An Experimental Study of the Technical Properties and Compressive Strength of Laterite Bricks Stabilised with Cement and Wood Ash

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ABSTRACT

An experimental study was carried out in order to determine the compressive strength and technical properties of laterite bricks stabilized with cement, wood ash and sawdust. Cement stabilized compressed laterite bricks were tested. The compressive strength of lateritic soil based materials were determined. The objective of this paper is to determine the effect(s) of addition of cement and wood ash to lateritic soil brick on the compressive strength using four soil samples. The findings showed positive effect of the additives of cement and wood ash on increasing the compressive strength of the stabilized laterite bricks. The study showed that the optimum value for water absorption of wood ash stabilisation is at 10% C with 5% WA (19.09%) replacement and 15% C with 10% SD. The compressive strength of the different samples measured showed increase in the failure point of the brick with increase in percentage of cement and wood ash.

Keywords: Technical Properties, Compressive Strength, Laterite Bricks , Cement and Wood Ash

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1. INTRODUCTION

In more recent past, the rate of building collapse in Nigeria has been on the increase. Most of the collapsed buildings leave scores of dead and/or maimed people trapped in the debris of such buildings for several days before rescue operations could salvage them. Findings at different times, on the remote and immediate causes of the collapse by the panels or commissions of enquiry set up by the government have been mainly attributed to the poor quality of building materials, especially with regards to the strength of the concrete blocks or unstabilized bricks used in post or pre- colonial buildings respectively. Therefore, there have been calls by major stakeholders in the indigenous arm of the Nigerian construction industry for the government to support local production of building materials in order to reduce the excessive cost of construction and erect durable structures. It is in recognition of this fact that the Nigerian government has started a massive campaign for the use of local building materials that can withstand the different weather conditions in the country.

There is the need to investigate ways and method by which locally based building materials can be improved upon to meet up with the international standard in terms of durability, strength, aesthetics and other technical properties. Koteswara Rao, Anusha, Pranav, and Venkatesh (2012:2) note that 'the loss caused due to damaged structures proved the need for more reliable investigation, of such soils and necessary methods to eliminate or reduce the effect of soil volume change'. Therefore, the demand for durable housing to stem the tide of building collapse in Nigeria has prompted renewed calls for the production of quality bricks for construction by using traditional earth material and construction technology. There is the need to look inwards for local building materials that will be of good thermal property and high strength. Oladunmoye (2016) posits that several studies have shown that the thermal properties of clay brick is better than that of sand-concrete blocks and also the compressive strength of brick can be improved through stabilization such that it can be able to serve the same structural purpose as sandcrete blocks and reinforced concrete.

Unlike other construction materials such as steel and reinforced concrete, laterite is found as a natural deposit with its properties being determined by its geological origin. It is a soil or rock found in the tropics and is very high in iron. It is not considered clay because it is usually devoid of silica, and is instead a mixture of fine grains of quartz with minute scales of hydrates of alumina. The choice of laterite in this study is informed by the availability and affordability of the material in all over Nigeria. However, there are some inadequacies in the nature of laterite, prominent among these are water absorption rate, shrinking, high porosity, workability etc. Also, laterite soils in particular can present great problems in construction due to the instability of the properties of the soil and the uncertainty of its chemical and organic compositions.

These factors have serious implications for the strength and performance of bricks made from such materials. These bricks are often unstable and susceptible to problems such as shrinking and cracking especially when exposed to changes in moisture content, heat and wetting conditions. Therefore, there is the need for the introduction of stabilisation agents to the soil in order to improve its strength and other properties. Koteswara et al (2012) proposed an improvement of the strength of soil by stabilization technique.

Similarly, any soil, irrespective of its properties can be stabilised and made suitable for the purpose of construction. There are available evidence in literature on several soil stabilisation processes and the findings of these studies have renewed the hope that stabilised bricks are effective at reducing the cost as well as improving the strength and aesthetics of construction. It is in this regard that this study investigated the strength of stabilised laterite bricks. According to Kasthurba et al (2005), before laterite can be of benefit to the engineer, it must be made to undergo a process of formation. Oladunmoye and Olutoge (2017) posits that the use of various additives such as lime, cement, bitumen and others have been found to improve the stability, durability and strength of laterite soil for better performance in building construction. Therefore, this paper will investigate the strength of laterite bricks stabilised with cement and wood ash

2. AIM AND OBJECTIVES

The aim of this study is to investigate the strength of laterite bricks stabilized with cement and wood ash to establish optimum percentage replacement for structural stability in building construction. The purpose of this study is to investigate the technical properties of laterite bricks stabilized with cement, wood ash and sawdust.The study will also examine the effects of stabilization on the properties of laterite bricks using cement and wood ash.

3. TECHNICAL PROPERTIES OF LATERITE

Laterite has unique property from hardening (indurate) on exposure to atmosphere due to drying (dehydration). The degree of indurations varies ranging from almost loose coherent mass, which can be broken by hand, to the most hardened blocks difficulty to break with hammer. The indurations of laterite are due to the development of constituent sesquioxides (Fe_2O_3 and $Al_2O_{3)}$), precipitated, concentrated and crystallized as a result of desiccation. The hardening phenomenon of exposed laterite by the formation of 2-cm hard crust on an exposed wall material due to wetting and drying has been reported by Alexander and Cady. It is agreed that the hardening of laterite is mainly due to the content and dehydration of iron oxides and arrangement of components. The depth of induration of laterite profiles varies due to water table fluctuation. (Houben, and Guillaud, 1994). Lateritic materials constitute the major surface deposit of engineering materials in many parts of Australia, Africa and South America.

The investigation of laterite for building purpose reveals that laterite shows a wide variation in engineering properties based on geographic location and within a quarry with depth. The thickness of concretionary laterite (suitable for building purpose) varies based on the region and depending on the formation in which it lies. The hard ferruginous vermicular laterite, possesses high strength, specific gravity and low water absorption and posses less clay content. This type of laterite can be categorised as good quality for building purposes (kasthurba et al, 2005). Kasthurba et al concluded that, "laterite that is categorised as weak rock can be used for low-rise buildings and partition walls, the strength of the laterite is found highly variable even though the specific gravity is high and good quality laterite for building purpose is located in the top portion of the profiles.

Other properties of laterite include plasticity, shrinkage under firing and under air drying, fineness of grain, colour after firing, hardness, cohesion, and capacity of the surface to take decoration. On the basis of such qualities, laterites are variously divided into classes or groups: products are generally made from mixtures of laterite, clay and other substances. From prehistoric times, laterite has been indispensable in engineering, industry, and agriculture. As a building material, it is used in brick moulding, either sun-dried or fired. Laterite are also of great industrial importance, for example, in the manufacturing of tile for wall and floor covering, of porcelain, china, and earthenware, and of pipe for drainage and sewage. Highly absorbent, bentonite is much used in foundry work for facing the moulds and preparing the moulding sands for casting metals.

Other uses of laterite soil in engineering are in the making of fillers, sizing, and dressings in construction, in clarifying water and wine, in purifying sewage, and in the paper, ceramics, plastics, and rubber industries. Laterite products are ideal for historic building refurbishment and for high comfort modern buildings. Their surfaces are cool in summer, warm in winter. It also has the capacity to absorb and diffuse water and it absorbs odours. Laterites are also Hygroscopic (absorbs & releases moisture), and good at reducing noise levels with low embodied energy (Kuma 1987).

Olutoge and Oladunmoye (2017) identified some of the advantages of using laterite for construction purposes and these are:

i. Availability: laterite is available in large quantities in most regions.
ii. Affordability: in most parts of the world, laterite soil is easily affordable to low-income groups.
iii. Ease of use - usually no very specialized equipment is required.
iv. Suitable as a construction material for most parts of the building.
v. Fire resistant - non-combustible with excellent fire resistance properties.
vi. (vi) Beneficial climatic performance in most regions due to its high thermal capacity, low thermal conductivity and porosity, thus it can moderate extreme outdoor temperatures and maintain a satisfactory internal temperature balance.
vii. Low energy input in processing and handling - only about 1% of the energy required for manufacturing and processing the same volume of cement concrete. This aspect as investigated by the Desert Architecture Unit which has discovered that the energy needed to manufacture and process one cubic meter of soil is about 36 MJ (10 kwh), while that required for the manufacture of the same volume of concrete is about 3000 MJ (833 kwh).
viii. Environmental appropriateness - the use of this almost unlimited resource in its natural state involves no pollution and negligible energy consumption thus further benefiting the environment by saving biomass fuel. (Gidigasu, 1976):

However, some of the limitations of using laterite as a building material are:

i. Reduced durability - if not regularly maintained and properly protected, particularly in areas affected by medium to high rainfall.
ii. Low tensile strength – poor resistance to bending moments, to be used only in compression e.g. bearing walls, domes and vaults.
iii. Low resistance to abrasion and impact - if not sufficiently reinforced or protected.
iv. Low acceptability amongst most social groups - considered by many to be a second class and generally inferior building material.

On account of these problems, it is necessary to introduce additives in order to stabilise laterite soil before its use in building construction. Some of the limitations observed in the chemical composition of laterite soil can be improved upon through the process of stabilisation. Oladunmoye (2017) averred that the technical properties of laterite soil have made its choice as a building material institutionally acceptable in most countries.

4. STABILISATION OF LATERITE SOIL

The process of soil stabilisation involves a procedure where natural or manufactured additives or binders are used to improve the properties of the soil (Koteswara Rao, Anusha, Pranav, and Venkatesh, 2012). Oladunmoye (2016) submits that the process of modifying soil properties by adding another material to improve its durability is called soil stabilisation. Soil stabilisation has been used widely since the 18th century for building construction though in a crude or primitive way. Several chemical additives, such as lime, cement, wood ash, saw dust and other additives can be introduced to stabilise a soil. Soil stabilisation processes have been investigated in different studies and varying success rates. Oladunmoye (2017)

Unfortunately the quality of compressed stabilized earth blocks in some construction schemes are far from adequate and often materials are wasted in the process of production.

It is important to extend the use of compressed stabilized earth building blocks to all types of housing in order to ensure that the production of high quality laterite bricks for construction. This will translate into the construction of durable houses that will reduce the loss of lives and monumental waste of resources that often come with building collapse. In the words of Olutoge and Oladunmoye (2017), there is a need to improve soil production techniques with regards to the stabilisation process so as to achieve better quality and reduce production costs. To do this, proportions between soil and stabilizer need to be optimized by taking into consideration the specific characteristics of the soil, compaction pressure applied to the moist soil mix should be sufficient so as to produce blocks that are dense and strong with regular surfaces and edges. A variety of physical and mechanical properties must be measured in order to achieve soil stability which must comply with the standards set by the American Society of Testing and Materials (ASTM). These properties include physical dimensions, density, and mechanical strength. Therefore, this study investigates the strength and technical properties of laterite bricks stabilized with cement and wood ash.

4.1. Common Additives in Laterite Stabilisation

Common additives used in this research are cement and wood ash. This study made use of ordinary Portland cement which hydrates when water is added. The reaction produces a cementitious gel that is independent of the soil. The major components of the gel are: calcium silicate hydrates; calcium aluminate hydrates and hydrated lime. The first two compounds form the main bulk of the cementitious gel, whereas the lime is deposited as a separate crystalline solid phase. The product of the cementation process results in deposition of an insoluble binder capable of embedding soil particles in a matrix of cementitious gel which enables the soil to be water-resistant by reducing swelling and increasing its compressive strength. However due to the presence of lime properties caused by the re-absorption of the expelled water and the formation of some chemicals compound such as calcium carbonate, and magnesium carbonate, cement is considered a good stabiliser for granular soils but unsatisfactory for clays while Lime in one form or another has been the most widely used stabilization agent for clay.

Another additive used for stabilisation in this is study is wood ash. Wood ash is an admixture: a pozzolana which is obtained from the combustion of wood. It can be related to fly ash since fly ash is obtained from coal, which is a fossilized wood. Studies (Tarun, Rudolph and Rafat) have reported the following elements in wood ash: carbon (5% to 30%), calcium (5% to 30%), carbon (7% to 33%), potassium (3% to 4%), magnesium (1% to 2%), phosphorus (0.3% to 1.4%) and sodium (0.2% to 0.5%). The study revealed that all the major compounds present in wood ash are present in fly ash.. Abdullahi (2006) found the specific gravity of wood ash obtained from a bakery in Minna, Niger State, Nigeria to be 2.13 and the bulk density 760 kg m^{-3} and his analysis showed the chemical constituents as SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, TiO_2, K_2O, SO_3 and organic matter (loss on ignition LOI = 27%). It is being usually rich in calcium carbonate, which is a good binding agent and its other chemical components, wood ash acts as a pozzolana with good stabilizing properties.

Naik (2000) performed some investigations into the properties of wood ash from different sources and established their potential for being used in cement-based construction materials. Similarly, Naik et al. (2003), in an investigation into the use of wood ash in cement-based materials, found that wood ash could be used in making self-compacting controlled low-strength materials, air-entrained and non-air-entrained concretes and bricks/blocks/paving stones. Also, Abdullahi (2006) successfully used a wood ash obtained from a bakery in Minna, Niger State, Nigeria as partial replacement for Portland cement in the production of concrete. With regards to the usage of wood ash for soil stabilization, according to Andres and Honkala (1978), wood ash is one of the oldest stabilizers known.

It is waterproof and its binding properties are adequate for stabilizing traditional adobe. It provides strength to the block and prevents cracking because of its chemical composition especially the potassium components, which aid the bonding properties.

5. EXPERIMENTAL PROCEDURES

The procedures used in this study involve preliminary investigations on soil materials, advanced laboratory tests such as compaction test, compressive strength, stabilization procedures, moulding of bricks, laboratory tests on brick sample and construction of structural models with the different samples of stabilized bricks to determine their strength. Also, the effect of the varying percentages of stabilising agents on the engineering properties of the laterite bricks was established for building purposes. A comparative analysis was also established on the compressive strength of different percentages of each of the two stabilizing agents in other to obtain sample that gives optimum strength for building construction.

5.1 Materials

The different materials used for this research and their sources are

i. Cement: Ordinary Portland Cement (OPC) with grade 42.5R and 50kg per bag
ii. Laterite: Soil samples used for the purpose of this study were collected at a laterite quarry situated at Toll-Gate area of Ibadan, along Lagos/Ibadan Expressway in South-west Nigeria . It is located between latitude $7^{0}2^{1}$ and $7^{0}28^{1}$ North of Equator and $3^{0}53^{1}$ East of the Greenwich Meridian. Predominant rock types in the study area are: Charnokites, granite gneiss and migmatitic rocks. It has been shown (Okunade, 2007) that the conditions enhancing the formation of laterites and lateritic soils are prevalent in the region and in fact there is a preponderance of such soils there, making them to be a readily available and useful source of building material. Four different samples of lateritic soil which was obtained from different spots within the same area and labelled 1, 2, 3 and 4
iii. Wood ash: this was produced by combustion of dried saw dust which, a waste product during the sawing process of hard wood into sizes. The saw dust was subjected to complete open burning to ashes. The bottom ash collected was then sieved through a BS sieve of 75µm to get very fine ash. Then it was stored in an air tight container to prevent moisture loss and any form of contamination.
iv. Water was used to mix the materials together for brick moulding. This clean water was used for mixing the materials until uniformity was achieved and was found not to be reactive with the materials used in this research.

5.2. Preliminary tests.

The natural moisture content was determined after which the clods were broken down and the samples well pulverized and were air-dried for two weeks before other analysis. Afterwards, classification and index, consistency, compaction and strength characteristics of the soil were obtained through standard procedures. Properties such as natural moisture content, sieve analysis, specific gravity, liquid limits, plastic limits, plasticity index, linear shrinkage, unconfined compressive strength, compaction, California bearing ratio (CBR), and shear strength were determined for each soil samples.

5.3. Stabilization of clay with different percentages of cement.

Using the four soil samples, different quantities or percentages (0%, 5%, 10%, 15% etc.) of a mixture of cement and wood ash as stabilization agents was obtained and the compressive strengths and water absorption tests were carried out on each sample.

To ensure uniformity in the compressed stabilised bricks produced, the volume of each material used in the brick making process was measured at the same physical state for subsequent batches of bricks. The volume of soil or stabilizer was measured in dry conditions.

5.4. Procedures for laterite soil stabilisation

This process of soil stabilisation employed in this study is in two categories. The first involves the stabilisation of four different samples of laterite with different percentages of cement (0%, 5%, 10% and 15 %). It is necessary to analyse the different types of laterite and their compressive strength when exposed to weather conditions and load. Four laterite soil samples were obtained and stabilized with different percentages of cement and wood ash. The stabilised soil samples were mixed and moulded into bricks. After treatment and curing of the stabilised laterite bricks, they were put to test in order to ascertain their compressive strengths. After 90 days, the compressive strengths were obtained. Samples of the bricks were then used to construct wall units and exposed to different weather conditions for more than 365 days to determine the sample that will not disintegrate under harsh weather conditions.

The second category of stabilisation process in this study involves the use of the best or most suitable soil sample from among the four samples stabilised in the first category above to further produce brick cubes of 150x150x150mm. Additives such as cement, wood ash and sawdust were used to stabilize the soil at varying percentages of 0, 5, 10, and 15% for each. After this, different percentages (5%, 10%, 15% etc) of a mixture of cement as stabilization agents was obtained and test compressive strengths and water absorption tests were carried out on each sample. To ensure a uniform mix of the stabilised samples, water was measured with a measuring cylinder to ascertain the actual amount of water needed for each mix type.

Oladumoye (2017) notes that the final wet compressive strength of a compressed brick depends not only on soil type, but also on the type and amount of stabiliser, the moulding pressure, and the curing conditions. Therefore, to achieve maximum strength for the compressed stabilized bricks in this study, t was ensured that the bricks were allowed a period of damp curing, where they are kept moist. As a common requirement for all cementitious materials, the moisture of the soil mix is retained within the body of the block for a few days through the use of plastic bags, grass, leaves, etc. to prevent moisture from escaping. the period of curing the stabilised laterite bricks was four weeks.

After establishing soil sample 4 as the soil sample with the most suitable properties for brick moulding, the soil sample D was used to produce cubes of 150x150x150mm with cement and different variations of wood ash and sawdust as stabilisation material at varying percentages of 5,10, and 15%. Three soil samples each of the different percentages (5%, 10%, 15% etc) of a mixture of cement as stabilization agents were obtained and the compressive strengths and water absorption tests were carried out on each sample mixes of 1,2,3,4 and 5 respectively.

The samples of the mix in the categories were labelled as follows:

MIX 1 0C= control sample with 100% laterite and 0% cement content
5C= sample with 95% laterite and 5% cement content
10C = sample with 90% laterite and 10% cement content
15C= sample with 85% laterite and 15% cement content

MIX 2 0C= control sample with 100% laterite, 0% cement and 0% wood ash content
5WA = sample with 95% laterite, 0% cement and 5% wood ash content
10WA = sample with 90% laterite, 0% cement and 10% wood ash content
15WA= sample with 85% laterite, 0% cement and 15% wood ash content

MIX 3 0C= control sample with 100% laterite, 0% cement and 0% wood ash content
5C5WA = sample with 90% laterite, 5% cement and 5% wood ash content
5C10WA = sample with 85% laterite, 5% cement and 10% wood ash content
5C15WA= sample with 80% laterite, 5% cement and 15% wood ash content
10C5WA = sample with 85% laterite, 10% cement and 5% wood ash content
10C10WA = sample with 80% laterite, 10% cement and 10% wood ash content
10C15WA= sample with 75% laterite, 10% cement and 15% wood ash content
15C5WA = sample with 80% laterite, 15% cement and 5% wood ash content
15C10WA = sample with 75% laterite, 15% cement and 10% wood ash content
15C15WA= sample with 70% laterite, 15% cement and 15% wood ash content

Table 5.1. Showing the Sample Label for the Different Design Mix of Bricks.

Sample label	Laterite content (%)	Cement content (%)	Wood Ash content (%)	Saw Dust content (%)
MIX 1				
0c (Control)	100	0	0	0
5C	95	5	0	0
10C	90	10	0	0
15C	85	15	0	0
MIX2				
0C(control)	100	0	0	0
5WA	95	0	0	5
10WA	90	0	0	10
15WA	85	0	0	15
MIX3				
0C(control)	100	0	0	0
5C5WA	90	5	5	0
5C10WA	85	5	10	0
5C15WA	80	5	15	0
10C5WA	85	10	5	0
10C10WA	80	10	10	0
10C15WA	75	10	15	0
15C5WA	80	15	5	0
15C10WA	75	15	10	0
15C15WA	70	15	15	0

Figure 5.1. Showing different bricks produced with varying percentages of stabilization.

Testing of brick samples

The stabilized laterite bricks were exposed to different tests to ascertain their water absorption rate and compressive strength.

Physical Tests

a) The block is oven-dried until a constant mass was obtained. The mass of the block is considered to be constant when the difference in mass between 2 weightings at a 24 hour interval is < 0.1 % of the initial mass.
b) On removal from the oven the block was left open to ambient air for 2 hours.
c) After this interval, the block mass m was weighed (in g, to the nearest g).

Figure 5.2. Weighing of the brick to determine dry and wet weight.

Water Absorption Tests

Water absorption test was carried out to determine the permeability of the bricks. The specimens were first dried in an oven for 48 hours at 110°C and later cooled at room temperature before weighing. After that, the specimens were placed inside a curing tank and with cold water for 6 hours. The specimens were removed after they had been immersed in the tank for some hours and then weighed. The ratio of the water content to the dry mass of bricks determines the quantity of the water absorption of specimens.

Figure 5.3. Showing stabilised brick soaked in water.

Mechanical Tests

1. Compression Tests

The compressive strength of a material determines the load-carrying capacity of that material before breakage. The compressive strength test was carried out by imposing the bricks on a compression load until breakage to examine the variation of strengths, allowing to categorise the bricks by their strength level. Compressive strength was calculated by dividing the maximum load by the load area of the specimen according to the standards.

Determination of Compressive strength.

The average weight of the brick samples of size 150mm x 150mmx 150mm were measured and recorded. Compressive strength test for bricks made from the samples were then measured at different intervals of 7, 14,21,28,56 and 90 days.

The brick Samples were crushed with a hydraulic machine of maximum capacity of 3000KN, types SWP 300 EM1, Masch Nr. 6329. Average maximum compressive force for the 4 brick samples for each grade was determined and recorded for computation of compressive strength which was conducted in accordance to British Standard (BS 1881, 1983)

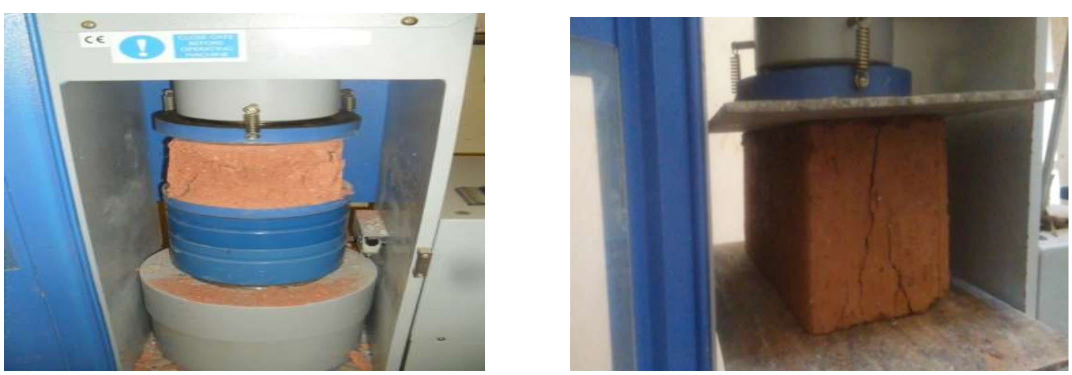


Figure 5.4. Brick from soil sample 1 and 2 at the point of failure

Figure 5.5. Brick from Soil Sample 3 and 4 at Point of Failure

Figure 5.6. Wall section with Samples 1, 2, 3 and 4 showing rate of disintegration of wall unit after exposure to weather conditions for two years.

Figure 5.7. Showing model constructed with bricks from different percentages of stability

6. RESULTS AND DISCUSSIONS

The results from the preliminary tests revealed that the soil sample A is highly clayey containing (1.81, 1.15, 97.04) % of gravel, sand and silt respectively, B is well graded clayey sand with gravel containing (22.73, 4.28, 72.99) % of gravel, sand and silt respectively while C and D are well graded low plastic clayey sand containing (6.09, 27.03, 66.88 and 7.81, 24.76, 67.43) of gravel, sand and silt respectively. Results of other tests such as grain size analysis, natural moisture contents, specific gravity and Atterberg's limits as well as the engineering property tests (compaction, California Bearing Ratio CBR), are presented and discussed below. The results are in close range with that obtained from a similar study by Thompson Henry (2011)

6.1. Sieve Analysis Result

The sieve analysis results for the unstabilised four laterite soil samples are stated in tables 4.1.1 - 4.1.4 and charts 4.1.1 - 4.1.4 below. The samples were classified using the AASHTO soil classification system. All the samples fell within the granular materials under the general classification as their percentages passing 75µm sieve were all less than 35%.this is in agreement with previous studies by Amu, O.O.*et al* (2011). However, Sample D recorded the highest sieve analysis result as follows:

TABLE 6.1

BS Sieve size	Weight Retained	% RET.	% PASSING
13.2mm	0	0	100
6.7mm	1.5	0.56	99.44
4.75mm	7.2	1.81	98.19
2.36mm	34.7	8.71	89.48
1.18mm	96.2	24.16	65.32
850µm	49.9	12.53	52.79
600µm	47.9	12.03	40.76
425µm	41.6	10.45	30.31
212µm	50.6	12.71	17.6
150µm	29.9	7.51	10.09
75µm	35.6	8.94	1.15
Ppan	4.6	1.15	-

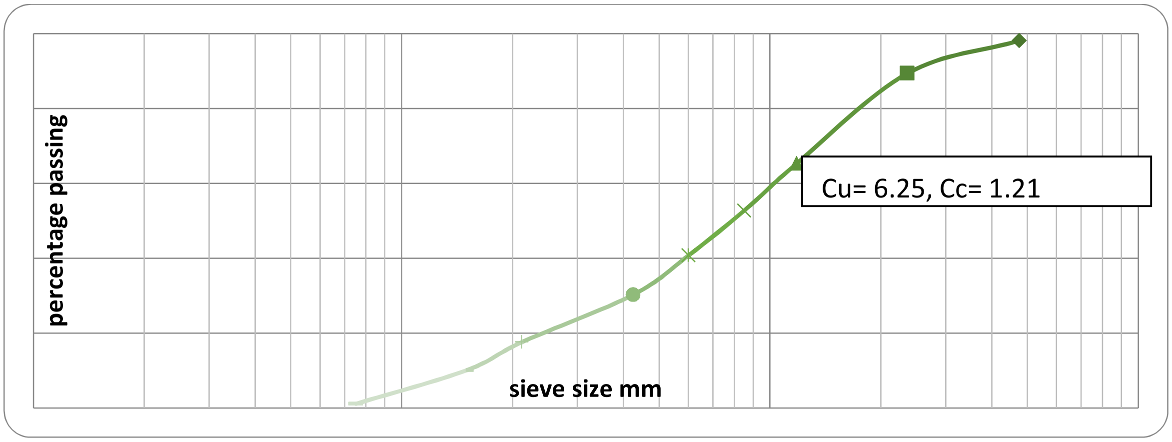


Chart 6.1: Sieve Analysis Result for Sample D

6.2. Compaction Test

The results of the compaction tests on the soil samples as presented in charts 4.2.1-4.2.4 showed the optimum moisture content and maximum dry density as (18.1 % and 1.76mg/m3, 13.5% and 1.87mg/m3,14% and 1.97mg/m3,12% and 1.9mg/m3) for sample A,B,C and D respectively. Sample B and D can be chosen as best option with respect to compaction test which is one of the major determinant for choosing a soil sample for brick molding. This also can be substantiated with an earlier study conducted by Mtallib *et al*. (2011) and Oluremi *et al*. (2012).

Table 6.2.1: Compaction Test for Sample A

Weight of mould and wet sample	6040	6485	6350	6250
Weight of mould	4355	4355	4355	4355
Weight of wet sample	1685	2130	1995	1895
Wet Density Mg/m³	1.69	2.13	2	1.9
Can No	SGA	SGB	SGC	SGD
Weight of can and wet sample	28.7	30.4	32	33.2
Weight of can and dry sample	27.5	28.8	29.3	29.6
Weight of moisture	1.2	1.6	2.7	3.6
Weight of can	13	15.8	14.3	15.1
Weight of dry sample	14.5	13	15	18.1
Moisture content %	8.28	12.31	18	19.89
Dry Density Mg/m³	1.56	1.9	1.69	1.59

Table 6.2.2. Compaction Test for Sample B

Weight of mould and wet sample	6015	6420	6495	6445
Weight of mould	4355	4355	4355	4355
Weight of wet sample	1660	2065	2140	2090
Wet Density Mg/m^3	1.66	2.07	2.14	2.09
Can No	SB1A	SB1B	SB1C	SB1D
Weight of can and wet sample	33	32.9	32.1	35.5
Weight of can and dry sample	31.7	30.8	29.9	32.5
Weight of moisture	1.3	2.1	2.2	3
Weight of can	14.7	14.5	17.7	14.6
Weight of dry sample	17	16.3	12.2	14.9
Moisture content %	7.65	12.88	18.03	20.13
Dry Density Mg/m^3	1.54	1.83	1.81	1.74

Table 6.2.3. Compaction Test for Sample C

Weight of mould and wet sample	6015	6420	6495	6445
Weight of mould	4355	4355	4355	4355
Weight of wet sample	1660	2065	2140	2090
Wet Density Mg/m^3	1.66	2.07	2.14	2.09
Can No	SB1A	SB1B	SB1C	SB1D
Weight of can and wet sample	33	32.9	32.1	35.5
Weight of can and dry sample	31.7	30.8	29.9	32.5
Weight of moisture	1.3	2.1	2.2	3
Weight of can	14.7	14.5	17.7	14.6
Weight of dry sample	17	16.3	12.2	14.9
Moisture content %	7.65	12.88	18.03	20.13
Dry Density Mg/m^3	1.54	1.83	1.81	1.74

Table 6.2.4. Compaction Test for Sample D

Weight of mould and wet sample	6040	6485	6350	6250
Weight of mould	4355	4355	4355	4355
Weight of wet sample	1685	2130	1995	1895
Wet Density Mg/m^3	1.69	2.13	2	1.9
Can No	SGA	SGB	SGC	SGD
Weight of can and wet sample	28.7	30.4	32	33.2
Weight of can and dry sample	27.5	28.8	29.3	29.6
Weight of moisture	1.2	1.6	2.7	3.6
Weight of can	13	15.8	14.3	15.1
Weight of dry sample	14.5	13	15	18.1
Moisture content %	8.28	12.31	18	19.89
Dry Density Mg/m^3	1.56	1.9	1.69	1.59

6.3. Liquid and Plastic Limit Test

The results for liquid and plastic limits are as follows:

sample A, Cu**=** 28.00, CC=1.29, LL=60.50, PL=30.10 and PI=30.50
Sample B, Cu= 14.05, CC=1.75, LL=32.50, PL=26.79 and PI=5.71
Sample C, Cu= 66.60, CC=0.96, LL=58.00, PL=32.35 and PI=25.65
Sample D, Cu= 6.25, CC=1.21, LL=34.00, PL=21.88 and PI=12.16.

6.4. Durability Test Result.

After exposure to ash weather for a period of two years the samples were discovered to have deteriorated in different degrees according to the soil types. Sample A had the highest degree of deterioration bu serious surface chipping as seen in figure below and sample C and D Had the best surface appearance with lowest degree of deterioration based on physical appearance.

6.5

6.6 Result for stabilization of laterite sample D with different percentages of cement and wood ash

After stabilizing the soil**,** the highest maximum dry density was reached after 5% addition of wood ash to the soil and the highest optimum moisture content was found after 10% wood ash addition to the soil before declining. Comparatively, the high liquid limit and plasticity index of the natural soil saw a gradual decline as the quantity of the wood ash increased. The general decrease in the liquid limits and plasticity indices of the soil are attributed to the additions of the wood ash which reduced the amount of the clay particles in the soil that can freely allow water molecules to enter between the layers causing expansion or shrinkage. The decline in the plasticity index of the soil corroborates the fact that stabilizing soil with wood ash improves its use as a construction material.

6.6 Compressive strength of laterite soil with Cement and Wood Ash Variations

The results of compressive strength development of the various bricks are presented in table 4.6.1 below. From the results, the compressive strength of the samples in all the mixes increased with curing days. At curing day 90, mix 1, 3A, 3B and 3C experienced increase in strength up to 10% stabilization with cement and wood ash variations respectively and decreased at stabilization above 10%. For MIX 2 the strength increased from 0.54 N/mm^2 (control) to 3.67 N/mm^2 (15%C) This value is in close range with a previous study by Silvia Smeu *et al*.

Table 4.6.1Compressive strength of laterite soil with Cement and Wood Ash Variations (N/mm^2

Sample (%)		**28 Days**	**56 Days**	**90 Days**
Control (0%)		**0.46**	**0.53**	**0.54**
Sample with 0% cement addition	5WA	0.45	0.56	0.70
	10WA	0.44	0.58	0.80
	15WA	0.44	0.58	0.80
Sample with cement variations MIX 2	Control (0%)	0.46	0.53	0.54
	5C	0.58	0.98	1.13
	10C	1.33	1.82	3.62
	15C	1.61	2.02	3.67

Sample (%)		28 Days	56 Days	90 Days
Sample with 5% Cement and wood ash variations (MIX 3a)	5C	0.58	0.98	1.13
	5C5WA	1.01	1.74	2.06
	5C10WA	1.04	1.64	2.28
	5C15WA	1.06	1.58	2.04
Sample with 10%Cement with wood ash variations Mix 3B	10C	1.33	1.82	3.62
	10C5WA	1.06	1.85	2.98
	10C10WA	1.08	1.96	2.50
	10C15WA	0.96	1.80	2.15
Sample with 15% Cement and wood ash variations MIX 3C	15C	1.61	2.02	3.67
	15C5WA	1.06	1.85	2.84
	15C10WA	1.07	1.96	2.86
	15C15WA	1.09	1.49	2.40

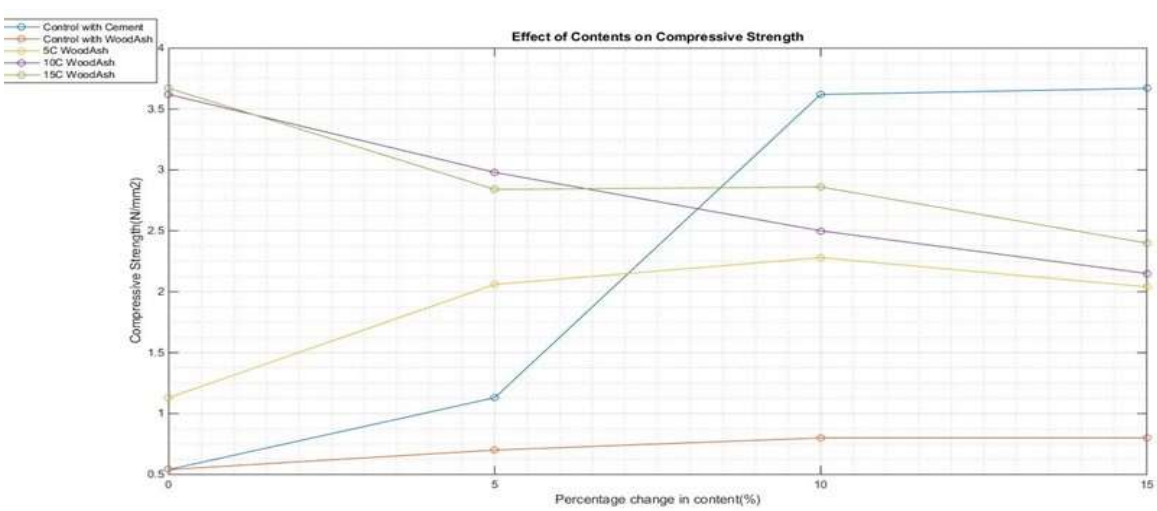
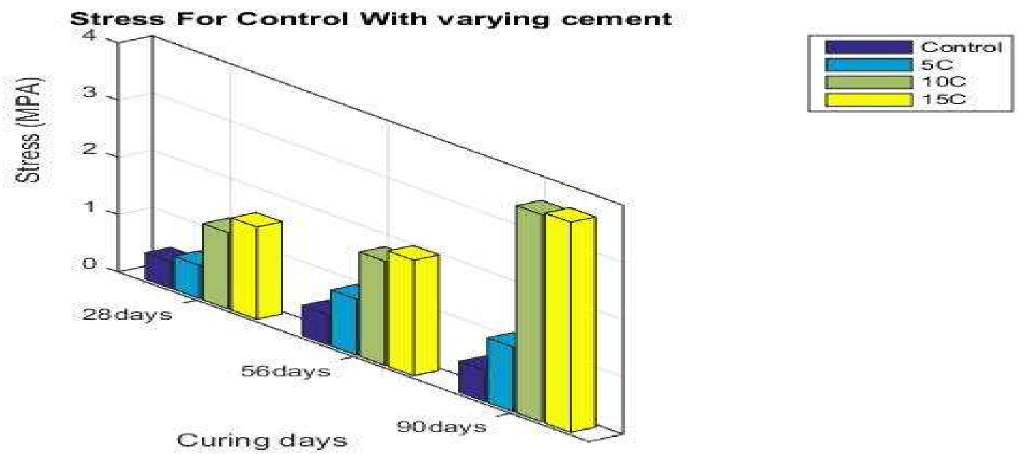
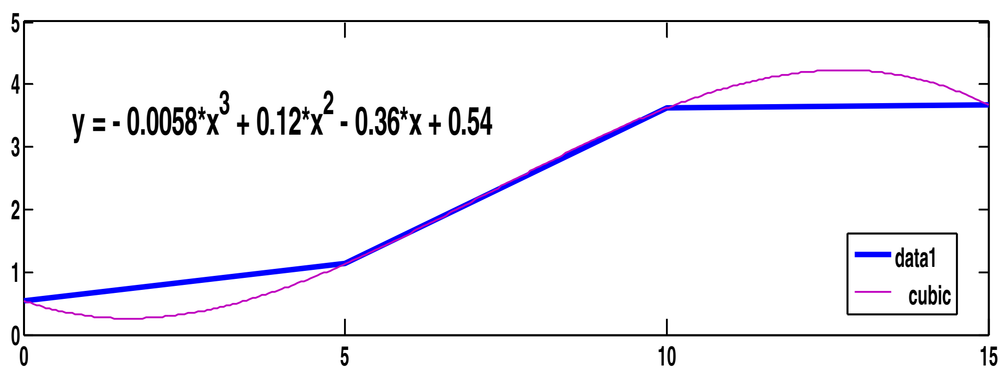


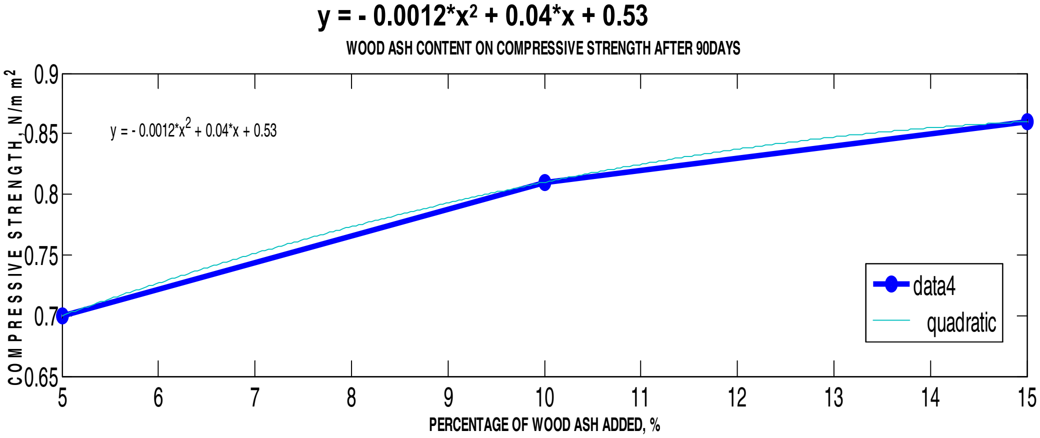
Fig. 4.5.3: Graph showing combined compressive strength for mix 1, 2, 3A, 3B and 3C. For wood ash variations



Effect of cement contents on the Compressive strength of Laterite after 90 days
$y = -0.0058*x^3 + 0.12*x^2 - 0.36*x + 0.54$



The effect of Wood Ash contents on the Compressive strength of Laterite after 90days
$y = -0.0012*x^2 + 0.04*x + 0.53$



The result showed that there was significant difference ($p<0.05$) in compressive strength of the lateriate as cement and wood ash contents are varied but there was no significant difference in the compressive strength values with respective to curing days There was significant difference ($p<0.05$) in compressive strength of the lateriate as cement and wood ash contents are varied but there was no significant difference in the compressive strength values with respective to curing days as showed in rows and columns of table 1

Table 4.6.3. Regression Table for Compressive Strength (Wood Ash Variations)

CONTENT	EQUATION	R
Control with Cement	$-0.0054X^2+0.3186X+0.323$	0.8833
Control with WoodAsh	$-0.0016X^2+0.0416X+0.538$	0.9982
5CWA	$-0.0117X^2+0.2345X+1.142$	0.9960
10CWA	$0.0029X^2-0.1413X+3.618$	1.00
15CWA	$0.0037X^2-0.1313X+3.603$	0.8948

7. CONCLUSION

The result showed that the compressive strength, linear shrinkage, natural moisture content, optimum moisture content, maximum dry density, plasticity index, CBR, specific gravity and water absorption of the studied soils are optimally improved by adding wood ash. The optimum value for water absoption of wood ash stabilization is at 10% C with 5%WA (19.09%) replacement at 10%C: Optimum compressive strength was achieved with 5% wood ash stabilization with a close range substitute mix at 15%C5%WA(2.98 N/mm^2). which falls within the recommended range of 2.5 to 3.5 N/mm^2 for stabilized brick. This value is in close range with a previous study by Silvia Smeu *et al*.

8. Recommendations

Since research is a continuous process, the following area of study can be explored for further investigations on the potentials of stabilization of laterite soil: Further investigations could be carried out on the effect of additives of other types of ash from agricultural waste on the compressive strength and other technical properties of bricks. The effect of exposure to chemical and some other types of adverse weather condition on the stabilized bricks can be further examined in a future research. Further research can also be carried out on how to maintain a aesthetically good and smooth surface appearance for the bricks .this is based on the observation of fungal growth on the surfaces of the bricks used in the physical model after exposure to weather for a long period of time.

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