical and biological) or decomposition (chemical) of materials at the surface or near the

surface of the earth. It is normally the first stage involved in the formation of soil and all weathering agencies (physical, biological or chemical) normally achieve the same end- result.

2.2.1.1 Physical agencies

Rocks and other materials involved in soil formation through this agency are broken down by disintegration. The new soil formed still retains the composition of the parent material.

i. Temperature (Thermal expansion/ contraction)

It is the degree of hotness or coldness of a body or environment. It common in very hot arid regions (deserts) of the world were rocks are exposed to the intense heat of the sun (Haywick, 2009). During the day, there is an increase in temperature causing the rocks to expand and contract when temperatures drop at night. Continuous expansion and contraction of the rock causes splitting due to differences in the thermal expansion of different minerals (Alam, 2002). This splitting or peeling of the rock surface is called exfoliation (sheeting).

ii. Water

This is a powerful weathering agent in the formation of soils. As moving water transports rock particles and other materials, collision occurs between their surfaces leading to mechanical wearing. This results in the formation of tiny bits of rock particles (Pidwirny, 2006). The effect of this physical agency can be seen in some regions of the world were running water has eroded land surfaces to form gorges, valleys and ravines.

iii. Wind

This agent is very active in the arid and semi-arid regions of the world e.g. deserts. Wind carries dust particles which collide with rock surfaces. The effects of the collision cause abrasion of the

rock surfaces resulting in its steady breakdown (Pidwirny, 2006). Loose materials are also removed from slopes leading to the exposure of new surfaces.

iv. Freeze-Thaw

Very active in polar and temperate regions of the world. It occurs when temperature continues to fluctuate above and below 0^0C. As temperatures drops below 0^0C, water which found its way into rocks through cracks freeze. When the temperature rises, the frozen water thaws. Repeated freezing and thawing widens and deepens cracks which eventually break down. Iwena (2000) added that some pieces of rocks which peels off from the rock surface gather at the bottom of high mountains to form screes.

2.2.1.2 Chemical agencies

Rocks breaks down mainly by decomposition thereby changing the chemical composition of the rock. The new soil formed does not contain any of the chemical or mineralogical composition of the parent materials.

i. Oxidation

A reaction that occurs when a compound takes oxygen from the atmosphere. Alam (2002) opined that this reaction was generally associated with rocks that contain iron and aluminum causing the rock to break –up. This action of oxidation is similar to the rusting of steel in the presence of moist air. This is as shown in equation 1.

$$4FeCO_3 + O_2 \longrightarrow 2Fe_2O_3 + 4CO_2 \quad \text{- - - - - - - - - - - - - - - - - -} \quad (2.1)$$

Rock mineral siderite Hematite

ii. Hydration

Murthy (2007) said that this chemical agency is very predominant in humid climates of the earth (rainforest). It mostly involves the combination of water with other substances to form a new material (soil). The relationship is shown in equation 2.

$$2Fe_2O_3 + 3H_2O \longrightarrow 2Fe_2O_3 . 3H_2O \text{ - - - - - - - - - - - - - - - - - - } (2.2)$$

Rock mineral hematite Limonite

iii. Carbonation

This term describes the process were carbondioxide dissolves in rain water to form carbonic acid. This acid reacts with chalk, limestones, marbles or other carbonates present in the rock, breaking it down to smaller pieces which are washed away. Pidwirny (2006) was of the view that this reaction is mostly predominant in areas with an abundance of carbon dioxide.

iv. Solution

This reaction is active in humid and hot regions of the world. Water, being a universal solvent can dissolve any soluble mineral present in a rock. Alam (2002) was of the view that the action of percolating water normally affected soluble salts. In the absence of drainages, soil solution accumulates in an area to form a particular type of soil.

2.2.1.3 Biological agency

Plant roots penetrate the rocks and land surfaces along joints and regions of weakness. Small animals (rodents and reptiles) and earthworms burrow through the ground causing disintegration of soil particles resulting in the subsequent formation of new soils (Alam, 2002). Minning, farming and construction activities by man also contributes to weathering

2.2.2 Transportation and deposition

Weathered soils are involved in some forms of movement during their formative periods. There are those that remain at the region of formation, these are called residual soils. Soils moved from place to place are called transported soils.

i. Transported soils

Venkatramaiah (2008) defined these soils as those found at locations far away from their place of formation. They are normally transported in sediments form through the aid of ice (glaciers), wind, gravity and running water. Examples of such soils include loess, talus and glacial till.

ii. Residual soils

These are soils formed at the same location were the weathering of the parent material took place. These soils are found in humid regions of the world were Vegetations keep the weathered materials from being transported.

2.3 Soil Profile

Michael (2009) defined soil profile as the product of weathering and continuous soils horizon development. A soil horizon is made up of a separate layer of soil. The soil profile starts from the soil surface and ends at the parent rock material. Tai (2013) and Michael (2009) were of the view that five basic horizons make up a soil profile. It is important to note here that not all soil profiles contain five horizons. This is due to the different climates found around the world. Soil profiles from humid regions have more horizons than those from the arid and tundra regions. The plates show two typical soil profiles indicating the number of horizons. Plate I is a soil profile from the forest region while Plate II shows the soil profile of the savannah (grassland).

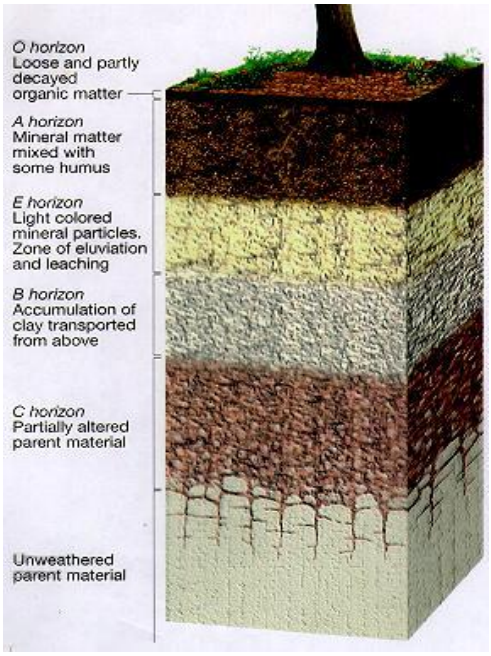


Plate I: Soil profile of forest (Sources: Tai, 2013)

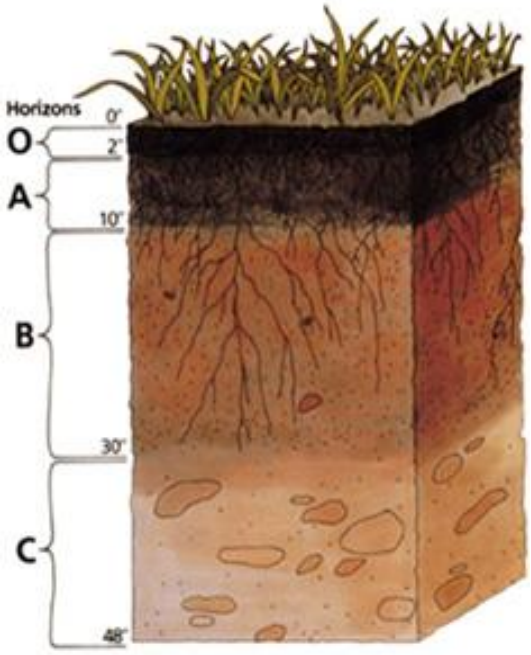


Plate II: Soil profile of Savannah

i. Horizon O

This is the first or topmost horizon of the soil profile. According to Michael (2009), this horizon is mainly made up of organic matter gotten from the leaves that fall in forested areas which are in different stages of decomposition. This zone is refered to as the zone of eluviation because minerals are leached (washed) from this zone down the soil profile due to the downward movement of soil water.

ii. Horizon A

This is the topmost horizon consisting of minerals and organic matter found mostly in grasslands and agricultural lands. Tai (2013) and David (2014) described this horizon as the region of intense biological activities. The removal of organic and inorganic substances through leaching (eluviations) is also active in this horizon.

iii. Horizon E

The removal of organic and inorganic materials together with oxides of iron and aluminum gives this horizon a light colored appearance (Michael, 2009).

iv. Horizon B

Venkatramaiah (2008) defined this horizon as the zone of accumulation (illuviation). Materials leached from the zones above get deposited in this horizon. The materials are fine- grained in nature.

v. Horizon C

Iwena (2000) called this horizon the zone of the parent material. It is the least weathered horizon of the soil profile containing weathered parent rocks.

2.4 Laterite

2.4.1 Description

Bello *et al* (2010) defined laterite as a product of weathering which is rich in oxides of iron and aluminum. Raheem *et al* (2012) opined that laterite is a red tropically weathered soil containing iron oxide derived from leaching conditions. Patrick *et al* (2011) was of the view that laterites are formed in tropical regions of the world through weathering processes that favours the production of aluminum, iron, manganese and titanium oxides. Furthermore, Amu *et al* (2011) added that laterite were mostly formed in leached soils of humid tropics rich in iron and aluminium. Finally, Aguwa (2013) described laterite as soil containing cementitous materials called sesquioxide. Sesquioxides are oxides with three atoms of oxygen and two atoms of another element. Examples of sesquioxides of laterite include hematite (Fe_2O_3), corundum

(Al_2O_3), manganese oxide (Mn_2O_3). Plate III shows lateritic soil formation with the distintive reddish brown colour.



Plate III. Lateritic Soil formation showing the distinctive red colour.

(Source: Field Work, 2014)

2.4.2 Laterite formation

Laterites are formed in hot, wet tropical climates whose annual range of rainfall lies between 700mm to 3000mm (Bello *et al*, 2010). This climate also experiences some dry periods. Elements such as calcium are washed away from the soil by rainfall or percolating subsurface water through the process of leaching (Amu *et al*, 2011). Iron, titanium aluminum and manganese oxides are not soluble and therefore not easily washed away. These elements in their different oxide form assist in the formation of the laterite.

Laterites is a residual soil because it is not transported to another location after its formation. Due to the laterization or leaching effect occurring in the soil, it possesses a distint reddish brown colour indicating the presence of oxides of iron. Also, the soil is cohensionless, has little

or no organic matter and hardens when exposed to air. Some factors affecting the formation of laterites include:

i. Capillary rise

Calcium and sodium which are dissolved in soil water are brought upward through capillary action were the precipitate from the water leaving behind less soluble metals like iron (Michael, 2009).

ii. Temperature

A high temperature such as in the case of tropical climate is very necessary for the formation of laterite (Bello *et al,* 2010.).

iii. Time

Lateritic soils are not formed overnight. It takes years of continuous weathering of the parent rock and leaching of the weathered soil before the final product is created.

iv. Parent Rock

Parent rock or iron-rich rocks produce lateritic soils through the process of weathering (Patrick *et al.,* 2011)

v. Precipitation

Abundant annual rainfall (750mm to 3000mm) is necessary as it aids the capillary action taking place in the soil (Bello et al, 2010).

vi Leaching

Soluble nutrients and elements are lost from the soil as a result of rainfall (Tai, 2013).

2.4.3 Laterite as a building material

Laterite has been employed as a construction material since the earliest existence of man. Earth buildings found in tropical and sub-tropical regions of the world indicates that the structures are made of laterite (Jamilu, 2010). Laterite which is a natural building material has been used to construct walls which enclose a space, hold the roof of buildings to keep out rain, resist sound, heat and fire transmission and protects the user of the structure (Adoeola, 2009). With the introduction of concrete, laterite has been relegated to the background due to the belief that it is a poor man's construction material (Gabriela *et al*, 2012). Joshua *et al* (2011), said that laterite, though abundant in Nigeria is mainly used for civil engineering works like road construction and landfills. As a result, the provision of cheap and affordable housing remains a very big challenge most especially on the African continent. Akeem *et al* (2012), also added that the ability to own a house seems impossible due to the high cost of building materials. Result from researches involving laterite have shown that cement stabilized laterite is suitable for building construction. Plate IV shows compressed laterite bricks used for construction in urban arears and Plate V shows sundried brick made from laterite used in building construction in rural areas. Furthermore, Okeke (2005) reported that laterite soils when properly stabilized with binding

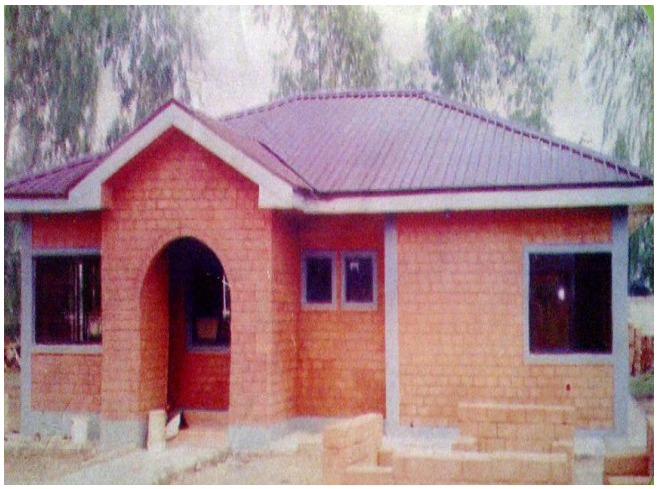


Plate IV: Compressed laterite bricks
(Source: www.nairaland.com/.../affordable-low-cost-housing-option)



Plate V: Sun dried laterite bricks
(Source: Field Work, 2014)

materials develop good weather resistant property. The availability and affordability of laterite with emphasis on building construction can solve the housing shortage problems in Nigeria. Akeem *et al* (2012) emphasized that the production of bricks and blocks using laterite is economical since it requires very little cement for stabilization.

2.4.4 Characteristics of laterite

2.4.4.1 Specific gravity

It is the ratio of the mass of solid particles to the mass of the same volume of water. The specific gravity of a soil depends on the density of the minerals that constitute the individual soil particles. Iron rich laterites from tropical regions including other lateritic soils have a specific gravity in the range of between 2.75 and 3.0. Values less than 2.60 indicate possible presence of organic matter in appreciable quantity (Agarwal, 2000). According to Shehu (2010), the specific gravity of laterites varies not only with the texture of soil group but also with different fractions.

2.4.4.2 Particle size distribution

Particle size distribution is the number of particles that fall into each of the various size ranges given as a percentage of the total number of all sieves in the sample of interest. Due to its ease of interpretation and affordability, sieve analysis is one of the most important techniques employed in particle size distribution test. Particle size distribution provides some relevant information such as classification of soil, compactibility, permeability and deformation characteristics of a given soil sample (Bwalya, 2001 as quoted by Shehu, 2010). It is important to note that all fractions of soil consisting of gravel, sand, silt and clay can be found in laterite.

2.4.4.3 Fineness modulus

The fineness modulus is the sum of the cumulative percentage of aggregate retained on each of a

series of sieves with the total divided by 100. The main aim of finding the fineness modulus is to determine which material aggregate would be suitable for a specific mix with a known strength and workability in mind. It also enables the mix designer calculate for the minimum quantity of cement that will be used. Fine aggregates have fineness modulus of between 2.0 – 3.5, combined aggregate 4.0 - 7.0 and coarse aggregate with a range of 5.5 – 8.0.

2.4.4.4 Bulk density

This is the weight of aggregates held by container of unit volume when filled or compacted under defined condition and expressed in kg/m^3 or g/cm^3.

$$\text{Bulk density} = \frac{\text{Mass of aggregate required to fill container}}{\text{Volume of the container}}$$

A high bulk density could be that the compaction of the laterite was good, structure of laterite was well graded or there was the presence of high moisture content. These are some of the factors that affects the bulk density of laterites.

2.4.4.5 Liquid limit

This is the minimum water content in which a soil begins to flow under a specific small disturbing force (Shehu, 2010). He further stated that the liquid limit of lateritic soils are not greater than 60% while the plasticity index, is less than 30% (LL – PL = <30%). This shows that laterites have a low to medium plasticity.

2.4.4.6 Shape and texture

The workability, strength, compaction and durability are some of the major factors which can be influenced by the shape and texture of aggregates present in lateritic soils. The workability and compaction of lateritic mixes are very high when the aggregate present in the laterite are round

and smooth. This is as a result of the low friction force generated between the aggregates when they are in contact during mixing or compaction. When the aggregates are angular and rough, the workability is low, though, there is an increase in interlocking or bonding between the aggregates and paste leading to improved strength and durability.

2.5 SOIL STABILIZATION

Abejide (2007) defined soil stabilization as a method used in improving the natural durability and strength of a soil. Also, this is the act of improving the physical and engineering characteristics of a soil in order to derive acceptable targets (Eisazadeh, 2010 as quoted by Aminaton, 2013). Such targets include increased strength, improved durability, reduction in permeability and compressibility of soil. Records have shown that the Romans and Mesopotamians separately discovered that it was possible to improve weak soils by mixing with pulverized limestone or calcium (Ellaby, 2010). According to Tim (2007), this was the first chemical stabilization of weak soils. This produced road surfaces capable of withstanding pressure produced from vehicular loads. In the building industry way back in time, stabilizing materials such as dry straw, animal blood and dung were employed in the manufacture of bricks for building and civil engineering structures. The Plate VI shows an example of a structure constructed using stabilized soil



Plate VI: The Mosque of Djenne, Mali.
(Source: http://www.sacredsites.com /Africa/ mali/djenne.html)

The structure (mosque) was constructed from sun-dried mud bricks coated with clay in 1907

2.5.1 Soil stabilization methods

Soil stabilization techniques can be broadly classified into two methods namely

2.5.1.1 Mechanical stabilization

2.5.1.2 Chemical stabilization

2.5.1.1 Mechanical stabilization

This is the easiest and least expensive form of stabilization used in the improvement of the bearing capacity of unstable soils. It involves physical processes such as the addition or removal of two or more gradations (grain sizes) before the compaction (densification) of the soil particles. This improves the durability, strength, soil structure and increases its resistance to erosion and water damage (Yaser, 2009).

2.5.1.2 Chemical stabilization

According to Gregory (2012), this method is based on the chemical reactions between the stabilizer (cementitious materials) and soil minerals to derive acceptable results. In this case, the primary additive is the stabilizer.

i. Cement stabilization

Onyelowe *et al* (2012) stated that cement stabilization first took place with a trial on Salisbury plain in 1917. Cement acts as a binding agent within the soil matrix resulting in a reaction involving inorganic soil, water and some amount of cement (binder). The main reaction is gotten from the hydration of anhydrous calcium silicates which produces calcium hydroxide (hydrated

lime) and calcium silicate hydrate (CSH) which is the main binder (Patrick *et al*, 2011). See equation 3 below.

$$\text{Cement} + H_2O \longrightarrow \underset{\text{Binder}}{CHS} + \underset{\text{portlandite}}{Ca(OH)_2} \text{ - - - - - - - - - } (2.3)$$

The end product of this reaction is a material with high compressive strength and low permeable property. Cement is one of the most important material used in the building industry today (Niklas, 2008). Cement is used in stabilizing numerous types of soil (Gregory, 2012) and its application can be seen in road and airfield pavement construction as well as block production (Aino, 2009). It is important to note that the type of soil to be stabilized depends on the kind of cement to be used.

ii. Lime Stabilization

This additive is produced from natural limestone. Quicklime (CaO) and hydrated lime or slaked lime (Ca $[OH]_2$) are employed for this type of stabilization. This form of stabilization is used in highway capping and slope stabilization. Foundation improvement can be done using lime stabilized soil columns (Gregory, 2012). Alam (2002) stated that lime stabilization also increases the durability of mud plaster in low-cost houses constructed with unburnt bricks. On the basis of setting time, lime soil reactions are slow and do not set as fast as cement soil reaction (Niklas, 2008). It is important to note that lime either alone or in combination with other materials can be used in treating a wide range of soils (Onyelowe *et al*, 2012).

iii. Bitumen stabilization

Bitumen is a mixture of organic substances which is highly viscous, black and sticky. Onyelowe *et al* (2012) defined bitumen stabilization as the process of mixing a controlled amount of bituminous materials thoroughly with an existing soil material which produces a stable base.

This form of stabilization improves load bearing capacity, increases cohesion and resistance to the ingress of moisture down the soil due to its water proofing nature.

iv. Fly ash

This is one of the by products gotten from the combustion of hard coal or bio fuel. During combustion, fly ash is trapped in a compartment preventing it from escaping into the atmosphere with the flue gases. Fly ash is generally a poor binder. Gregory (2012) emphasized that when fly ash is used with a small amount of cement or lime, it produces a cementitous compound which increases the strength of soil.

2.6 History of Earth Construction

There is no doubt that earth is an important ingredient in the production or construction of any building. From the earliest existence of man, earth has been used to erect shelters to protect man from the physical element. Also, other structures apart from buildings such as retaining walls, dams, roads, religious building e.t.c were made of earth. Becky *et al* (2001) was of the opinion that earth is the most basic building material known to man. This is as a result of its wide usage as a building material in different regions of the world. Graeme (2008) added that earth is an ancient building material that has been used in many different ways around the world for thousands of years. This therefore, reinforces the opinion that earth is as old as man.

Earth has been used in different ways or techniques to construct man's dwelling place. Minke (2006) made it known that earth construction techniques have been known for over 900 years. There are recorded cases of earth bricks used in construction around 8000BC in Mesopotamia (Middendorf, 2001 as quoted by Yaser, 2009). The temple of Rameses ll at Egypt, built 3,200 years ago, the citadel of Bam in Iran which is 2,500 years old and a city in the Draa valley in

Morocco which is 250years old were all constructed with mud bricks (Minke, 2006). The Great Wall of China which is 4000 years old was constructed of rammed earth and had its surface faced in stone (Jedidah, 2012). wattle and daub, cob, mud brick and rammed earth were used by early European settlers in New Zealand (Graeme, 2008).The ancient walls of Zaria and Kano which are hundreds of years old were constructed using earth. Jedidiah (2012) said majority of the earliest forms of surviving earth constructions are found in the middle East. Since the middle East is predominantly a desert, there is a vast quantity of earth available for use as the main or principal building material. Building with earth helps in the sustenance of the planet's resources (Graeme, 2008).

2.7. Poured Earth Construction

This technique involves mixing water with earth (e.g. laterite) and cement until it can be poured into moulds without creating voids and then removing the mould once the poured earth has set (Graeme, 2008). The soil which is selected must be subjected to various tests to ensure it conforms to specified engineering standards. Poured earth has certain similarities with concrete which includes its usage of cement as a binder and the procedure involved in its production. Jedidiah (2012) emphasized that all traditional earth construction methods are very labour intensive with only poured earth method having the highest potential to be mechanized leading to reduced labour. A concrete pump can be the best option in achieving this task. This technique of construction makes use of a lot of water and so the appropriate soil needs to be selected and careful calculations carried out first in order to avoid excessive shrinkages and cracks. Although, standards are not readily available on poured earth, New Zealand Standard NZS4298 deals with some aspects of testing and quality control of poured earth (Jedidiah, 2012). To get the best out

of poured earth construction, more emphasis should be laid on the shrinkage and compressive aspect of the material so that it falls within certified standards.

2.8 Polypropylene

Todd (2014) defines polypropylene (PP) as a thermoplastic resin. It is a linear chemical structure with a general molecular formula of C_nH_{2n}, where n is a positive whole number equal to or greater than 2 (Osei, 2000). This is a multipurpose material with lots of applications to our everyday activities. Its presence can be seen in Laboratory products, parts of automobiles, stationery materials, clothing's, industrial and domestic products, e.t.c. Plate VII shows the picture of polypropylene rope in orange and yellow colours.



Plate VII: Polypropylene Rope
(Source: Field Survey, 2014)

In the building industry, numerous researches on the use of PP as a reinforcement in concrete are currently being undertaken (Gencel *et al*, 2011; mounir *et al*, 2013; Roohollah *et al*, 2012). This reinforcement fiber has been shown to improve both mechanical and physical properties of light weight concrete (Roohollah et al, 2012). These fibers are cut to designed sizes either in monofilament or polyfilament form. Though, little research has been done using pp rope as

reinforcement, it offers a lot of potentials in crack control of both concrete and poured earth. Alan (2009) pointed out that pp is resistant to most chemicals. The property of pp resistance to chemicals is necessary in the aspect of durability of the reinforcement. This fact was supported by researches carried out by Andrzej (2009) and Balaguru *et al* (1995) as quoted by Roohollah *et al* (2012) which showed that pp have excellent alkali resistance. Apart from its chemical resistant nature, it is light weight in nature, flexible, does not deteriorate in the presence of bacterial and is non-toxic (Todd, 2014). It floats on water and can be handled with ease (Alan, 2009). It can be purchased in large quantities at an affordable price due to it's availability.

2.9 Formwork

Chirag (2011) defined formwork as a form of support construction used for holding fresh slurry (concrete or latecrete) which hardens subsequently. It is a structure which gives shape and support to latecrete, concrete or similar materials until it acquires enough strength to support its weight. Damon (2014), made it known that the Roman and Egyptian civilizations employed the use of formwork in the construction of their buildings and civil engineering structures. Formworks must be rigid, light and strong to prevent excessive leakages at the time of placing the material since it exerts hydrostatic pressure on the sides of the formwork. The pressure depends on the rate of placement of the material and the temperature at which it is placed. The formwork must be able to withstand all live and dead load that will act on it.

2.9.1 Materials for formwork

i. Wood

This is in the form of timber or plywood. Wooden formworks are used in building construction due to their economy, ease of handling, light weight and ability to be formed into shapes.

ii. Metal

Produced from either steel or aluminum. Consists of prefabricated panel steel or metal plates held together through suitable clamps, bolts or nuts (Chirag, 2011). Normally used were high strength is required or where construction is duplicated at different locations. It is strong, durable, does not shrink or absorb moisture from the slurry (Gopal, 2014).

iii. Plastic

Modular and interlocking systems are used to build simple structures for low cost mass housing. The panels are light weight in nature making handling easier and possess superior strength.



Plate VIII: Plastic Formwork

(Source: http://www.inhabitat.com/palstic-formwork-system/)



Plate IX: Right – Slurry poured into formwork to create a wall.
Left – finished Construction of the low-cost house
(Source: http://www.inhabitat.com/palstic-formwork-system/)

Plate VIII Plastic formwork showing outline of door and window. Plate IX Right – slurry poured into formwork to create a wall. Left – finished construction of the low-cost house

CHAPTER THREE

3.0 EXPERIMENTAL PROGRAMME

3.1 Research Materials

3.1.1 Laterite

Laterite samples were collected from numerous burrow pits and the best was selected upon visual examination which showed that it was well graded with absence of tree roots, debris and inorganic material. Trial pit method of disturbed sampling was employed in collecting the samples from a depth of about 3m. The laterite sample was gotten from Shika village near Ahmadu Bello University Teaching Hospital, Zaria. It was air dried in the departmental laboratory for seven days and sieved using a BS 4.75mm sieve before being bagged in preparation for use. Only the grain sizes which passed through the BS 4.75mm sieve was used in this research. Plate X shows the dried laterite in sacks ready for use.



Plate X: Bagged Laterite
(Source: Laboratory Work, 2014)

3.1.2 Water

Pipe – borne water pumped from the Ahmadu Bello University water works was used throughout the research. The quality of the water conformed to the specification of BS 3148, (1980) which specified the use of water to be free from odour, colour, taste and impurities. The water was necessary for starting the chemical reaction between the cement and laterite.

3.1.3 Cement

Dangote cement brand of 50kg by weight was used. It was bought from a mini cement depot opposite the Ahmadu Bello University, Zaria and conformed to NIS 444, (2003).

3.1.4 Polypropylene rope (pp)

Reinforcement used in the beams was PP rope of diameter 3.75mm bought from a dealer at the Samaru market. Tension test or tensile test was performed on the PP rope in order to determine some mechanical properties of the rope when it is subjected to tension.

3.1.5 Engine oil

Engine oil was applied to the inside surfaces of the mould before each casting. This was to prevent the specimen from sticking to the sides of the mould during extrusion.



Plate XI: Moulds Oiled and Ready for casting
(Source: laboratory work, 2014)

Plate XI shows cube, cylinder and beam moulds oiled and ready for casting

3.2 Preparation of Samples

Laterite, cement and water were the main constituents used in the production of cubes, cylinders and beam specimens. All specimens were prepared by proportioning based on the calculation carried out during the trial test. Two sets of samples each of 10% and 15% were cast and cured both outside and in the laboratory. Samples cured in the laboratory showed a higher compressive strength than those cured outside hence, the curing done inside the laboratory was adopted throughout this research. Three sets of mixes were prepared to include 0%, 10% and 15% cement stabilization using a water to solid ratio (w/s) of 0.37. A total number of 171 specimens consisting of 108 cubes, 27 cylinders and 36 beams were produced. The calculations for the proportioning of the materials are shown in the appendix 12.

Specimen dimension included 100mm x 100mm x 100mm cubes for tests such as compressive strength (wet and dry), abrasion resistance, water absorption, 100mm x 200mm cylinders for tensile split test and 100mm x 100mm x 500mm beams for flexural strength. Moulds for casting to ensure they specimens were checked were properly attached or fixed properly. Mould were oiled to prevent the finished product from sticking to the moulds interior. Also, PP reinforcement were set in the beam moulds before casting of beams was done. All specimen (cubes, cylinders and beams) were produced by feeding calculated amount of laterite, cement and water into a mobile concrete mixer which churned the materials into a uniform poridge consistency. Next, the samples were cast by pouring the slurry into moulds from a height of approximately 30cm to compact it as specified in BS 1377, (1975). After casting, the samples were covered with polythene sheets to prevent excessive loss of moisture and allowed to set for two days before demoulding. The demoulded specimens (10% and 15%) were transferred to the curing area of the laboratory where they were again covered with polythene sheets for three days. This was to

enable the hydration process continue uninterrupted. Two days prior to the first test, the sheets were removed to prevent the growth of both moulds and fungus and to fasten the hardening process of the specimens.

The laterite though, uniformly graded was mainly fine aggregate which holds water for longer periods and therefore encourage the formation of fungus and moulds in moist environment. Specimen with 0% cements (control) had a slower hardening time and were demoulded 9 days after casting. Specimens of 10% and 15% stabilization were cured and tested at 7, 14 and 28 days except for beams which were tested at 14 and 28 days respectively. Also, 0% cement specimen were tested at 14 and 28 days. No test was carried out on day 7 for 0% cement specimen of cubes and cylinders because they were still soft. Zero percent cement specimen for beams could not be tested as the all developed cracks during curing as a result of shrinkage and therefore, had to be discarded. For any day a test was conducted, three samples for each percentage (0%, 10% and15%) were used.



Plate XII: Mobile concrete mixer spewing out mixture of laterite, cement and water.
(Source: laboratory work, 2014)



Plate XIII:10% cement specimen
(Source: laboratory work, 2014)

Plate XII shows the mobile concrete mixer used in mixing the different constituents and Plate XIII shows 10% specimens (cubes, cylinders and beams) ready for demoulding.



Plate XIV:15% Cement Specimen under blue polythene sheet
(Source: laboratory work, 2014)



Plate XV: Zero percent (control).
(Source: laboratory work, 2014)



Plate XVI: Arrangement of Polypropylene rope reinforcement in timber mould
(Source: laboratory work, 2014)



Plate XVII: Ten Percent polypropylene reinforced beams
(Source: laboratory work, 2014)

Plate XIV shows specimen containing 15% cement content under blue polythene sheet in continuation of curing after demoulding. Plate XV shows zero percent (control) specimen few minutes after casting. Plate XVI shows arrangement of polypropylene rope reinforcement fixed in timber mould. Plate XVII shows ten percent polypropylene reinforced poured laterite beams.

The table shows the quantities of the various materials used in the production of the specimens for each test.

Table 3.1 Test, specimen types, specimen number and quantity of materials used

S/No	Type of test	Specimen	No of samples	Addition of cement (%)	Mass of cement (kg)	Mass of laterite (kg)	Mass of water (kg)	w/s ratio
1.	Compressive strength (dry)	Cube	9	0	0	14.4	5.34	0.37
			9	10	1.44	14.4	5.86	0.37
			9	15	2.16	14.4	6.14	0.37
2.	Flexural strength (No reinforcement)	Beam	6	0	0	49.2	18.20	0.37
			6	10	4.92	49.2	20.02	0.37
			6	15	7.38	49.2	20.94	0.37
3.	Flexural strength (Reinforcement)	Beam	6	0	0	49.2	18.20	0.37
			6	10	4.92	49.2	20.02	0.37
			6	15	7.38	49.2	20.94	0.37
4.	Tensile strength	Cylinder	9	0	0	22.78	8.44	0.37
			9	10	2.8	22.78	9.28	0.37
			9	15	3.42	22.78	9.70	0.37
5.	Abrasion resistance	Cube	9	0	0	14.4	5.34	0.37
			9	10	1.44	14.4	5.86	0.37
			9	15	2.16	14.4	6.14	0.37
6.	Water absorption	Cube	9	0	0	14.4	5.34	0.37
			9	10	1.44	14.4	5.86	0.37
			9	15	2.16	14.4	6.14	0.37
7.	Compressive strength (wet)	Cube	9	0	0	14.4	5.34	0.37
			9	10	1.44	14.4	5.86	0.37
			9	15	2.16	14.4	6.14	0.37

(Source: laboratory experiment 2014)

3.3 Laboratory Test

3.3.1 Physical test

The physical test conducted on the laterite included particle size distribution, specific gravity, Atterberg test, moisture content, fineness modulus and bulk density. These tests were conducted after the laterite had been air dried.

3.3.1.1 Particle size distribution

This test was conducted in accordance with BS 1377 (1975). It was necessary to determine the fraction of gravel, sand, silt and clay content present in the sample. This was to determine if the soil was poorly graded, gap graded or well graded and provide some basic information on the engineering description of the laterite. A sample of dried laterite weighing 500g was placed in a set of BS sieves having passing pores ranging from 4.75mm to 150μm in descending order. After shaking the sieves vigorously, the laterite sample separated into different fractions based on their passing BS sieve sizes. These process is known as gradation analysis. The laterites recovered from each BS sieve and pan were weighed and recorded. The results obtained was used in plotting the grain size distribution curve and particle distribution table in appendix 3.

3.3.1.2 Specific gravity

This is the ratio of the mass of solid particles to the mass of the same volume of water at room temperature (20^0C). The test was done as stated in BS 1377 (1975) in other to determine the value of the laterite specific gravity. An empty gas jar with it's glass plate was weighed and its mass recorded. Next, about 260g of laterite was poured into the gas jar and after the new weight was noted, 500ml of water was added to the content and shaked thoroughly before filling the jar to the brim. The glass plate was placed on the top of the jar and the air spaces at the top were

eliminated. The body of the jar was cleaned with a dry cloth to get rid of excess water and its mass was recorded. The gas jar was emptied of it's content and filled with clean water to the brim before the final mass was again recorded. This procedure was repeated for the second time and the specific gravity was finally obtained from the average of the two results as seen in appendix 1.

$$\therefore \text{ specific gravity} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Were W_1= weight of empty cylinder

W_2= weight of cylinder + laterite

W_3= weight of cylinder + laterite + water

W_4= weight of cylinder + water

3.3.1.3 Atterberg test

This is the limit of water content used in describing soil behavior in order to estimate strength and settlement characteristics. Atterberg test was conducted on the laterite sample to determine the plastic index. This index gives an idea of the type of plasticity of the laterite, be it a high plastic or low plastic value. It should be noted that the best soil for stabilization are those with low plasticity index (<35). The test was conducted according to the description given by BS 1377 (1975). The liquid limit (LL) was determined based on the Casagrande method. 200g of air-dried laterite was sieved using a BS 425 μm sieve (No. 40). Water was added to the sample and mixed thoroughly until the paste acquired a plastic consistency. A small quantity of the laterite paste was taken and placed in the casagrande cup and spread out to produce a thickness of about 10mm. A grooving tools was used to produce a groove on the laterite paste after which the casagrande handle was rotated to produce blows that closed the groove. A blow occurred at

every two revolutions per second and the number of blows taken to close the grove was recorded for 4 different test. Next, a sample of laterite paste was used for plastic limit (PL) test by rolling the laterite paste between the finger and the work surface. This was done four times and the necessary mass recorded. When the rolled paste became a thread with a 3mm diameter, it was placed in a container, weighed and put in an over at 105^{o}C. Twenty four hours later, the sample was taken out of the oven, weighed again and recorded. A graph was used in plotting the values for the number of blows and water content. At the end of this test, the plastic index (PI) was derived by subtracting the plastic limit (PL) from the liquid limit (LL). Data's of the Atterberg test can be seen in appendix 15.

3.3.1.4 Percentage moisture content

Moisture content test was conducted as described in BS 1377 (1975). This test was necessary to determine the percentage quantity of moisture present in the laterite sample. To start the test, the mass of an empty container and its lid were recorded. Next, a sample of laterite was placed in the container and covered and a new mass was recorded. The laterite sample plus the container was placed in an oven at 105^{o}C for 24 hours after which it was brought out, cooled and a new mass recorded.Result is seen in appendix 6.

$$\% \text{ Moisture content} = \frac{W_w \text{ x } 100}{W_s}$$

Where W_c = mass of container and lid
W_1 = mass of container + lid + moist specimen
W_2 = mass of container + lid + oven dry specimen
W_w = mass of water
W_s = mass of soil (oven dry)
W_w = $W_1 - W_2$
W_s = $W_2 _ W_c$

3.3.1.5 Fineness modulus

This is another method apart from the particle size distribution which is used in determining the fineness or coarseness of aggregates. The fineness modulus of an aggregated is the empirical factor which is the sum of the cumulative percentage of aggregate retained on each series of sieves and the total divided by 100. Sieve sizes used in the laboratory work included 4.75mm (No 4), 2.36mm (No 8), 1.18mm (No. 16). 600 µm (No. 30) 300 µm (no. 50) and 150 µm (no. 100). The result obtained was divided by 100 to give the fineness modulus seen in appendix 2.

$$\text{Fineness modulus} = \frac{\Sigma \text{(Cummulative retained percentage)}}{100}$$

3.3.1.6 Bulk density

Bulk density is the weight of aggregate confined within a container of unit volume when compacted under specified conditions. For this test, a cylinder of known volume was filled in three different layers with laterite. At each layer, a metal rod (rammer) was used in tamping the laterite 25 times to consolidate it before adding the next layer. Finally, the top of the cylinder was leveled with the laterite using the metal rod.

$$\text{Bulk density} = \frac{\text{Mass of aggregate required to fill container}}{\text{Volume of the container}} = kg/m^3$$

This test was performed in accordance with the specification given in BS. 812 part 2: (1995) and result can be seen in appendix 5.

3.3.1.7 Polypropylene tension test

Three samples of PP ropes were tested at the materials laboratory section of mechanical engineering department of Ahmadu Bello University. It was to determine the maximum force the PP ropes could withstand before failure. Apparatus used in this test was the motorized automatic

recording tensometer. The ropes were cut into equal length with the gauge length having a linear measurement of 60mm located using a red marker on the ropes. Next, a beam with a capacity of 2.5kN was fixed to the apparatus to be used in tensioning or stretching the rope. Also, a graph sheet was attached to a rolling mechanism to aid the graph in ploting the forces applied together with the corresponding extensions. A sample of the rope was attached between two points that griped the ends of the rope. As the lever was consistently turned, the PP sample was stretched and the forces and extensions experienced were plotted on the graph till the sample failed. The test was repeated two more times and the best of the three result was selected. Result of the test can be seen in appendix 13.

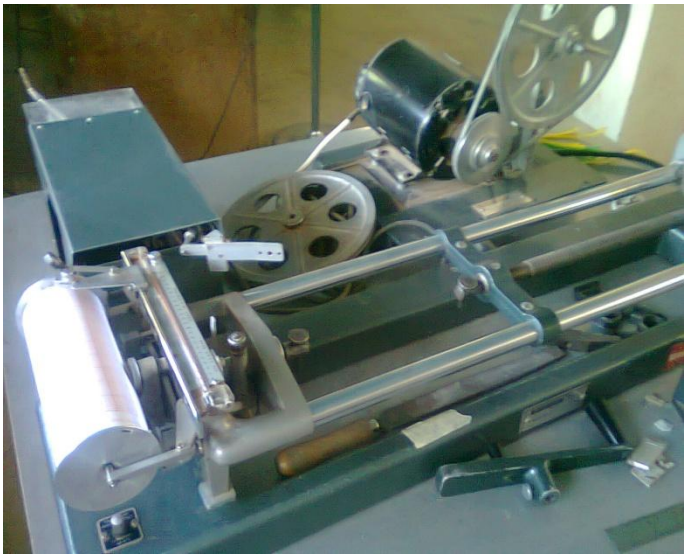


Plate XVIII:Motorised automatic recording tensometer
(Source: laboratory work, 2014)



Plate XIX:Polypropylene ropes
(Source: laboratory work, 2014)

Plate XVIII shows the tensometer equipment used in the tensile test and plate XIX shows three samples of the polypropylene rope to be tested.

3.3.2 Chemical Test

The chemical test carried out on the laterite to determine the chemical constituents was performed at the department of Chemistry, Ahmadu Bello University using the XRF florescence spectrophotometer equipment. This equipment is used for non – destructive chemical analyses of materials and can detect major and trace elements in sediments, rock, soil, etc. It determined the mineralogical composition of the laterite showing the various oxides and their corresponding by weight percentage

3.4 Dry Compressive Test

This is the most important property of hardened laterite in measuring its resistance to axial loading. Twenty seven 100mm x100mm x100mm cubes were produced for dry compressive strength out of which only twenty four were used The twenty four cubes consisted of 9 cubes for 10%, 9 cubes for 15% and 6 cubes for 0% cement content. Three cubes of each cement percentage content (10% and 15%) were subjected to crushing at 7,14 and 28 days while 0% cement cubes were crushed at 14 and 28 days respectively. After the cubes had been dried, they were weighed before crushing was carried out using an ELE compressive testing machine. The cubes were sandwiched between two metal plates at the top and bottom before being subjected to compression. The load at failure was recorded and divided by the sectional area to arrive at the compressive strength and the average compressive strength was calculated. This was done according to the specification as given in BS 1881, part 116 (1983). Compressive strength result for the cubes can be viewed in Appendix 9.

$$\text{Compressive strength} = \frac{\text{Maximum load (KN)} \times 1000}{\text{Crossectional Area (mm}^2\text{)}}$$

Where P = Maximum load (KN)

3.5 Tensile Strength

The tensile split test was done in accordance with BS 1881: part 117 (1983). Twenty seven 100mm x 200mm cylinders were produced for the tensile split test out of which twenty- four were used as was with the case of the dry compressive strength. After the curing, their masses were recorded before being split using the ELE compressive testing machine. Wooden packings were placed at the top and bottom of the cylinder prevent the cylinder before subjecting it to load. After the failure was recorded, the tensile strength was derived using the formular below and finally, the average tensile strength calculated. Data for the tensile strength information is seen in appendix 10.

$$\text{Tensile stress} = \frac{2p}{\lambda LD}$$

Where P = Maximum load (KN)
λ = constant
L = Length (mm)
D = Diameter (mm)

3.6 Flexural Strength

This test was necessary to determine the actual loading conditions the beam will be subjected to before failure. It was conducted in accordance with the specification in BS 1881: part 4: (1970) using the third point loading method on an ELE testing machine. Thirty-six laterite beam specimen measuring 100mm x100mm x 500mm were produced in two sets. One set made up of 18 beams having 0%, 10% and 15% cement content had no PP reinforcement while the other 18 beams had the PP reinforcement with the same cement percentages. Due to the massive shrinkage that took place in the control (0%), cracks developed in all the control specimens (0%) and hence, they were discarded. In all, a total of 24 beams for flexural test consisting of 12 beams for PP reinforced beams and another 12 for non PP reinforced beams was conducted on

day 14 and day 28. The flexural test was calculated based on the value of "a" being greater than 133mm for a 100mm beam specimen.

$$F_b = \frac{PL}{bd^2}$$

Where F_b = modulus of rupture
P = Maximum load applied to the beam in kilonewton
L = Distance in millimeters between the axes of the outer part of roller
b = Width in millimeters of the beam at the line of fracture
d = depth in millimeters of the beam at the line of fracture

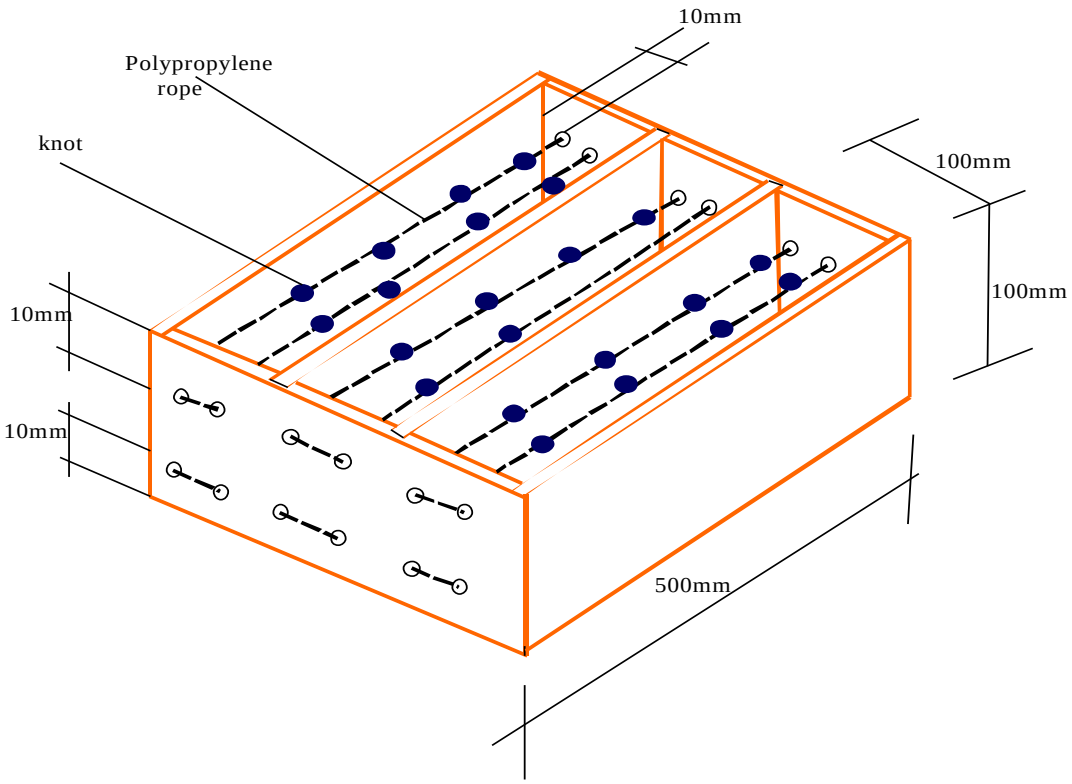


Fig. 3.1 A timber mould

A View of a timber mould showing the arrangement of the Polypropylene rope reinforcement and dimensions of the individual beams.

3.7 Abrasive Strength Test

Twenty seven cubes having a dimension of 100mm x 100mm x 100mm where produced for this test out of which only 24 were used. After curing, the specimens had their surfaces wire brushed at a constant pressure using a 3kg mass attached to the brush. This was done for 60 seconds as one second corresponded to a forward and backward motion. Percentage weight loss was used in determining the abrasive resistance of the cubes. Test were conducted at 7, 14 and 28 days but for the control, it's test was done on the 14 and 28 day. Test result can be seen in appendix 11.

$$\text{Percentage weight loss} = \frac{\text{Weight before abrasion} - \text{Weight after abrasion}}{\text{Weight before abrasion}} \times \frac{100}{1}$$

Where W_1 = weight before abrasion

W_2 = weight after abrasion

3.8 Water Absorption

The absorption capacity of laterite stabilized blocks provides basic information about the presence of voids. Twenty seven cubes were produced for this test out of which only twenty four were used as was in the case of the dry compressive strength test. These cubes were subjected to heat at a temperature of 105^0C for 3 days (72hrs) in an oven. Next, they were cooled in an airtight container for a period of one day (24hrs) before their masses were recorded. The cubes were immersed in water at room temperature (20^0C) for 30minutes with 25mm of water above their surfaces. After the 30 minutes duration, it was observed that the 0% cement cubes lost half of their masses as they partially dissolved in water. The cubes were removed from the water, shaked and dried quickly with a cloth to remove free surface water before their final masses were recorded. The 0% cement cubes recorded negative results and hence, their datas were not used. The above description was done in accordance with BS 1881: part 122 (1983). Absorption data of cubes can be seen in appendix 7.

Absorption capacity = $\frac{\text{Final weight (kg) - Initial Weight (kg)}}{\text{Initial weight (kg)}} \times 100\ \%$

$= \frac{W_2 - W_1}{W_1} \times 100\ \%$

Where

W_1 = Initial weight

W_2 = Final Weight

3.9 Wet Compressive Strength

The test was conducted in accordance with the Nigerian Building and Road Research Institute (NBRRI) specifications. The test was necessary in determining the strength of the cubes during heavy rainfall and flooding. Just as was with the case of the dry compressive strength test, 27 cubes of 100mmx100mmx100mm were produced and out of which only 24 cubes were used. Cubes of 10% and 15% cement content were tested at 7,14 and 28 days while 0% (control) was tested at 14 and 28 days respectively. The cube's initial masses were first recorded before completely immersing in water for 24hrs. Next, the cubes were removed from the water, wiped dry and the final mass recorded before crushing. All cubes of 0% (control) dissolved completely in water. Wet compressive strength data can be seen in appendix 8.

Compressive strength = $\frac{\text{Maximum load (KN)}}{\text{Crossectional Area (mm}^2\text{)}} \times 1000$

Where P = Maximum load (KN)

CHAPTER FOUR

4.0 RESULT AND ANALYSIS

4.1 Result of Physical and Chemical Test on Laterite

The result of the physical property test conducted on the laterite sample are shown in table 4.1.

Table 4.1 Physical Properties of the laterite sample

Properties	Description
Natural Moisture content (%)	5.4
Liquid limit (%)	37
Plastic limit (%)	24
Plastic index (%)	13
AASHTO classification system	A-2-6
Bulk density	1416kg /m^3
Specific gravity	2.59
Fineness modulus	3.98
Condition of sample	Air –dried
Colour	Reddish – brown
Coefficient of curvature (Cc)	0.8
Coefficient of uniformity (Cu)	4.8

(Source: Laboratory work 2014)

The natural moisture content of the laterite was 5.4% which was higher than 2.4% gotten by James (2009). The plasticity index of laterite was given as 13%. This was lower than the value of 17% gotten by Shehu (2010). It indicated that the laterite had a low plasticity (<35%) and therefore satisfies the condition specified in BS 1377 (1975). The American Association of State

Highways and Transportation Officials (AASHTO) classification system for this laterite falls under the sub-group of A – 2 – 6 which indicates that the laterite is made up of sands, some gravels with elastic silt fines. The bulk density of the laterite was found to be 1416kg/m^3. This value is close to 1460 kg/m^3 obtained by Joseph et al (2012). Specific gravity was 2.59, though this was higher than 2.56 obtained by Shehu (2010) but lower than 2.64 gotten by James (2009). These three values however fell within the range specified for laterite. The fineness modulus for the laterite was 3.98 which was above the maximum value of 3.50 for fine aggregate but close to the value of 4.00 for combined aggregate. This indicates that the laterite is mostly fine aggregate with some quantity of coarse aggregate. A reddish – brown colour was observed by visual examination of the laterite sample indicating a high quantity of iron and some appreciable amount of silicon and aluminum oxide. Coefficient of curvature (Cc) for the laterite is 0.8 which is close to the standard range of 1 to 3. Also, Coefficient of uniformity (Cu) is 4.8 which is greater than the minimum specified value of 4. This, therefore indicates that the soil is well graded.

The result of the chemical tests conducted on the laterite sample can be seen in table 4.2

Table 4.2 Chemical properties of the laterite sample

Element	**Concentration (Wt%)**
Na_2O	0.000
MgO	0.045
Al_2O_3	6.521
S_iO_2	29.757
P_2O_5	0.00
SO_3	0.132
CL	0.026
K_2O	0.680
CaO	0.446
T_iO_2	2.962
Cr_2O_3	0.076
Mn_2O_3	0.193
Fe_2O_3	59.098
Z_nO	0.00
S_rO	0.064
Total	**100.000**

Source: Laboratory work, 2014

The most active chemical elements present in the laterite in oxide form include Alumina, silica, titanium and iron with corresponding percentages of 6.52% 29.75%, 2.96% and 59.09% respectively. The listed elements satisfy the condition given by Abood *et al* (2007) and Subramania (2011) as quoted by Onyelowe et al (2012) which must be present or contained in laterite soils. Alumina had a weight percentage of 6.52% far below the value of 19.40 according to the international geochemical reference standard specified by Flanagan (1973) and below the range of 10.28 – 17.11 (David, 1983). Silica with a corresponding percentage weight of 29.75

was close to the value of 34.40 while titanium with a weight of 2.96% corresponded with the value of 2.55% as specified by Flanagan (1973). Iron having a weight percentage of 59.09 exceeded the range of 11.06 – 27.00 (David, 1983). It can be noted here that the high percentage of iron (59.09%) is responsible for the laterite distinctive reddish –brown colour (Aguwa, 2013).

4.2 Result of Polypropylene Tensile Test

The graph in Fig 4.1 shows the stress - strain curve of the Polypropylene Rope

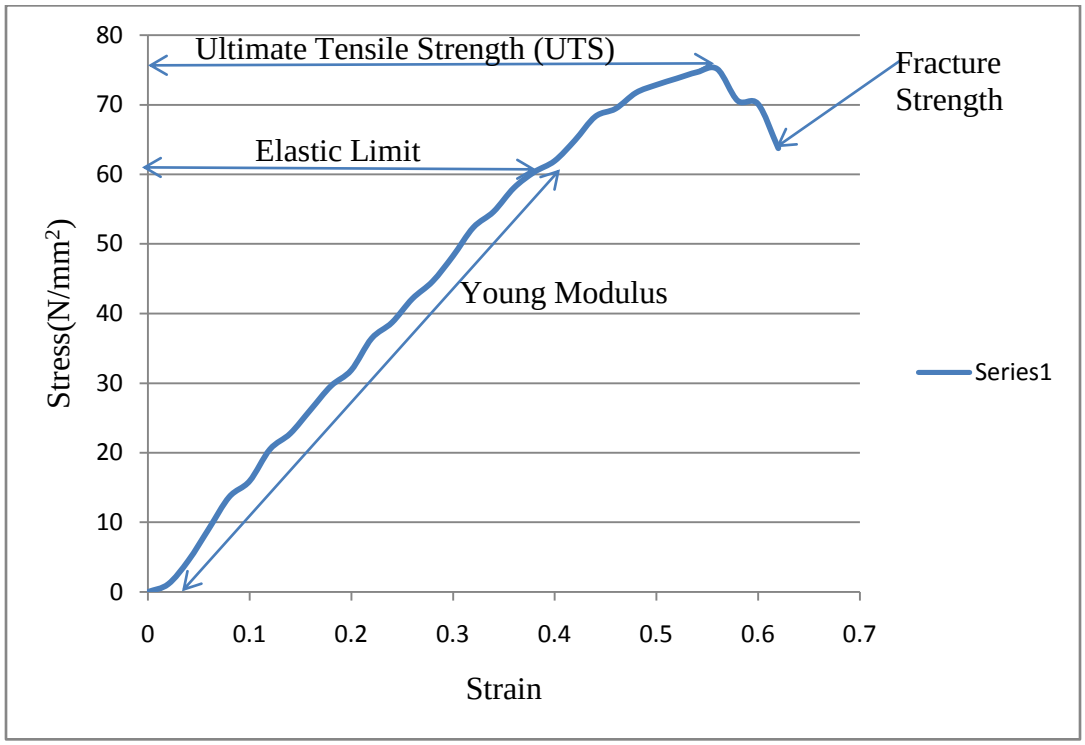


Fig 4.1 Stress - strain relationship for polypropylene rope

From the graph of force against extension, test 3 was selected. Fig 4.1 shows four mechanical properties. Young Modulus which is the region of elasticity were the stress is proportional to the strain (Hooke's Law). The Elastic Limit with a value of 61.93N/mm^2 is the point beyond which the PP rope deforms permanently without regaining its original length. The Ultimate Tensile Strength (UTS) with a value of 75.13N/mm^2 was the maximum stress the PP rope could

withstand when it was subjected to tension (loading). Finally, the fracture strength with a corresponding value of 63.75N/mm^2 was the value of stress at the point of rupture.

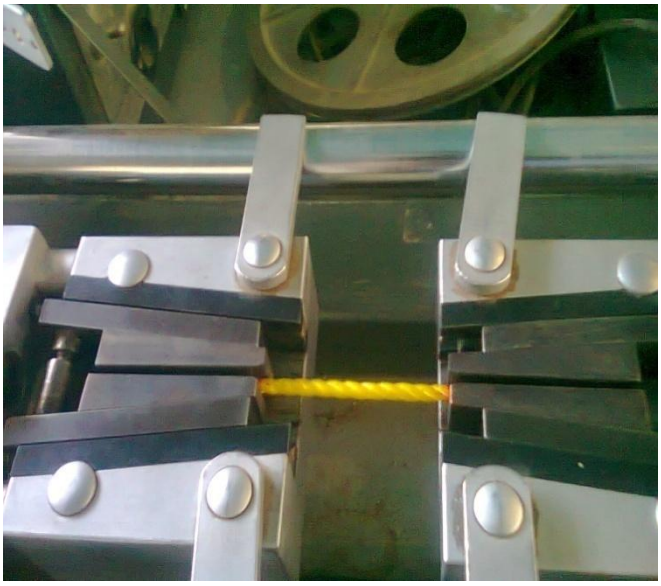


Plate XX:Polypropylene before test
(Source: laboratory work, 2014)

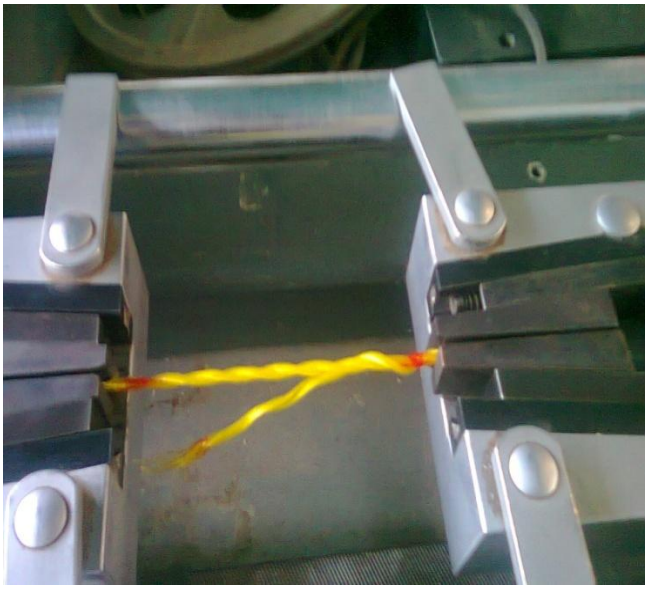


Plate XXI:Polypropylene after test
(Source: laboratory work, 2014)

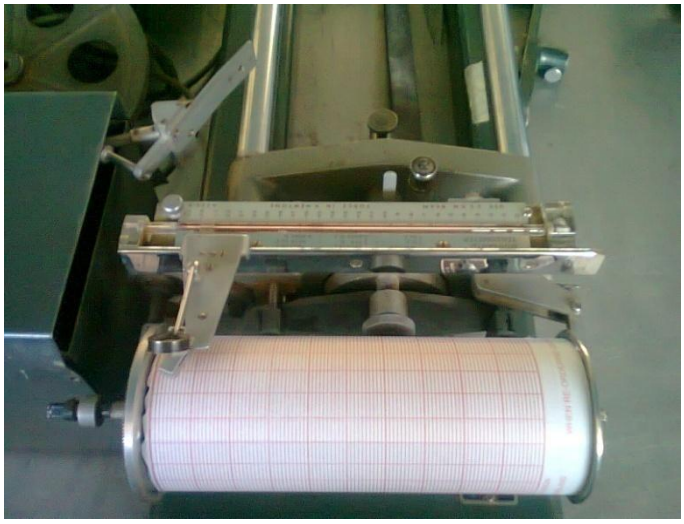


Plate XXII: Graph plotter
(Source: laboratory work, 2014)

Plate XX shows the PP rope before the tensile test. Plate XXI shows the PP rope after the tensile test showing the failure that occurred. Plate XXII shows the graph plotter used in plotting the force experienced by the PP rope with the corresponding extensions.

4.3 Result of Dry Compressive Strength for Poured Laterite Cubes

The relationship between compressive strength and hydration period is shown in figure 4.2.

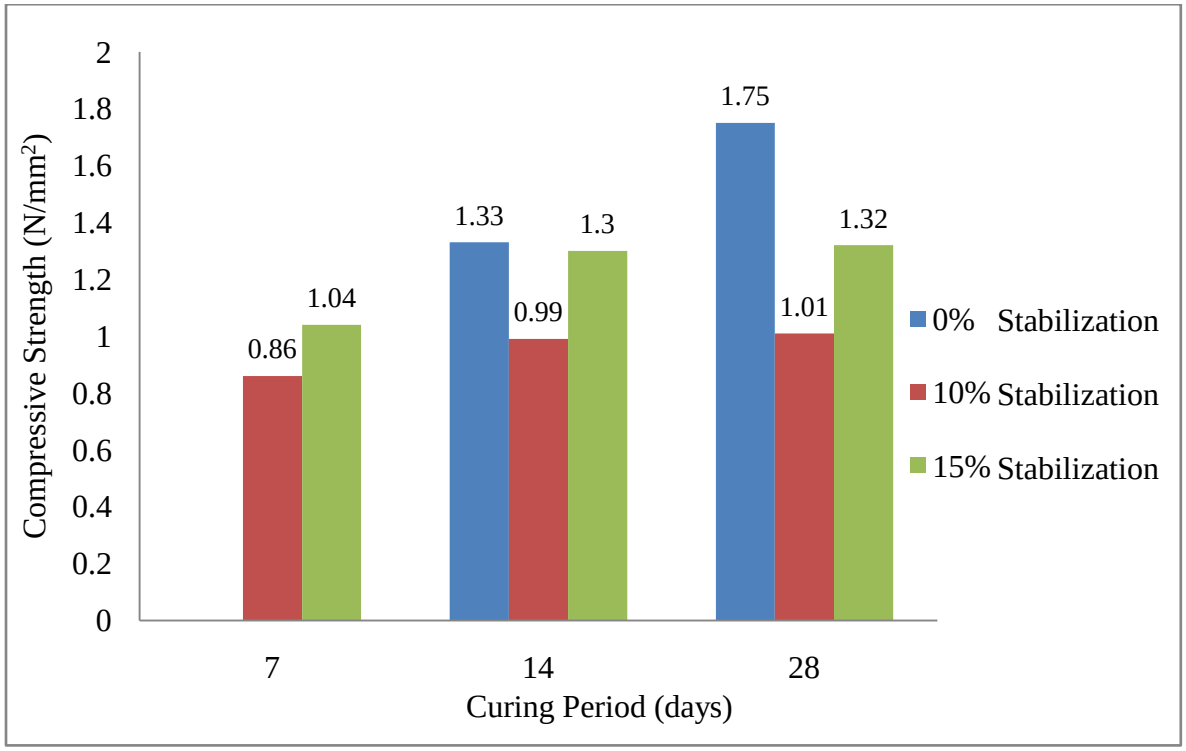


Fig 4.2: Compressive strength - age of curing relation for poured laterite cubes

It was observed that the compressive strength of the laterite cubes (0%, 10% and 15%) all had an increase in strength with a corresponding increase in curing time. No test was conducted for cubes with 0% cement content on day 7 as they were still weak. This was due to the fact that the aggregates which are mostly fine aggregate and in the absence of cement, took longer periods to absorb moisture and harden. On both day 14 and 28, 0% cement cubes surprisingly recorded the highest compressive strengths with 10% cement cubes having the least strength. The longer period it took for the 0% cubes to harden as a result of the water present in its pores contributed to its strength. This shows that presence of moisture during curing can improve strength. Also the massive shrinkage which leads to a reduced cube dimension eliminated a lot of air pores which increased the density of the cubes. This was as a result of the binding properties of the

clay particles which have angular or non-rounded shapes. They formed flakes that stuck together when the desired amount of water was added (Ocholi et al, 2014) thus, enabling them produce the highest compressive strength. The clay content caused strong cohesion and massive shrinkage. This shows that laterite has some cementing material that can bind particles together. The small quantity of coarse aggregate contributed to the cubes (0%,10% and 15%) not having a very high compressive strength as coarse aggregate are known to improve mechanical strength.



Plate XXIII: shrinkage in control specimen (cubes)
(Source: laboratory work, 2014)



Plate XXIV: Shrinkage and moulds in control specimen (cubes)
(Source: laboratory work, 2014)

Plate XXIII Shrinkage observed in control sample (cube). Plate XXIV Arial view of shrinkage observed in control sample with presence of moulds (cube)

4.4 Result of Tensile Strength for Poured laterite Cylinders

The relationship between the tensile strength and the hydration period of poured earth cylinders is shown in figure 4.3

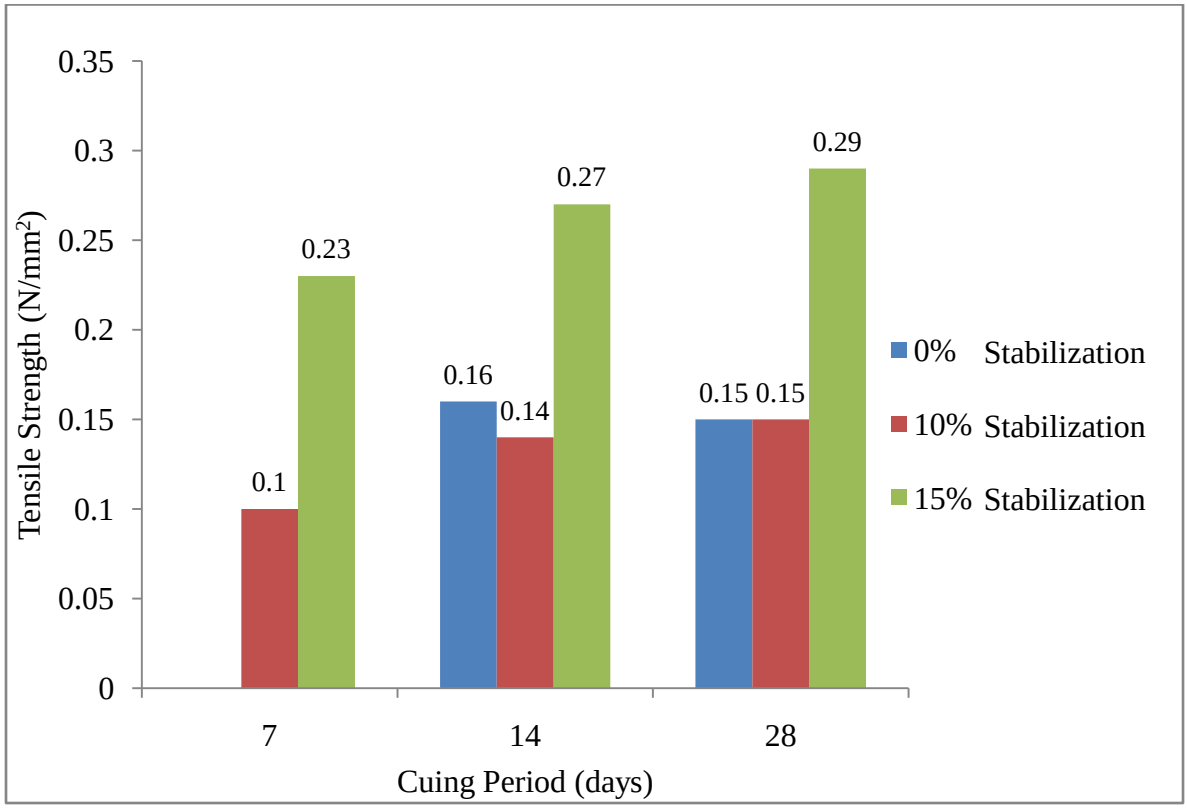


Fig 4.3: Tensile strength - age of curing relation for poured laterite cylinders

The tensile strength increased from day 7 to day 28 for both 10% and 15% cement cubes. This was however not the case for 0% cement cubes as the experienced a decline in tensile strength from 0.16N/mm^2 at day 14 to 0.15N/mm^2 at day 28. Ten percent cement cylinders had an increase in strength from 0.10N/mm^2 at day 7 to 0.15N/mm^2 at day 28. The performance for 10% cylinders was the same with those of 0% cylinders as the both almost achieved the same strength on day 14 and acquired equal strength on day 28. The proportion of clay particles was more than the proportion of cement in the 10% cylinders. The clay particles were able to coat the

aggregates surface thereby preventing proper bond formation between cement paste and aggregate. This lead to the 10% cylinders having a weak matrix with a corresponding low strength. fifteen percent cement cylinders had more cement resulting in an increase in the number of contacts with the aggregates surface. This produced a stronger matrix with a corresponding high strength.



Plate XXV: Shrinkage in control specimen (cylinder)
(Source: laboratory work, 2014)



Plate XXVI: Tensile test
(Source: laboratory work, 2014)

Plate XXV shows shrinkage observed in control sample (cylinder) due to absence of cement.

Plate XXVI shows the tensile split test showing failure of poured laterite cylinder

4.5 Flexural Strength

4.5.1 Unreinforced beams

Table 4.3 Flexural strength for 10% and 15% unreinforced beams

Sample shape	Designation	Cement content (%)	Curing duration (days)	L (mm)	B (mm)	D (mm)	P (KN)	Flexural strength (N/mm^2)	Average Flexural Strength (N/mm^2)
Beam	A_2	10	14	385	100	100	2	0.77	
	B_2	10	14	385	100	100	2	0.77	0.79
	C_2	10	14	385	100	100	2.2	0.85	
	A_3	10	28	385	100	100	2	0.77	
	B_3	10	28	385	100	100	2.2	0.85	0.85
	C_3	10	28	385	100	100	2.4	0.92	
Beam	A_2	15	14	385	100	100	3	1.16	
	B_2	15	14	385	100	100	2.2	0.85	1.10
	C_2	15	14	385	100	100	3	1.16	
	A_3	15	28	385	100	100	3.2	1.23	
	B_3	15	28	385	100	100	2.8	1.08	1.16
	C_3	15	28	385	100	100	3.0	1.16	

(Source: Laboratory Work, 2014)

An increase in flexural strength was observed for all the unreinforced beams tested. Fifteen percent cement beams had a higher strength on both day 14 and day 28. This showed that stabilizing agents are necessary for strength development.

4.5.2 Polypropylene reinforced beams

Table 4.4 Flexural strength for 10% and 15% reinforced polypropylene beams

sample shape	Designation	Cement content (%)	Curing duration (days)	Water/ solid ratio	L (mm)	B (mm)	D (mm)	P (KN)	Flexural strength (N/mm^2)	Average flexural strength (N/mm^2)
Beam	A_2	10	14	0.37	385	100	100	2	0.77	
	B_2	10	14	0.37	385	100	100	1.8	0.69	0.74
	C_2	10	14	0.37	385	100	100	2	0.77	
	A_3	10	28	0.37	385	100	100	2.2	0.85	
	B_3	10	28	0.37	385	100	100	2.4	0.92	0.85
	C_3	10	28	0.37	385	100	100	2	0.77	
Beam	A_2	15	14	0.37	385	100	100	2.4	0.92	
	B_2	15	14	0.37	385	100	100	2.5	0.96	0.88
	C_2	15	14	0.37	385	100	100	2	0.77	
	A_3	15	28	0.37	385	100	100	2.4	0.92	
	B_3	15	28	0.37	385	100	100	2.4	0.92	0.93
	C_3	15	28	0.37	385	100	100	2.5	0.96	

(Sources: Laboratory Work, 2014)

An increase in flexural strength was also observed for all the PP reinforced beams as was in the case of the unreinforced beams. Fifteen percent cement beams still recorded the higher strength between the two cement specimen (10% and 15%). It was assumed that with the inclusion of the PP reinforcement, there would be a large increase in strength. But comparing both the unreinforced beams and the PP reinforced beams, they had almost the same result but with the unreinforced beams posting better readings. This showed that PP rope of 3.75mm diameter failed to improve the flexural strength of the PP reinforced beams. It indicated that there was anchorage failure implying no bonding between the PP rope and the laterite.



Plate XXVII: Anchorage failure
(Source: laboratory work, 2014)



Plate XXVIII: Cracks in control specimen
(Source: laboratory work, 2014)

Plate XXVII shows poor bonding between laterite and polypropylene rope as can be seen at the bottom of the beam. Plate XXVIII shows the surface view of cracks observed in control sample of beam



Plate XXIX: Flexural Test for Beam.
(Source: laboratory work, 2014)



Plate XXX: Beam Showing Failure after flexural Test.
(Source: laboratory work, 2014)

Plate XXIX shows an unreinforced poured laterite beam specimen undergoing flexural test. Plate XXX shows beam failure after flexural test.

4.6 Result of Water Absorption for Poured Laterite Cubes

The result for water absorption test showing the relationship between water absorption capacity and hydration period is presented in figure 4.4.

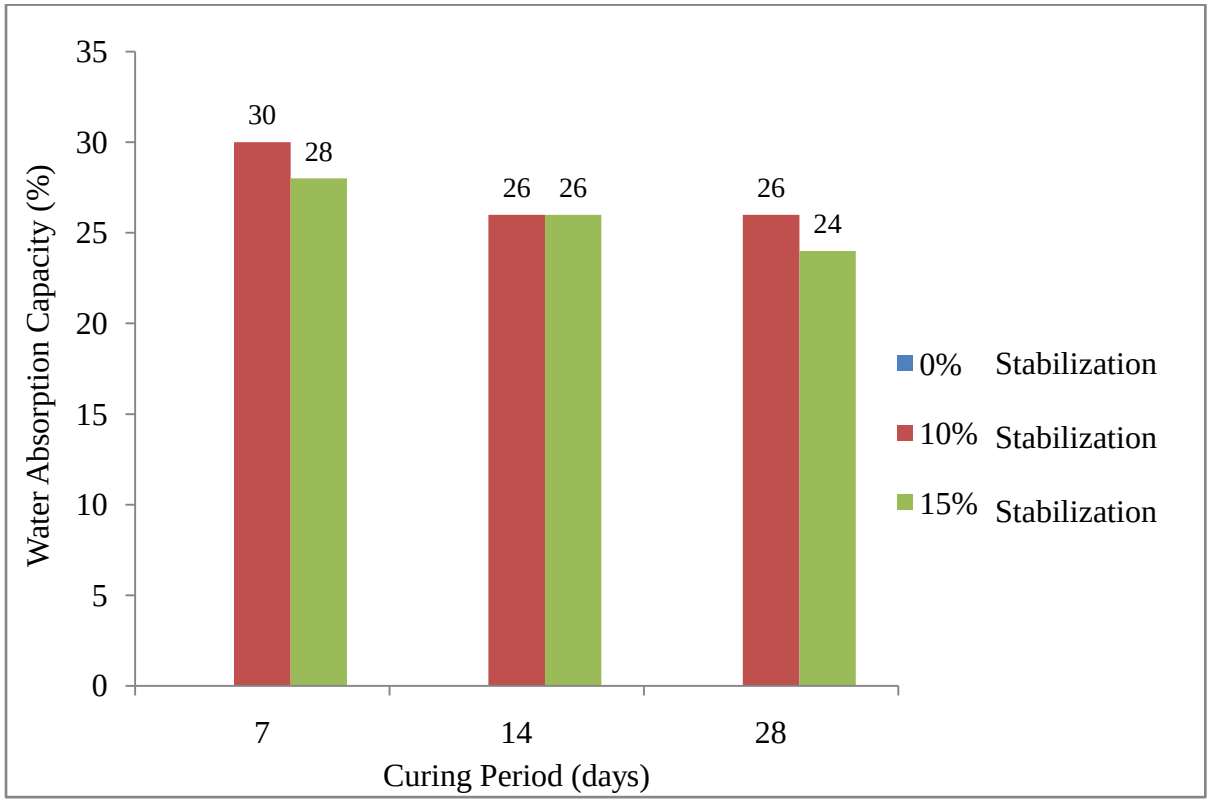


Fig 4.4: Water absorption capacity - age of curing relation for poured laterite cubes

Ten percent cement cubes recorded an absorption capacity of 30% on day 7. On day 14, it dropped to 26% and this value remained constant even at day 28. However, there was a steady decrease from 28% to 24% for 15% cement cubes from day 7 to day 28. Both cement contents (10% and 15%) recorded the same absorption percentage on day 14. The high absorption capacity for both cubes gives an idea on the pores present in the cubes. It was as a result of the kind of compaction used in their production. Self compaction which was used for the blocks was inadequate to seal off the existing air pores in the cube's matrixes. This pores contributed to the

high absorption because as the air in the pores escaped, it was replaced by water thus, making it a lightweight stabilized hardened laterite. Advantages of its lightweight include

i. Reduction in dead load (saves cost)

ii. Longer spans

iii. Thinner sections

iv. Less reinforcement

v. Improved thermal conductivity

Cubes with 0% cement stabilization dissolved partially in water indicating that cement was a better stabilizer than clay.

4.7 Result of Wet Compressive Strength for Poured Laterite Cubes

The result for wet compressive strength test showing the relationship between wet compressive strength and hydration period is presented in figure 4.5.

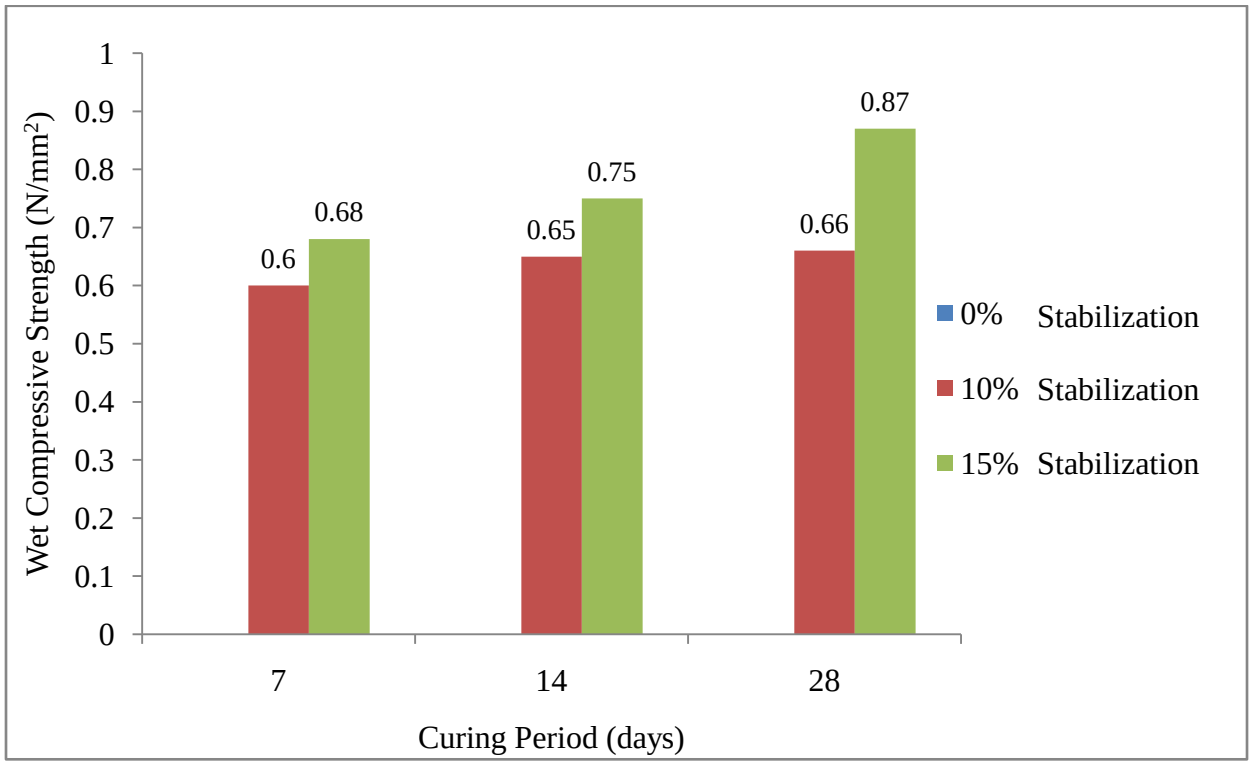


Fig 4.5: Wet compressive strength - age of curing relation for poured laterite cubes

Cubes with 10% and 15% cement content had a steady increase in average wet compressive strength with 15% cement content showing a higher value. At day 14, 10% cement cubes recorded an average wet compressive strength of 0.65N/mm^2 and 0.66N/mm^2 at 28 days. This showed that there was a slowing down of strength for the 10% cement cubes. However, that was not the case for 15% cement cubes as it continued to record higher average wet compressive strength as the days went by. No recording was available for cubes with 0% cement content due to their complete dissolution in water. The absence of cement to bind the particles together and

the corresponding weak nature of clay as a binder when exposed to water resulted in the complete melt down of the cubes.

4.8 Result of Abrasion Resistance for Poured Laterite Cubes

The result for abrasion resistance test showing the relationship between abrasion resistance and hydration period is presented in figure 4.6.

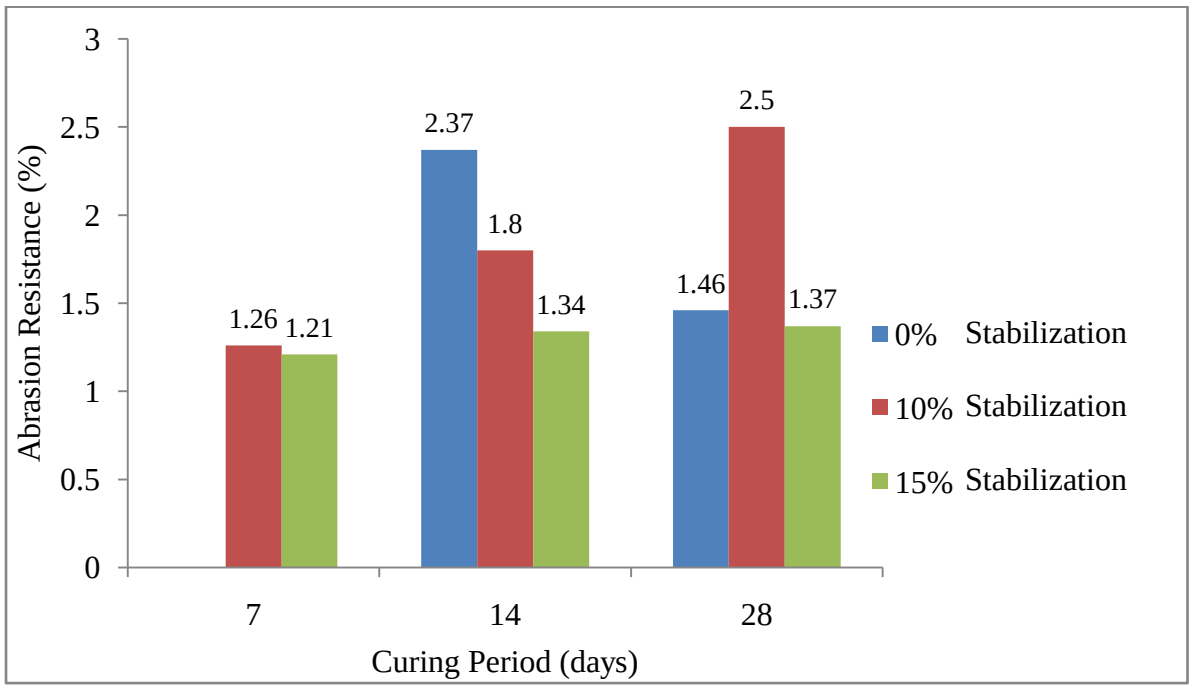


Fig 4.6: Abrasion resistance - age of curing relation for poured laterite cubes

The abrasion of cubes shows two types of activity. One activity produced percentage weight loss that reduced with increase in curing time while the second activity showed an increases with increase in curing time. Zero percent cement cubes (control) performed better as there was a reduction in percentage weight loss from 2.37% at day 14 to 1.46% at day 28. The reverse was the case for both 10% cement cubes and 15% cement cubes as the recorded an increase in weight loss from day 7, day 14 and day 28. Comparing both 10% and 15% cement cubes, there was a gradual increase in weight loss for 15% cement cubes than that of 10% cement cubes which

recorded rapid weight loss result. The clay and silt content in the 0% cement cubes caused a high amount of cohesion resulting in massive shrinkage of the 0% cubes. The clay and silt flakes in the cubes matrix stuck together during curing thus, closing the air pores. As the curing days increased, the bond between the clay particles became stronger resulting in its low abrasion. The cement particles in the 10% cubes were not enough to properly bond with the aggregates because the clay particles coated the aggregate surfaces. For the 15% cement cubes, the abrasion was better than the 10% cement cubes. The cement particles in the 15% stabilized cubes were to some extent able to form more bonds between themselves and the aggregates. This was shown by the slow increase in the quantity of materials abraded away as the curing days increased.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSION AND RECOMMENDATION.

5.1 Summary of Research Findings.

a. Specific gravity of the laterite used was 2.59 close to the value obtained by Shehu (2010) which was 2.56. The plastic index (P.I) of the laterite was 13% which satisfied the condition specified in BS 1377 (1975). The American Association of state Highways and Transportation official (AASHTO) classification system for this Laterite falls under sub-group of A -2- 6 indicating the presence of sand, elastic silt fines and some gravels. The gradation analysis with C_U=4.8 and Cc = 0.8 showed a well graded soil.

b. Aluminum, Silica, titanium and iron which were found to be present with their oxides in appreciable amounts satisfy the condition given by Oyelowe *et al* (2012) for a soil to be referred to as laterite.

c. The average dry compressive strength for the cubes of 0%, 10% and 15% cement content at 28 days was 1.75N/mm^2, 1.01N/mm^2 and 1.32N/mm^2 respectively. Only the 28 day average compressive strength of the cubes with 0% and 15% cement content compare closely with 1.8N/mm^2 recommended by the Nigerian Industrial Standard NIS: 87:2004 as the minimum for non-load bearing blocks.

d. The result for the tensile strength indicated that cylinders with 15% cement content had the highest average values of 0.23N/mm^2, 0.27N/mm^2 and 0.29N/mm^2 on the 7, 14 and 28 day respectively. Tensile strength of the PP rope was found to be 75.13N/mm^2.

e. Flexural test result showed that beams (10% and 15%) without PP reinforcement performed better than beams (10% and 15%) having the PP reinforcement. Anchorage

failure of the PP rope was a contributory factor to the poor performance of PP reinforced poured laterite beams.

f. The absorption capacity for all cubes (0%, 10% and 15%) was lowest in 15% cement cubes at day 7 and day 28. There was an equilibrium in absorption for 10% cubes and 15% cubes at day 14. All 0% cement cubes partially dissolved in water.

g. The average wet compressive strength value of 0.87N/mm2 at 28 days was recorded by 15% cement cubes. This value was close to the minimum of 1.0N/mm^2 recommended by the Nigerian Building and Road Research Institute (NBRRI, 2006). zero percent cement cubes completely dissolved in water.

h. On day 28, 15% cement cubes recorded the least amount of percentage weight loss which was 1.37%. The opposite was the case for 10% cement cubes which produced the highest amount of weight loss with a value of 2.50% on day 28.

5.2 Conclusion

Based on the limited findings of this study, the following conclusions were drawn

a. The laterite soil was well graded and identified to be an A – 2 – 6 soil based on AASHTO classification system. The physical and chemical properties of the laterite were satisfied.

b. At 28 days, specimen with 15% cement content gave highest tensile strength, flexural strength (reinforced and non reinforced PP beams), absorption capacity, wet compressive strength and abrasion resistance. However, 0% cement content (control) only gave the highest dry compressive strength value during test at 28 days.

c. The average dry and wet compressive strengths of the 15% cement cubes at 28 days was satisfactory. The strength (wet and dry) could still increase with increase in curing time.

d. The high absorption capacity values recorded by the cubes (0%,10% and 15%) shows that they contain numerous air pores.

e. Polypropylene (PP) rope failed to improve the flexural strength of the beams at all cement percentages due to poor bonding or anchorage with the laterite .However, if the anchorage can be improved in some way, the flexural strength may increase.

f. The low tensile strength values recorded for all cement percentages indicates the inability to be used as a structural member for construction but suitable for members in compression e.g. walls.

5.3 Recommendation

i. Aggregates sizes higher than 4.75mm should be adopted when using cement stabilized poured laterite.

ii. Mix of 15% cement stabilized poured laterite can be used in the construction of non load bearing internal walls.

iii. Cheap and alternative stabilizers should be used in conjunction with cement. This will reduce the quantity and over-reliance on cement usage.

iv. Government should equip the laboratories with modern equipment to improve research work.

v. Standards or guides need to be developed for poured earth method. This will assist construction professionals when handling a job using poured earth.

5.4 Recommendation for Further Research

i. Research should be conducted on the resistance capability of poured laterite to chemical attack or aggressive media.

ii. Effect of fungus or moulds on poured laterite.

iii. Higher cement content on the properties of compressive strength (dry and wet), tensile strength, flexural strength, water absorption and abrasion.

iv. The replacement of cement with other pozzolanic materials.

v. Effect of moist curing on strength properties of poured laterite e.g. compressive strength (dry and wet).

vi. The suitability of using other plastic ropes as a form of reinforcement

5.5 Contribution to Knowledge

i. It has been established that poured laterite construction is a new innovation.

ii. Also, it was established that polypropylene rope failed to improve the flexural strength of reinforced poured laterite beam.

iii. The research also showed that poured laterite is lightweight in nature.

iv. Poured laterite has been shown to be suitable for building construction.

v. A small quantity of cement is required for stabilization in poured laterite.

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Appendix 1.

Specific Gravity Test.

	Test 1	Test 2
Weight of empty cylinder (W1)	1,060g	1,060g
Weight of cylinder + Laterite (W2)	1320g	1,324g
Weight of cylinder + Laterite + Water (W3)	2,440g	2,442g
Weight of cylinder + Water (W4)	2,280g	2,280g

Therefore, specific gravity $= \dfrac{W2 - W1}{(W4 - W1) - (W3 - W2)}$

$= \dfrac{1320 - 1060}{(2280 - 1060) - (2440 - 1320)} \qquad \dfrac{1324 - 060}{(2280 - 1060) - (2442 - 1324)}$

$= \dfrac{260}{1220 - 1120} = \dfrac{264}{1220 - 1118}$

$= \dfrac{260}{100} = \dfrac{264}{102}$

$= 2.60 \qquad 2.58$

Average Specific Gravity $= 2.59$

Appendix 2

Fineness Modulus

$$\text{Fineness modulus} = \sum\left(\frac{\text{cumulative retained percentage}}{100}\right)$$

$$= \sum\left(\frac{0.6 + 16.6 + 38.2 + 60 + 88.4 + 95 + 100}{100}\right)$$

$$= \frac{398.8}{100}$$

$$= 3.98\text{mm}$$

This is a combined aggregate having silt, sand and some gravel.

Appendix 3

PARTICLE SIZE DISTRIBUTION GRAPH

Standard : BS 1377 (1975) **laboratory: Building Department**

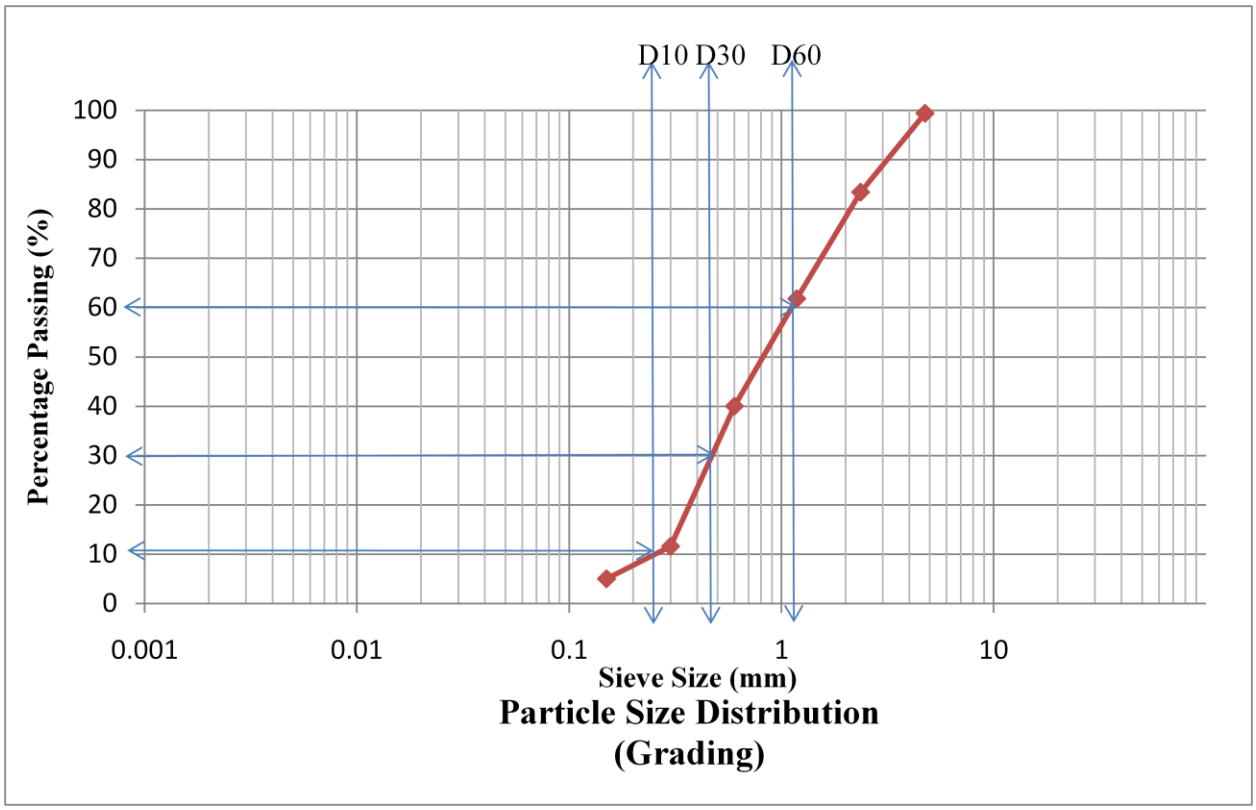
Identification of the Sample: Laterite **Date: 4 – 9 - 2013**

Operator: Kweku Sackey

Dry mass of test sample M_1= 500 g

Sieve sizes (mm)	Weight retained (g)	Weight passing(g)	Percentage weight passing (%)	Percentage weight retained (%)	Cumulative Percentage Retained (%)
4.75mm	3g	497	99.4	0.6	0.6
2.36mm	80g	417	83.4	16	16.6
1.18mm	108g	309	61.8	21.6	38.2
600µm	109g	200	40	21.8	60
300µm	142g	58	11.6	28.4	88.4
150µm	33g	25	5	6.6	95
Pan	25g			5	100

GRADING IN LOG SCALE



Appendix 4

Sieve analysis of particle size distribution curve

D_{10}=0.25mm

D_{30}= 0.48mm

D_{60}= 1.20mm

$\therefore$ coefficient of curvature (Cc)= $\frac{(D_{30})^2}{D_{10}D_{60}}$

$= \frac{(0.48)^2}{0.25x1.2}$

$= \frac{0.2304mm^2}{0.3mm^2}$

$= 0.7680 \sim 0.8$

$\therefore$ Coefficient of uniformity (Cu) = $\frac{D_{60}}{D_{10}}$

$= \frac{1.20mm}{0.25mm}$

$= 4.8$

Appendix 5

Bulk Density

		First Test	Second Test	Third Test
Mass of compacted laterite		2.68kg	2.62kg	2.64kg
Volume of cylinder (m^3)		0.0018686925	0.0018686925	0.0018686925
Bulk density = $\frac{\text{Mass}}{\text{Volume}}$	=	$\frac{2.68kg}{0.0018686925m^3}$	$\frac{2.62kg}{0.0018686925m^3}$	$\frac{2.64kg}{0.0018686925}$
	=	$1434kg/m^3$	$1402kg/m^3$	$1413kg/m^3$

Average Bulk density $= \frac{1434 + 1402 + 1413}{3}$

$= \frac{4249}{3} = 1416\ kg/m^3$

Appendix 6

Percentage moisture water content

Weight of container (Wc) = 61g

Weight of container, lid and moist specimen (W_1) =100g

Weight of container, lid and oven dry specimen (W_2) = 98g

Weight of water (W_w) = W_1 - W_2 = 100g – 98g = 2g

Weight of soil (Ws) = W_2 – Wc = 98g – 61g =37

$$\% \text{ moisture water content} = \frac{Ww}{Ws} \times 100$$

$$= \frac{2g}{37g} \times 100$$

$$= 5.40\%$$

Appendix 7

Water absorption of cubes at various cement percentages.

Sample shape	Desig-nation	Cement Content (%)	Curing Duration (days)	Water/ Solid Ratio	Initial Weight W1(kg)	Final Weight W2(kg)	Increase In Weight W(kg)	Absorption (%)	Average Absorption Capacity (%)
	A1	10	7	0.37	1.36	1.80	0.44	32	
Cube	B1	10	7	0.37	1.42	1.82	0.40	28	30
	C1	10	7	0.37	1.54	1.98	0.44	29	
	A2	10	14	0.37	1.50	1.92	0.42	28	
	B2	10	14	0.37	1.46	1.84	0.38	26	26
	C2	10	14	0.37	1.40	1.76	0.36	25	
	A3	10	28	0.37	1.38	1.72	0.34	25	
	B3	10	28	0.37	1.40	1.78	0.38	27	26
	C3	10	28	0.37	1.40	1.78	0.38	27	
	A1	15	7	0.37	1.36	1.74	0.38	28	
Cube	B1	15	7	0.37	1.40	1.78	0.38	27	28
	C1	15	7	0.37	1.44	1.86	0.42	29	
	A2	15	14	0.37	1.56	1.96	0.40	26	
	B2	15	14	0.37	1.38	1.74	0.36	26	26
	C2	15	14	0.37	1.30	1.64	0.34	26	
	A2	15	28	0.37	1.42	1.74	0.32	23	
	B2	15	28	0.37	1.34	1.68	0.34	25	24
	C2	15	28	0.37	1.40	1.72	0.32	23	

Sources: Laboratory Work, 2014

Appendix 8

Wet Compressive strength of cubes at various cement percentages

Sample shape	Designation	Cement Content (%)	Curing Duration (days)	Crossectional Area (mm^2)	Failure (KN)	Compressive Strength (N/mm^2)	Average Compressive Strength(N/mm^2)
	A_1	10	7	100 x 100=10,000	6.2	0.62	
Cube	B_1	10	7	10,000	6.4	0.64	0.60
	C_1	10	7	10,000	5.4	0.54	
	A_2	10	14	10,000	6.4	0.64	
	B_2	10	14	10,000	7.6	0.76	0.65
	C_2	10	14	10,000	5.6	0.56	
	A_3	10	28	10,000	6.7	0.67	
	B_3	10	28	10,000	6.5	0.65	0.66
	C_3	10	28	10,000	6.5	0.65	
	A_1	15	7	10,000	5.9	0.59	
Cube	B_1	15	7	10,000	7.8	0.78	0.68
	C_1	15	7	10,000	6.8	0.68	
	A_2	15	14	10,000	7.9	0.79	
	B_2	15	14	10,000	7.2	0.72	0.75
	C_2	15	14	10,000	7.6	0.76	
	A_3	15	28	10,000	7.4	0.74	
	B_3	15	28	10,000	8.9	0.89	0.87
	C_3	15	28	10,000	9.9	0.99	

Sources: Laboratory Work, 2014

Appendix 9

Dry Compressive Strength of cubes at various cement prercentages

Sample shape	Designation	Cement content (%)	Curing duration (days)	Cross sectional area (mm^2)	Failure (KN)	Compressive strength (N/mm^2)	Average
Cube	A_2	0	14	100x100= 10,000	14	1.4	
	B_2	0	14	10,000	14.5	1.45	1.33
	C_2	0	14	10,000	11.5	1.15	
	A_3	0	28	10,000	19.3	1.93	
	B_3	0	28	10,000	16.4	1.64	1.75
	C_3	0	28	10,000	17	1.7	
Cube	A_1	10	7	10,000	6	0.6	
	B_1	10	7	10,000	10	1	0.86
	C_1	10	7	10,000	10	1	
	A_2	10	14	10,000	9.4	0.94	
	B_2	10	14	10,000	10.2	1.02	0.99
	C_2	10	14	10,000	10.2	1.02	
	A_3	10	28	10,000	11.8	1.18	
	B_3	10	28	10,000	8.4	0.84	1.01
	C_3	10	28	10,000	10.1	1.01	
Cube	A_1	15	7	10,000	9.2	0.92	
	B_1	15	7	10,000	11	1.1	1.04
	C_1	15	7	10,000	11.6	1.16	
	A_2	15	14	10,000	14.6	1.46	
	B_2	15	14	10,000	12.5	1.25	1.30
	C_2	15	14	10,000	12	1.2	
	A_3	15	28	10,000	15.6	1.56	
	B_3	15	28	10,000	11	1.1	1.32
	C_3	15	28	10,000	13	1.3`	

Sources: Laboratory Work, 2014

Appendix 10

Tensile strength of cylinders at various cement percentages

Sample shape	**Designation**	**Cement Content (%)**	**Curing duration (days**	Water /Soil Ratio	**P (KN)**	^	**L (mm)**	**D (mm)**	**Tensile strength N/mm^2**	**Average tensile strength (N/mm^2)**
Cylinder	A_2	0	14	0.37	5	3.14	200	100	0.16	
	B_2	0	14	0.37	5.8	3.14	200	100	0.18	0.16
	C_2	0	14	0.37	4.8	3.14	200	100	0.15	
	A_3	0	28	0.37	4.5	3.14	200	100	0.14	
	B_3	0	28	0.37	4.7	3.14	200	100	0.15	0.15
	C_3	0	28	0.37	5.2	3.14	200	100	0.17	
	A_1	10	7	0.37	3.9	3.14	200	100	0.12	
	B_1	10	7	0.37	4	3.14	200	100	0.13	0.10
	C_1	10	7	0.37	2	3.14	200	100	0.06	
	A_2	0	14	0.37	4.8	3.14	200	100	0.15	
	B_2	0	14	0.37	3.4	3.14	200	100	0.11	0.14
	C_2	0	14	0.37	4.8	3.14	200	100	0.15	
	A_3	10	28	0.37	4.9	3.14	200	100	0.16	
	B_3	10	28	0.37	4.8	3.14	200	100	0.15	0.15
	C_3	10	28	0.37	4.8	3.14	200	100	0.15	
	A_1	15	7	0.37	6.8	3.14	200	100	0.22	
	B_1	15	7	0.37	7.2	3.14	200	100	0.23	0.23
	C_1	15	7	0.37	7.2	3.14	200	100	0.23	
	A_2	15	14	0.37	9	3.14	200	100	0.28	
	B_2	15	14	0.37	9	3.14	200	100	0.28	0.27
	C_2	15	14	0.37	8	3.14	200	100	0.25	
	A_3	15	28	0.37	9.4	3.14	200	100	0.29	
	B_3	15	28	0.37	9.4	3.14	200	100	0.29	0.29
	C_3	15	28	0.37	9.9	3.14	200	100	0.30	

Sources: Laboratory Work, 2014

Appendix 11

Abrasion test for poured earth cubes

Designation	Cement content (%)	Curing (days)	Initial weight (kg)	Final weight (kg)	Abraded away (%)	Average abraded away (%)
A_2	0	14	1.40	1.38	1.43	
B_2	0	14	1.40	1.36	2.86	2.37
C_2	0	14	1.42	1.38	2.82	
A_3	0	28	1.38	1.36	1.45	
B_3	0	28	1.40	1.38	1.43	1.46
C_3	0	28	1.34	1.32	1.49	
A_1	10	7	1.58	1.56	1.27	
B_1	10	7	1.64	1.62	1.22	1.26
C_1	10	7	1.56	1.54	1.28	
A_2	10	14	1.42	1.40	1.41	
B_2	10	14	1.54	1.50	2.59	1.80
C_2	10	14	1.34	1.32	1.49	
A_3	10	28	1.36	1.32	2.94	
B_3	10	28	1.36	1.34	1.47	2.50
C_3	10	28	1.30	1.26	3.10	
A_1	15	7	1.64	1.62	1.22	
B_1	15	7	1.66	1.64	1.21	1.21
C_1	15	7	1.66	1.64	1.21	
A_2	15	14	1.50	1.48	1.33	
B_2	15	14	1.48	1.46	1.35	1.34
C_2	15	14	1.50	1.48	1.33	
A_3	15	28	1.46	1.44	1.37	
B_3	15	28	1.52	1.50	1.32	1.37
C_3	15	28	1.40	1.38	1.43	

Source: Laboratory work, 2014

Appendix 12

Specimen calculations

Trial test

Density of Laterite = 1416kg/m^3

Volume of beam = 0.1x0.1x0.5 = 0.005m^3

$$\text{Density} = \frac{\text{mass}}{\text{Volume}}$$

But mass = Density x volume

= 1416 x 0.005

= 7.08kg

∴ Assume 10kg of laterite to produce 1 beam

5% cement content for 10kg beam = $\frac{5 \times 10{,}000g}{100}$ = 500g of cement

∴Cement + Lateite = 500g + 10,000g

= 10,500g or 10.5kg

3.30kg of H_2O was used in mixing laterite + Cement

$$\therefore \text{ water/solid ratio} = \frac{3.30\text{kg of } H_2O}{10.5\text{kg of Laterite + Cement}}$$

$$= 0.314 \simeq 0.31$$

During trials with the water/solid ratio of 0.31 it was not sufficient to enable the slurry pour or flow hence, an acceptable value of 0.37 was finally reached after further trials.

CUBE

Volume of 1 cube = 0.1x0.1x0.1 = $0.001m^3$

Density of laterite = 1416 kg/m^3

∴ mass of laterite for 1 cube = Density x volume
1416 x 0.001 = 1.4kg

Add 15% waste = $\frac{115}{100}$ x 1.4kg = 1.6kg

Laterite = 1 cube = 1.6kg
∴ 27 cubes = 27 x 1.6 = 43.2kg
∴ 3 sets of cubes = 43.2 ÷ 3 (0%,10%, 15%) = 14.4kg each

Cement = 0% cement = $\frac{0}{100}$ x 14.4kg = 0kg

10% cement = $\frac{10}{100}$ x 14.4kg = 1.44kg

15% cement = $\frac{15}{100}$ x 14.4kg = 2.16kg

Water = laterite + cement x Ratio

0% water = 14.4kg + 0kg x 0.37
14.4kg x 0.37 = 5.328 ~ 5.34kg

10% water = 14.4kg + 1.44kg x 0.37
15.84kg x 0.37 = 5.86kg

15% water = 14.4kg + 2.16kg x 0.37
16.56kg x 0.37 = 6.127 ~ 6.14kg

CYLINDER

Volume of 1 cylinder = $\lambda r^2 h$ = 3.14 x $(50)^2$ x 200
= 3.14 x $(0.05)^2$ x 0.2
= 0.00157m^3

Density of laterite = 1416kg/m^3
∴mass of laterite for 1 cylinder = Density x volume
= 1416 x 0.00157
= 2.2kg

Add 15% waste = $\frac{115}{100}$ x 2.2kg = 2.53kg

Laterite => 1 cylinder = 2.53kg

∴ 27 cylinders = 27 x 2.53 = 68.31 ~ 68.32kg

∴ 3 sets of cylinders = 68.32 ÷ 3 (0%,10%,15%) = 22.77 ~ 22.78kg

Cement => 0% cement = $\frac{0}{100}$ x22.78kg = 0kg

10% cement = $\frac{10}{100}$ x 22.78kg = 2.278 ~ 2.28kg

15% cement = $\frac{15}{100}$ x 22.78kg = 3.417 ~ 3.42kg

Water => Laterite + cement x Ratio

0% water = 22.78 + 0kg x 0.37

22.78 x 0.37 = 8.428 ~ 8.44kg

10% water = 22.78 + 2.28 x 0.37

25.06 x 0.37 = 9.272 ~ 9.28kg

15% water = 22.78 + 3.42 x 0.37

26.20x 0.37 = 9.694 ~ 9.70kg

Beam

Volume of 1 beam = $0.1 \times 0.1 \times 0.5 = 0.005 m^3$

Density of laterite = $1416 kg/m^3$

$\therefore$ Mass of laterite for 1 beam = Density x volume

= 1416 x 0.005

= 7.1kg

Add 15% waste = $\frac{115}{100}$ x 7.1kg = 8.2kg

Laterite => 1 beam = 8.2kg

$\therefore$ 18 beams = 18x 8.2 = 147.6kg

$\therefore$ 3 sets of beams = 147.6 ÷ 3 (0%,10%,15%) = 49.2kg

Cement => 0% cement = $\frac{0}{100}$ x 49.2kg = 0

10% cement = $\frac{10}{100}$ x 49.2kg = 4.92kg

15% cement = $\frac{15}{100}$ x 49.2kg = 7.38kg

Water => Laterite + cement x Ratio

0% water 49.2kg + 0 x 0.37

49.2kg x 0.37 = 18.20 $\simeq$ 18.20kg

10% water 49.2kg + 4.92kg x 0.37

54.12 x 0.37 = 20.02 $\simeq$ 20.02kg

15% water 49.2kg + 7.38 x 0.37

56.58 x 0.37 = 20.94 $\simeq$ 20.94kg

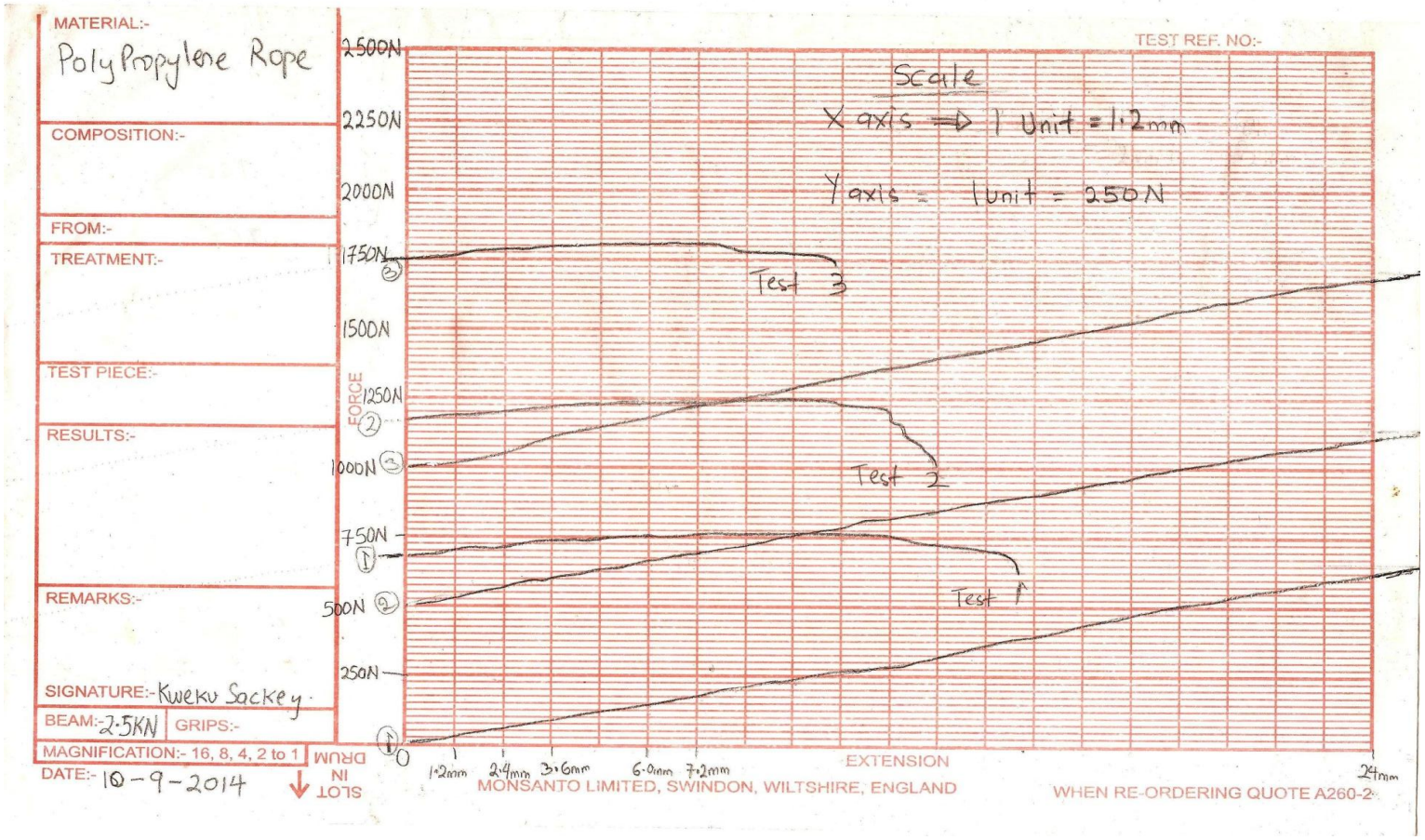
APPENDIX 13

Tensile Test for Polypropylene

Specimen = Polypropylene
Diameter = 3.75mm
Area = πr^2 = 10.98mm^2
Gage Length = 60mm

S/NO	Force (N)	Area (mm^2)	Stress (N/mm^2)	Extension (mm)	Original length (mm)	Strain (no unit)
1.	0	10.98	0	0	60	0
2.	12.5	10.98	1.13	1.2	60	0.02
3.	50	10.98	4.55	2.4	60	0.04
4.	100	10.98	9.10	3.6	60	0.06
5.	150	10.98	13.66	4.8	60	0.08
6.	175	10.98	15.93	6.0	60	0.10
7.	225	10.98	20.49	7.2	60	0.12
8.	250	10.98	22.76	8.4	60	0.14
9.	287.5	10.98	26.18	9.6	60	0.16
10.	325	10.98	29.59	10.8	60	0.18
11.	350	10.98	31.87	12	60	0.20
12.	400	10.98	36.42	13.2	60	0.22
13.	425	10.98	38.70	14.4	60	0.24
14.	462.5	10.98	42.12	15.6	60	0.26
15.	490	10.98	44.62	16.8	60	0.28
16.	530	10.98	48.26	18	60	0.30
17.	575	10.98	52.36	19.2	60	0.32
18.	600	10.98	54.64	20.4	60	0.34
19.	637.5	10.98	58.06	21.6	60	0.36
20.	662.5	10.98	60.33	22.8	60	0.38
21.	680	10.98	61.93	24	60	0.40
22.	712.5	10.98	64.89	25.2	60	0.42
23.	750	10.98	68.30	26.4	60	0.44
24.	762.5	10.98	69.44	27.6	60	0.46
25.	787.5	10.98	71.72	28.8	60	0.48
26.	800	10.98	72.85	30	60	0.50
27.	810	10.98	73.77	31.2	60	0.52
28.	820	10.98	74.68	32.4	60	0.54
29.	825	10.98	75.13	33.6	60	0.56
30.	775	10.98	70.58	34.8	60	0.58
31.	770	10.98	70.12	36	60	0.60
32.	700	10.98	63.75	37.2	60	0.62

Source: laboratory experiment, 2014


MATERIAL:-
Poly Propylene Rope
COMPOSITION:-
FROM:-
TREATMENT:-
TEST PIECE:-
RESULTS:-
REMARKS:-
SIGNATURE:- Kweku Sackey.
BEAM:-2·5KN
GRIPS:-
MAGNIFICATION:- 16, 8, 4, 2 to 1
DATE:- 10-9-2014
SLOT IN DRUM
TEST REF. NO:-
Scale
X axis → 1 Unit = 1·2mm
Y axis - 1unit = 250N
2500N
2250N
2000N
1750N
1500N
1250N
1000N
750N
500N
250N
0
FORCE
Test 3
Test 2
Test 1
1·2mm
2·4mm
3·6mm
6·0mm
7·2mm
24mm
EXTENSION
MONSANTO LIMITED, SWINDON, WILTSHIRE, ENGLAND
WHEN RE-ORDERING QUOTE A260-2

Appendix 14 AASHTO CLASSIFICATION SYSTEM

		PERCENTAGE PASSING B.S. SIEVE No.			CHARACTERS OF FRACTION PASSING No. 40 SIEVE		Group		
No	Sub-group	10 mm 3/8"	40 425 µm	200	Liquid Limit	Plasticity Index	Index No.	Soil Description	Subgrade Rating
1			50 max	20 max	Non plastic	6 max	0	Well - graded gravel or sand; may include fines.	Excellent to good
2	A - 1- a	50 max	50 max	15 max		6 max	0	Largely gravel but can include sand and fines.	Excellent to good.
3				35 max	Non plastic		0 - 4	Sands and gravels with excessive fines	Excellent to good
4	A - 2 - 4			35 max	40 max	10 max	0	Sands, gravels with low - plasticity silt fines.	Sub Bae
5	A - 2 - 5			35 max	41 min	10 max	0	Sands, gravels with elastic silt fines	Sub Bae
6	A - 2 - 6			35 max	40 max	11 min	4 max	Sands, gravels with elastic silt fines	Sub base/sub grade
7	A - 2 - 7			35 max	35 min	11 min	4 max	Sands, gravels with highly plastic clay fines.	subgrade/fill
8			51 min	10 max	Non plastic		0	Fine sands	Fill
9				36 min	40 max	10 max	8 max	Low - compressibility silts	Fill
10				36 min	40 max	10 max	12 max	High-compressibility silts, micaceous silts.	Fill
11				36 min	40 max	11 min	16 max	Low-to-medium compressibility clays	Fair to poor fill
12				36 min	41 min	11 min	20 max	High compressibility silty clays	Poor
13	A - 7 - 5			36 min	41 min	11 min	20 max	High compressibility silty clays	Poor
14				36 min	41 min	11 min	20 max	High compressibility, high volume change clays, highly organic soils	Poor

Appendix 15

AHMADU BELLO UNIVERSITY, ZARIA
DEPT. OF CIVIL ENGINEERING

LIQUID AND PLASTIC LIMIT CHART

Site..... Job. 1

Sample No. 1 Depth. 3m Date 2-9-2013

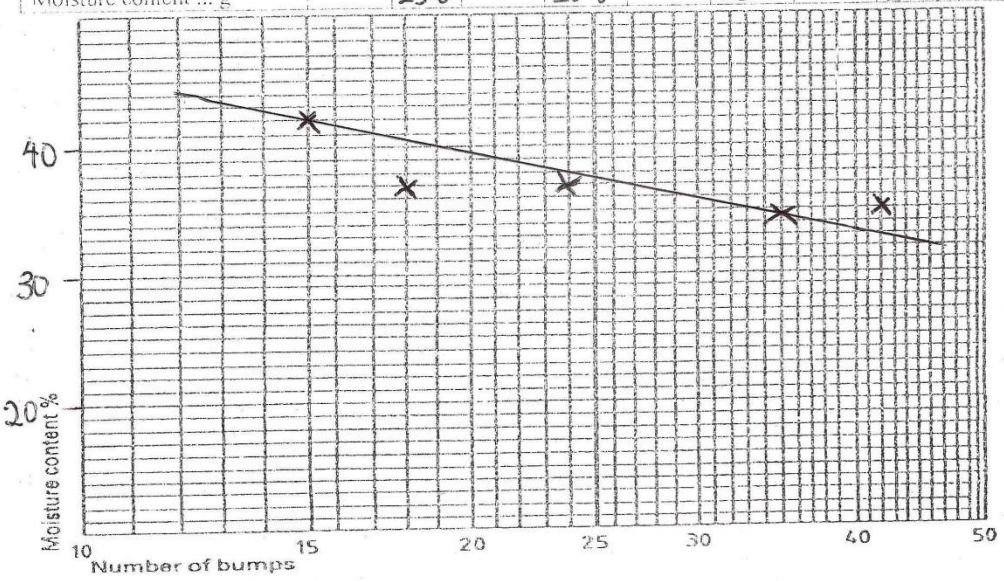
Liquid Limit (L.L) 37 Plastic Limit (P.L) 24 P.I. 13

Linear Shrinkage (L.S) Operator. Kweku Sackey

Description of Soil. Reddish-Brown well graded soil (Laterite)

PLASTIC AND LIQUID LIMITS

Type of Test	LL		LL		LL		LL		LL	
No of blows	42		35		24		18		15	
Container No.	58		X68		X7		63		A9	
Wt. of wet soil & cont.. g	29.8		42.0		33.9		45.5		40.7	
Wt. of dry soil and cont.. g	25.0		33.8		27.7		36.10		32.7	
Wt. of container. g	11.3		10.3		10.8		10.70		13.5	
Wt of dry soil (Wd).. g	13.7		23.5		16.9		25.4		19.2	
Wt. of moisture (Ww).. g	4.8		8.2		6.2		9.4		8.0	
Moisture content ... g	35.0		34.9		36.7		37.0		41.7	
Type of Test		PL		PL		PL		PL		PL
No of blows		—		—		—		—		—
Container No.		70		X39		20		A50		A1
Wt. of wet soil & cont.. g		14.1		17.2		18.7		15.1		14.0
Wt. of dry soil and cont.. g		13.5		16.7		17.8		14.3		13.4
Wt. of container. g		11.1		14.3		14.6		10.8		11.0
Wt of dry soil (Wd).. g		2.4		2.4		3.2		3.5		2.4
Wt. of moisture (Ww).. g		0.6		0.5		0.9		0.8		0.6
Moisture content ... g		25.0		20.8		28.1		22.9		25.0



3