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Prediction of Mechanical Properties of Sawdust Ash Blended Unfired Clay Bricks

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ABSTRACT
This study predicted the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks for construction of structural masonry walls. The compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks was first determined experimentally. The size of the solid cement stabilized clay brick used in this study was 250mm*120mm*60mm. Mathematical models were developed based on Osadebe's regression theory to predict the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks and their corresponding mix ratios. Three computer programs were developed in visual basic language to quicken the prediction of compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks. The mathematical models developed were tested for adequacy using F-statistics at 5% level of significance and were found to be adequate. The written computer program can predict with accuracy and without waste of time, the mix ratios when the desired value of compressive strength, static modulus of elasticity and water absorption is specified and vice versa. It was found that the mix proportion that the maximum value of the compressive strength is 4.33N/mm^{2}which is above the minimum value of 3.5N/mm^2 (Deodhar, 2009) showing that is suitable for the construction of structural masonry walls**.** It was also found that the maximum value of water absorption was 4.25% which is less than 20% showing that the sawdust ash blended cement stabilized unfired clay bricks is a durable masonry construction material. The computer programs developed are interactive, quick and eliminate arbitrary mix ratios in brick design and construction.
Keywords: Mechanical properties, sawdust, bricks and unfired clay

INTRODUCTION
One of man's basic needs is housing, and it is important to note that housing is something that man cannot exist without. Inadequate housing and accommodations are a persistent issue in most developing nations, including Nigeria. Over seven million Nigerians lack a place to live, according to a recent investigation (Punch, 2012). Brick is undoubtedly one of the most widely used building materials in the world. It is also incredibly adaptable, inexpensive, and simple to use. Although it is typically applied to vertical surfaces, like floors, it also exhibits excellent properties on horizontal surfaces. Worldwide, the production of bricks is a major business that supports both residential and commercial construction. The three main materials used to make burnt clay bricks have historically been clay, sand, and cement (Olutoge et al., 2018). One of the main binding agents that increases the bricks' strength and durability is cement. Cement manufacture, however, uses a lot of energy and produces a lot of carbon dioxide emissions, which exacerbates climate change and environmental deterioration. Fired clay brick is a popular building material and has been used for a long time. This brick has several advantages, including good thermal insulating property and low price. The disadvantages include heavy weight and small size. These drawbacks negatively affect its transportation and also slow down the construction speed. Phonphuak and Chindaprasirt (2014) and Olutoge et al. (2018) on types of waste, properties and durability of pore

forming waste-based fired masonry bricks, investigating substitute materials and techniques to lessen the environmental effect of brick manufacture has gained popularity in recent years. Waste ash such as sawdust ash (SDA), corn cub ash (CCA), rice husk ash (RHA), bagasse ash (BA) etc have proven to poses some high amount of pozzolanic properties which can possibly be used as a replacement to chemical stabilizers such as cement which contribute to the emission of $C0_2$ to the atmosphere(Sampson et al., 2024).

Saw dust is one of the by-product from timber industries and wood cutting factories. It is one such potentially useful waste item that is reasonably cheap and widely available (Awal et al., 2016). With the development of concrete technology, sawdust has become more useful in the production of bricks and blocks. Using sawdust to create structural lightweight concrete seems to be a novel solution to the environmental issue as well as the cost-effective design of appropriate building construction. Sawdust cement is created by bonding sawdust, an industrial waste that is obtained as byproducts from cutting, sawing, or grinding wood into small particles. If a mixture of cement and lime is used as the binder, sawdust normally blends in well with the cement, though there are occasional settings or hardening issues. In various regions of the world, cement, sawdust, and sand are frequently used to create wall and floor panels. Due to its versatility, this material can be modified and adjusted to be used as roofs, eaves, cladding, and ceilings (Awal et al., 2016). Sawdust is an organic waste produced when produced when wood mechanically milled or processed into a variety of sizes and form. Typically, dust is utilized as for homes. Sawdust ash (SDA), the resultant ash, is a type of pozzolana(Vikas et al., 2021).

Typically thrown away as waste, wood chippings, pieces, off cuts, sawdust, and shavings are leftovers from the processing of wood for industrial use. Studies reveal facilities large heaps of sawdust at saw milling plants across the country. This causes disposal problems for the saw millers. Because of this sawdust is usually burned at milling sites and other wood-related industries. The majority of sawmills that process wood produces waste, such as sawdust and slabs which contaminate the environment and the general public health. In order to solve this, waste wood ought to be turned into items that are helpful such as briquettes, asbestos, particleboard, and composite boards. The benefits of using the same volume of wood can be maximized by combining multiple sawmill (Osuntuyi, 2021). Waste wood has the potential to be an invaluable resource for the production of a variety of materials and goods (Lykidis & Grigoriou, 2008).

Statement of the Problem

Two of the biggest issues facing sustainable manufacturing production in the twenty-first century are waste material recycling and carbon dioxide emission reduction. Bricks are the most widely used building material in the world. Large volumes of solid waste are created worldwide by activities related to home, industrial, manufacturing, and building demolition. It's critical to recycle this trash to lessen their impact on the environment (Vikas et al., 2022).Despite the potential benefits of incorporating sawdust ash into construction materials, there is limited research on its use in clay bricks. Fired clay bricks are widely used in construction due to their durability, thermal insulation properties, and aesthetic appeal. However, the high energy consumption associated with brick firing processes and the environmental impact of cement-based mortar joints underscore the need for sustainable alternatives. Assessing the performance of unfired clay bricks with partial replacement of cement with sawdust ash is essential to evaluate their suitability for construction applications. Mechanical properties, compressive strength, water absorption, thermal conductivity, durability and environmental sustainability need to be investigated to ensure that the modified bricks meet relevant industry standards and regulatory requirements. However, their limited mechanical properties restrict their use in modern applications (Soleymani et al., 2022). To overcome these limitations, stabilizing earth bricks with cement is a commonly used method (Guadagnuolo et al., 2020). This stabilization significantly improves the compressive strength and durability of the bricks (Yu-Ming et al., et al., 2024).

Aim and Objectives of the Study

The aim of this study is to determine the mechanical properties of sawdust ash blended cement stabilized unfired clay bricks.

The specific objectives of the study are:

i. Determine the experimentally compressive strength of sawdust ash blended cement stabilized unfired clay bricks.
ii. Determine experimentally the water absorption of sawdust ash blended cement stabilized unfired clay bricks.
iii. Determine the modulus of elasticity of sawdust ash blended cement stabilized unfired clay bricks.
iv. Develop mathematical models to predict the compressive strength, modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks
v. Compare the predicted results with the experimental values.
vi. Write computer programs in Visual basic language to quickly predict the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks.

Explanation of concept

A brick is rectangular in shape and of size that can be conveniently handled with one hand. Brick may be made of burnt clay or mixture of sand and lime or of Portland cement concrete. Clay bricks have been an important component of building in Nigeria before the advent of sandcrete blocks. Especially in the South-West zone of the country, locally made bricks were the major component as walling material in a building. According to Raheem et al. (2012), walling materials in any building contributes about 22% of the total building cost. The choice of a walling material are based on various factors such as; cost, durability, aesthetics, and ability to weather the immediate environmental conditions.

Clay brick masonry is one of the oldest and most durable construction techniques used by mankind clay bricks. Masonry consists of manually built stable stacks of small elements, with or without mortar. This study bricks are produced different percentages of clay and sawdust using .There are two categories of bricks such as fired and unfired bricks. Fired bricks have normal strength, light weight and long lasting and strongest building materials. Bricks are sometimes referred as natural stone. It gives high protection over the other wall cladding materials. It requires less maintenance than the other building materials. Clay bricks are made by mixing clay with water such as to prevent shrinkage and provide bulk.

The advantages of clay bricks are they are very economical when comparing to other bricks, they require minimum repairing work will be enough, they are good looking, proper drainage can be maintained, damage of bricks due to wear and temperature is reduced, laying of clay bricks can be easily taken and the duration to construct the bricks is reduced due to normal clay bricks.A brick is a building material used to make walls, pavements and other elements in masonry construction. Traditionally, the term brick referred to unit composed of clay, but it is now used to denote any rectangular units laid in mortar. A brick can be composed of clay-bearing soil, sand and lime, or concrete materials. Bricks are produced in numerous classes, types, materials, and sizes which vary with region and time period, and are produced in bulk quantities. Two basic categories of bricks are fired *and* non-fired bricks.

Classification of Bricks according to Constituent Raw Materials

According to raw materials, bricks are classified as clay bricks, lime - sand bricks, glass brick and concrete bricks.

Clay bricks:

One of the oldest building material brick continues to be a most popular and leading construction material because of being cheap, durable and easy to handle and work with. Clay bricks are used for building-up exterior and interior walls, partitions, piers, footings and other load bearing structures.

Clay brick are essentially made of clay which has some specific properties.

i. The Plasticity behavior when it mixed with water.
ii. Clay particles fuse together when subjected to high temperature.
iii. Economical and easily available.

Raw materials:

Silica (SiO_2)

Free silica is a main constituent, if added to clay in suitable proportion makes hard and prevents it from warping and shrinkage on drying. Silica, if present in greater proportion, makes a brick brittle. Silica present in the combined form (aluminum silicate) does not form good bricks, as it will shrink and develop cracks.

Alumina (AI_2O_3)

Alumina is one of main constituents of clay. Loam soil forms good clay. In absence of sand, pure clay will develop cracks due to shrinkage on drying and burning. A good clay bricks should contain about 20% of alumina.

Alumina absorbs water and renders the clay plastic. If alumina is present in excess of the specified quantity, it produces cracks in brick on drying. Clays having exceedingly high alumina content are likely to be very refractory. Both silica and alumina should be in free form.

Lime ($CaCO_3$)

Normally constitutes less than 10 percent of clay. This also should be present in small quantities in the brick earth. It should be in a finely produced condition and it should not be in the form lamps or clods. Lime prevents shrinkage of raw bricks on drying. It helps fusion of sand at the kiln temperature. This fused sand will bind the bricks particles fast.

Iron Oxide

A small quantity of oxide of iron (5-6%) is desirable. It helps the fusion of sand like lime. It gives red colure to burn bricks. Excess of iron oxide imparts dark blue or blackish colure to brick, while, a lower percentage of iron oxide makes the brick yellow in colure. Iron oxide makes the bricks hard and strong.

Brick is one of the most important building materials that made of clay burnt in a kiln. The most common ceramic product is brick, which is used in both modern and historic buildings. These are among the most commonly used building materials, along with stone and concrete (Crespo-López & Cultrone, 2022). When we study history, we can observe that throughout the Stone Age, people who lived in caves-built structures out of rocks and boulders of different forms for a variety of functions. Menhirs, dolmens, and cromlechs-stone constructions used for religious purposes-have remained to this day. It was used in the Colosseum in Rome, the ancient Egyptian homes, and many parts of the Great Wall of China. Brick is among the oldest building materials (Bel-Anzué & Elert, 2021). Hemisphere (Henn et al., 2016).

Clay

Clay, a naturally occurring sedimentary material composed of fine-grained minerals, has been traditionally used in construction primarily as a binding agent in the form of clay bricks, tiles, and ceramics. It is a ubiquitous natural material, utilized in various construction applications for centuries. Clay is often associated with soil stabilization and as a binder in earthen construction, its potential as an aggregate in construction materials has gained attention in recent years (Arif et al., 2019). Clay exhibits unique properties that make it suitable for use as an aggregate in construction materials. Its fine particle size and plasticity contribute to improved workability and cohesion in mixtures. Additionally, clay has good thermal insulation properties, which can be advantageous in certain applications (Biniciet al., 2004). One of the primary applications of clay as an aggregate is in the production of lightweight concrete. Lightweight aggregates are essential for achieving reduced density and enhanced insulation properties in concrete structures. Clay aggregates can be produced through processes such as sintering or pelletization, resulting in lightweight particles suitable for concrete production (Kwan & Ramli, 2017). These clay aggregates exhibit low density, high porosity, and thermal insulation properties, making them suitable for applications in lightweight concrete blocks, precast panels, and insulation materials (Katsioti & Papadopoulos, 2021).

Brick Components and Classification

An artificial stone that has been shaped into bars is called a brick. Its mineral composition and the stone-like properties it acquires after the fire allow it to be used to build rather big structures, especially low-rise rural houses. Clay bricks are made from locally available materials, are affordable, durable, and offer a number of advantages like moisture absorption, fire prevention, and heat and sound insulation. They are widely used in construction projects involving civil engineering. Originally, red clay with low fertility was employed in agriculture, but clay was also used as a raw material to make bricks. Laterite bricks may have been used in many early human societies, and this red clay brick is extremely durable (Lum, 2018). However, people started using new raw materials to make industrial bricks that didn't require fire as the industrial revolution spread and environmental concerns became more prevalent in the 20th century. Based on the production process, silicate brick accounts for about 10% of the market. This kind of brick is created by autoclaving a mixture of quartz sand and slaked lime to harden the lime mortar. 90% lime, 10% clay, and a very little number of additives make up silicate brick (Hamburg & Lorenzon, 2022).

Brick in Post-Modern and Contemporary Architecture

Natural resources are usually used extensively in the brick-making process. A recent advancement in research and application intends to reduce the brick production sector's carbon footprint by reusing industrial wastes to generate sustainable bricks (Chin et al, 2022). Brick is still a widely used and favoured building material, nonetheless. But decorators and interior designers are always coming back to him to create a unique and stylish space. These days, brick is widely used as a decorative element to create brick walls, which may add style and comfort to an interior. It should be noted that indoor bricklaying is not to everyone's taste. Some believe interior brick to be excessively harsh, while others find interior brick to be gloomy. However, the majority of fans who like to combine stability with unrestricted creativity are happy to use a brick wall inside their building. This creative technique works with almost any type of home design. Moreover, a fireplace next to a brick wall will look quite natural. Use of brick in the bedroom and nursery is safe because it is a raw material. Due of their resistance to heat, brick walls are useful inside of buildings. For instance, brickwork can be used in the kitchen, where it represents a fresh take on contemporary design and makes sense given that stoves and chimneys are usually placed there. Typically, a brick wall serves as the room's main focal point. This building material is given an initial heat treatment. Consequently, mold doesn't scare the brick (ATM, 2022). Even after many years, a wall like this will still look great and retain its original appearance.

Composition of Bricks

The following are the ingredients of a high-quality brick (Vetturayasudharsanan et al, 2020).

1. **Alumina**

Alumina content in good brick soil should range from 20% to 30%. It is in charge of the earth's plasticity, which is crucial for moulding processes. If highly present, the uncured brick will contract and distort as it dries.

2. **Silica**

A brick should have a silica content of roughly 50%. It is in charge of keeping raw bricks from shrinking, cracking, or warping. It also has an impact on bricks' longevity. Excessive presence of it causes the particles to lose their cohesiveness, making the brick fragile.

3. **Lime**

For an excellent brick, the lime content should be between 5% and 10%. When bricks dry, it stops them from shrinking. It helps bind clay by causing the silica to melt when clay burns. When there is too much lime added, the brick melts and becomes distorted.

4. **Iron Oxide**

A clay brick should have an iron oxide content of 5% to 7%. It increases durability and impermeability. It imparts hardness and strength. If excess, the brick takes on a dark blue or blackish hue. The brick turns yellowish in colour if there is relatively less iron oxide present.

5. **Magnesia**

A good brick should have less than 1% magnesia in it. Brick contains magnesium, which gives the brick a yellow hue. It is in charge of lowering shrinking. Bricks deteriorate when there is an excess of magnesia.

Empirical Review

Sawdust is an organic waste resulting from the mechanical milling or processing of timber (wood) into various shapes and sizes (Rahmi et al., 2024). The dust is usually used as domestic fuel. The resulting ash known as saw-dust ash (SDA) is a form of pozzolana. Experimental investigations to evaluate the possibility of using Sawdust Ash (SDA) as a construction material and the possibility of using it as a part replacement for Cement in brick construction has been the focus of many researchers in recent times(Rahmi et al., 2024). Rahmi et al. (2024) utilised the wood SDA in developing an eco-friendly interlocking bricks in a sustainable approach. In this study, bricks with increased porosity levels were manufactured by adding more recycled wood sawdust ash (SDA) additive at larger sizes. The findings demonstrated that while sound insulation and water absorption increased with the addition of SDA, compressive strength decreased. SDA was added to aid increase unit weight and compressive strength. A higher SDA results in improved sound absorption. SDA are therefore intriguing raw materials for the creation of construction materials that use less energy. Sampson et al. (2024) studied the influence of burnt sawdust ash from timber species on the chemical strength properties of laterite-interlocking blocks. Mix proportion was 1:6 (cement + BSDA: laterite) with a 0.50 water-to-cement ratio. Two (2) tests were targeted for the research: Energy Dispersive X-Ray Spectroscopy (EDS) and Scanning Electron Microscopy (SEM) strength. It was observed that, the combined SiO_2, Fe_2O_3 and $Al2O_3$ content satisfied the minimum requirement and the SiO_2 (29.5537.38%), $Al2O_3$ (10.95-35%) contents were significantly great. it can be concluded that BSDA replacement interlocking laterite blocks have the potential of supporting the affordable housing concept in Ghana.

Gap Identification

Bricks are the most widely used building materials in the world. Despite the potential benefits of these building and construction materials, there is limited research on its use. Clay bricks are widely used in construction due to their durability, thermal insulation properties, and aesthetic appeal. However, the high energy consumption associated with brick firing processes and the environmental impact of cement-based mortar joints underscore the need for sustainable alternatives. Assessing the performance of clay bricks with partial replacement of cement with sawdust ash is essential to evaluate their suitability for construction applications. Mechanical properties, compressive strength, water absorption, thermal conductivity, durability and environmental sustainability need to be investigated to ensure that the modified bricks meet relevant industry standards and regulatory requirements. However, their limited knowledge of their suitable mix ratios and optimum proportion of other component parts restrict their use in modern applications (Yu-Ming et al., 2024; Soleymani et al., 2022; Guadagnuolo et al., 2020

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Resear

This research was carried out to experimentally determine the compressive strength, static modulus of elasticity and water absorption of unfired sawdust ash blended cement stabilized clay brick as masonry construction material. Initial mix ratios used to produce the cement stabilized clay bricks were obtained from literatures. The remaining mix ratios were generated using the simplex lattice theory making a total of ten initial mix ratios. The mathematical models that were used to predict the compressive strength, static modulus of elasticity and water absorption of unfired cement stabilized clay bricks were developed from the results of the tests carried out on the test specimens based the trial mix ratios at 28 days curing age. A total of sixty (60) sawdust ash blended cement stabilized unfired clay bricks were produced and subjected to compressive strength test at age 28 days. Three computer programs were developed in Visual basic language to quickly predict the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay bricks.

Methodology

The materials used in this study are locally available. The materials used to produce the clay bricks in this study were laterite, cement, sawdust ash and water respectively.

The materials used in this study are discussed as follows:.

1. **Cement**

   The cement used was Ordinary Portland Cement (OPC) purchased from a cement shop in Choba Community with properties conforming to BS 12 (1978).

2. **Laterite**

   The laterite used in this study was sourced from borrow pit at Rumuokpani in Obio Akpor Local Government Area of Rivers State. They were collected in bags and subjected to laboratory test to ascertain its suitability for use in brick production. The grading and properties were carried out in accordance with provisions of BS 882 (1983).

3. **Water**

   The water that was used in this study was clean tap water that was free from contaminants either dissolved or in suspension as specified by BS 3148 (1980).

4. **Sawdust Ash**

   The sawdust ash that was used in this study was obtained from Obigbo Timber Market in Rivers State. It was first burnt in an enclosure and later pulverized and grinded to obtain particles that were as fine as cement. Oxide composition test was carried out in the Laboratory at Choba close to UPTH to ascertain its suitability for use as cement replacement material for brick production.

Laboratory Tests

All laboratory tests on laterite for the purpose of characterization including natural moisture content, particle size distribution, atterberg limits tests, compaction, compressive and specific gravity tests were carried out according to BS 1377 (1990).

A total of thirty (60) cement stabilized clay bricks of size 250mm x 120mm x 60mm were produced and cured under laboratory conditions for 28 days curing periods.

The laboratory tests carried out on unfired cement stabilized clay bricks are as follows:

1. Compressive Strength
2. Static Modulus of Elasticity
3. Water Absorption

Sawdust Ash Preparation

Saw dust ash was obtained at a saw mill in Obigbo timber market, Portharcourt, River State. Maximum care was taken to avoid the inclusion of sticks, barks of wood and other macro impurities. The sawdust were air dried at room temperature, then incinerated at temperatures between 600-630 under a controlled burning system for about 2-3 hours. The ash obtained was allowed to cool at room temperature before sieving through 75µm test sieve. The chemical properties of the sawdust ash were also obtained after incineration to assess the pozzolanic behavior of the additive materials for the stabilization purposes.

Index Properties of Soil

The laterite was subjected to laboratory test to ascertain its specific gravity, natural moisture content, liquid limit, plastic limit and the plasticity index respectively. The Atterberg limit test was conducted in compliance with the BS: 1377.

Particle Size Distribution

The particle size distribution of the laterite was carried out in accordance with BS: 1377.

The laterite passed through the various sieve sizes and the mass retained on each sieve was recorded. The total weight passing was obtained. During the sieving process, the particles passing through the sieve were not in any way pushed through the sieve rather a brush was used. The percentage of weight retained and the cumulative percentage passing was determined by calculation;

$$\text{Percentage retained } (\%) = \frac{WeightRetained}{TotalWeightofSoil} \times 100 \quad (3.1)$$

Moisture Content Test

Moisture-content is the water quantity contained in the laterite. It can be given on a mass or volumetric basis, usually measured in percentage (%).This test was carried out to derive the natural moisture-content of the soil-sample. Oven drying method was adopted for the test and is hence described following these procedures: Moisture content cans with lids were collected, dried and weighed and their masses recorded as M_1 (g). The soil quantities required from the collected sample were collected in the moisture-content cans, the cans were covered with the lid and weighed with their masses recorded as M_2 (g).Cans with their contents and the lids were placed in the oven and allowed to dry at fixed temperature of 105^0c for minimum of 24 hrs. The cans were removed from the oven; the lids replaced and placed in the desiccator for cooling. After cooling, they were weighed with lids, and their masses were recorded as M_3 (g).

The moisture-content (w) was calculated in percentage as shown in Equations (3.2- 3.3).

$$w = \frac{mass of water}{mass of soil}(\%) \quad (3.2)$$

$$\frac{M_W}{M_S} = \frac{M_2 - M_3}{M_3 - M_1} \quad (3.3)$$

Specific Gravity of Laterite

The specific gravity of soil was determined by weighing a completely dried density bottle with a stopper and weight recorded as W_1. About 10g of an oven dried soil that passes through 2mm BS sieve were put into the density bottle. The weight of the bottle with the dried soil and the stopper was recorded as $\mathbf{W_2}$. De-aired distilled water was added to cover the soil in the density bottle and air were completely removed from the bottle by subjecting it to vacuum in a desiccators for about an hour. More water was added at a constant temperature of 200C for an hour. The exterior of the bottle were dried, and its weight taken as $\mathbf{W_3}$ the bottle was cleaned, filled with de-aired water, and allowed to stand for one hour. The weight of the bottle containing water with a stopper were taken as $\mathbf{W_4}$and the specific gravity was computed with the following equation

$$G_S = (W_2 - W_1)/[(W_4 - W_1) - (W_3 - W_2)] \quad (3.4)$$

Liquid Limit

The liquid limit is the empirically established moisture content at which a soil passes from the liquid state to the plastic state. It provides a means of classifying a soil, especially when the plastic limit is also known. The Casagrande apparatus method was used. This is an alternative method for the determination of the liquid limit of a sample of natural soil, or of a sample of soil from which material retained on a 425 µm test sieve has been removed.

A sample of about 300g were taken from the soil paste prepared as specified in (natural condition) or (sieved soil) and then placed on the glass plate. The prepared paste was mixed for at least 10 min using the two palette knives. If necessary, more distilled water were added so that the first blow count is about 50 blows. With the cup of the apparatus resting on the base, a portion of the mixed soil was placed on the cup without entrapping air. The soil surface parallel to the base was levelled off. The grooving tool was used to divide the soil into two equal parts by drawing the tool from the hinge towards the front in a continuous circular movement. The grooving tool was held normal to the surface of the cup, with the chamfered edge facing the direction of movement. Turn the crank handle at the rate of 2 r/s so that the cup is lifted and dropped, counting the number of bumps. Continue until the two parts of the soil come into contact at the bottom of the groove along a distance of 13 mm, measured with the end of the grooving tool or with a ruler. Add a little more of the prepared soil from the glass plate and mix it with the soil in the cup. Repeat the steps above until two consecutive runs gives the same number of bumps for closure. Take about 10 g of soil with a spatula from the portions of the sample that have just flowed together. Place the soil in a suitable container and determine the moisture content. Repeat the process at least three more times using the same sample of soil to which further increments of distilled water have been added. Proceed from the drier to the wetter condition of the soil. The amount of water added shall be such that when the four or more moisture contents are plotted, they are evenly distributed over the range between 50 bumps to 10 bumps. [illegible] tool.

Plastic Limit

The plastic limit is the empirically established moisture content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart (BS 5930) provides a means of classifying cohesive soils. It is recognized that the results are subject to the judgement of the operator, and that some variability in results will occur. This method covers the determination of the plastic limit of a soil sample, i.e., the lowest moisture content at which the soil is plastic. The sample shall be of soil in its natural state, or of soil from which material retained on a 425 µm test sieve has been removed. Take a sample of about 20 g from the soil paste in natural condition or sieved, and place it on the glass mixing plate. Allow the soil to dry partially on the plate until it becomes plastic enough to be shaped into a ball. Mould the ball of soil between the fingers and roll it between the palms of the hands until the heat of the hands has dried the soil sufficiently for slight cracks to appear on its surface. Divide this sample into two subsamples of about 10 g each and carry out a separate determination on each portion. Divide each subsample into four more or less equal parts and treat each part. Mould the soil in the fingers to equalize the distribution of moisture, and then form the soil into a thread about 6 mm diameter between the first finger and thumb of each hand. Roll the thread between the fingers, from finger-tip to the second joint, of one hand and the surface of the glass rolling plate. Use enough pressure to reduce the diameter of the thread to about 3 mm in five to 10 complete, forward and back, movements of the hand. Some heavy clays will require 10 to 15 movements when the soil is near the plastic limit because the soil hardens at this stage. It is important to maintain a uniform rolling pressure; do not reduce the pressure as the thread diameter approaches 3 mm. Pick up the soil, mould it between the fingers to dry it further, form it into a thread and roll it out again. Repeat the step above until the thread shears both longitudinally and transversely when it has been rolled to about 3 mm diameter, as gauged by the rod. Do not gather the pieces of soil together after they have crumbled, in order to reform a thread and to continue rolling; the first crumbling point is the plastic limit. Gather together the portions of the crumbled soil thread transfer them to a suitable container and replace the lid immediately. Repeat the process on the other three portions of soil, placing them all in the same container. Determine the moisture content.

Characterization of Sawdust Ash

Scanning Electron Microscopy

SEM imaging is a relatively quick way to investigate the microstructure and surface morphology of a soil sample. To obtain such an image, the sample was prepared and mounted onto a stud and placed in the chamber of a machine with SEM capabilities. The most important equipment is the SEM equipment itself; however, care needs to be taken to adequately prepare the sample for imaging. To achieve this, conductive graphite paint are used to mount the samples onto a non-contaminated surface. After the samples are secure, a coat of conductive material is applied to the sample in order to allow the SEM to generate electrons from the sample. To mount the soil samples onto a carbon stud so as to fasten the sample to a stable surface during analysis, a conductive graphic paint needs to be used. The paint should be an "isopropanol-based graphite resistive and dry film lubricant coating" The paint secures the sample safely to the carbon stud without contaminating the working surface. A high-resolution sputter coater is used to coat the sample in a conductive material. As it stands, soil is a nonconductive material and the electron microscope functions by emitting electrons through a sample to emit a transfer of heat. Therefore, the soil sample must be coated with a conductive material so as to allow the electron beam to be transferred to the sample.

Brick Production

The ingredients at each experimental point were weighed and kept at a particular location. The mixing of the ingredients was achieved by hand mixing. The cement, laterite, and sawdust ash were mixed thoroughly until the uniform distribution of the ingredients in the mix was obtained. Water was then added and the mix was turned over and over until the concrete mix became homogeneous. The mixture was then compacted into 250mm x 120mm x 60mm wooden moulds in layers. The specimens were demoulded after proper compaction and then cured by water sprinkling for 28days after which they were taken out for compressive strength and water absorption tests.

The mix ratios that were used to manufacture the clay bricks in this study are presented in Tables 1 and 2 respectively. The first four initial mix ratios were obtained from literatures (Mama and Osadebe, 2011; Okere et al., 2015). The results obtained based on the mix ratios in Table 1 were used to develop the mathematical models to predict the compressive strength, static modulus of elasticity and water absorption of unfired cement stabilized clay brick. Additional ten (10) mix ratios shown in Table 2 were obtained and used to validate the results of the predictive models. The trial and control mix ratios used for brick production were first generated using Scheffe's simplex theory.

Table 1: Design Matrix for Trial Mix Ratios

X_1	X_2	X_3	X_4	**Response**	**Water** S_1	**Cement** S_2	**SDA** S_3	**Laterite** S_4
1	0	0	0	Y_1	0.95	0.82	0.18	14
0	1	0	0	Y_2	0.85	0.92	0.08	10
0	0	1	0	Y_3	0.9	0.85	0.15	12
0	0	0	1	Y_4	0.8	0.78	0.22	8
0.5	0.5	0	0	Y_{12}	0.9	0.87	0.13	12
0.5	0	0.5	0	Y_{13}	0.925	0.835	0.165	13
0.5	0	0	0.5	Y_{14}	0.875	0.80	0.2	11
0	0.5	0.5	0	Y_{23}	0.875	0.885	0.115	11

0	0.5	0	0.5	Y_{24}	0.825	0.85	0.15	9
0	0	0.5	0.5	Y_{34}	0.85	0.815	0.185	10

Table.2: Design Matrix for Mix Ratios

X_1	X_2	X_3	X_4	**Response**	**Water** S_1	**Cement** S_2	**SDA** S_3	**Laterite** S_4
0.2	0.2	0.2	0.4	C_1	0.86	0.83	0.17	10.4
0.25	0.25	0	0.5	C_2	0.85	0.825	0.175	10
0.4	0.2	0.2	0.2	C_3	0.89	0.838	0.162	11.6
0.5	0	0.25	0.25	C_4	0.9	0.8175	0.1825	12
0	0.25	0.25	0.5	C_{12}	0.8375	0.8325	0.1675	9.5
0.5	0.25	0.25	0	C_{13}	0.9125	0.8525	0.1475	12.5
0.1	0.25	0.25	0.4	C_{14}	0.8575	0.8365	0.1635	10.1
0.2	0.4	0.2	0.2	C_{23}	0.87	0.858	0.142	10.8
0.2	0.2	0.4	0.2	C_{24}	0.88	0.844	0.156	11.2
0.1	0.1	0.4	0.4	C_{34}	0.86	0.826	0.174	10.4

Where: X_1, X_2, X_3, X_4 represents pseudo proportion of water, cement, sawdust ash and laterite respectively
S_1, S_2, S_3, S_4 represents actual proportion of water, cement, sawdust ash and laterite respectively.
The mechanical properties tests carried out on the brick specimens manufactured based on the mix ratios in Tables 1 and 2 are described as follows:

1. **Compressive Strength Test**

Compressive strength of each of the samples was determined using the Compressive Test Machine after 28days of curing. The compressive strengths and dimensions of the lateritic bricks were determined in accordance using a compression machine. Load measurements were taken at the point of failure of the lateritic brick samples. Equation (3.5) was used to calculate the maximum compressive stress in the unfired clay bricks at failure:

$$\sigma = \frac{P}{A} \tag{3.5}$$

Where σ = calculated normal stress, P = measured applied load and A = area of the surface on which the load is applied

2. **Static Modulus of Elasticity**

The empirical equation obtained by Neville and Brook (2000) was used to obtain the static modulus of elasticity.

$$E_c = 1.7\rho^2 f_{cu}^{0.33} \ x \ 10^{-6} \tag{3.6}$$

Where:
f_{cu} = Compressive strength
ρ = Brick density

3. **Water Absorption Test**

Water absorption was performed on the unfired brick specimens after 28 days of curing. The bricks specimens were first dried in an oven at a temperature of 105ºC. The mass of each brick was recorded as dry mass. The samples were then immersed in water for 24 hours and their wet masses were recorded. The difference in mass was used to determine the percentage of water absorbed for each brick sample as follows

$$W_a = \frac{M_w - M_d}{M_d} \times 100 \tag{3.7}$$

Where W

Mathematical Model Development

Osadebe (2003) assumed that the response function, is continuous and differentiable with respect to its predictors, Z_i. By using Taylor series, the response function could be expanded in the neighbourhood of a chosen point, $Z^{(0)}$ as follows:

$$Z^{(0)} = Z_1^{(0)}, Z_2^{(0)}, Z_3^{(0)}, Z_4^{(0)} \tag{3.8}$$

$$f(Z) = \Sigma f^{m}(Z^{(0)}) + \frac{(Z_i - Z^{(0)})}{m!} \tag{3.9}$$

Where $0 \le m \le \infty$, m = the degree of the polynomial function

According to Osadebe, the polynomial function for concrete properties optimization is given by Tailor series as follows:

$$F(0) = F(Z^{(0)}) + \sum_{i=1}^{4} \frac{\partial f(Z^{(0)})}{\partial Z_i}(Z_i - Z_i^{(0)}) + \frac{1}{2}! \sum_{i=1}^{3} \sum_{j=1}^{4} \frac{\partial^2 f(Z^{(0)})}{\partial Z_i \partial Z_j}(Z_i - Z_i^{(0)})(Z_i - Z_j^{(0)})$$

$$+ \frac{1}{2}! \sum_{i=1}^{5} \frac{\partial^2 f(Z^{(0)})}{\partial Z_i^{2}}(Z_i - Z_i^{(0)})^2 + \ldots \tag{3.10}$$

The point $Z^{(0)}$ is chosen as the origin for the sake of convenience. The predictor Z_i is not the actual portion of the mixture component, but the ratio of the actual portion to the total concrete quantity. Let Z_i be the fractional portion. The actual portions of the mixture components are S_i.

For a 4-component concrete mixture, $1 \le i \le 4$,

If the total quantity of concrete is S, then:

$$\sum_{i=1}^{4} S_i = S \tag{3.11}$$

Implying that:

$$S_1 + S_2 + S_3 + S_4 = S \tag{3.12}$$

Dividing both sides of Equation (3.12) by S yields:

$$S_1 / S + S_2 / S + S_3 / S + S_4 / S = 1 \tag{3.13}$$

Let:

$$S_i / S = Z_i \,(i = 1, 2, 3, 4) \tag{3.14}$$

Therefore, Equation (3.13) becomes:

$$Z_1 + Z_2 + Z_3 + Z_4 = 1 \tag{3.15}$$

Where: $Z_1, Z_2, Z_3, Z_4 \; and \; Z_5$ are proportions of water, cement, sawdust ash and laterite respectively

In general, for a 4-component concrete mixture, there exists a vector $Z(Z_1, Z_2, Z_3, Z_4)$ whose elements satisfy equation (3.15). In addition, for each Z_i, the following inequality holds:

$$Z_i > 0 \tag{3.16}$$

Point $Z^{(0)}$ is chosen as the origin. Consequently, $Z^{(0)}$=0.
Implying that:

$$Z_1^{(0)} = 0, Z_2^{(0)} = 0, Z_3^{(0)}, Z_4^{(0)} = 0, Z_5^{(0)} = 0. \tag{3.17}$$

Let: $b_0 = f(0), \quad b_i = \frac{\partial f(0)}{\partial z_i}, \quad b_{ij} = \frac{\partial^2 f(0)}{\partial z_i \partial z_j}, \; and \; b_{ii} = \frac{\partial^2 f(0)}{\partial z_i^2},$

Equation (3.10) can now be written as follows:

$$f(z) = b_o + \sum_{i=1}^{4} b_i z_i + \sum_{i=1}^{3}\sum_{i=1}^{4} b_{ij} z_i z_j + \sum_{i=1}^{4} b_{ii} z_i^2 + ... \tag{3.18}$$

Multiplying equation (3.15) by b_0 gives the following expression:

$$b_0 = b_0 Z_1 + b_0 Z_2 + b_0 Z_3 + b_0 Z_4 + b_0 Z_5 \tag{3.19}$$

Also, multiplying equation (3.15) by Z_i gives:

$$Z_1 = Z_1^2 + Z_1 Z_2 + Z_1 Z_3 + Z_1 Z_4 \tag{3.20}$$

$$Z_2 = Z_2^2 + Z_1 Z_2 + Z_2 Z_3 + Z_2 Z_4 \tag{3.21}$$

$$Z_3 = Z_3^2 + Z_1 Z_3 + Z_2 Z_3 + Z_3 Z_4 \tag{3.22}$$

$$Z_4 = Z_4^2 + Z_1 Z_4 + Z_2 Z_4 + Z_4 Z_3 \tag{3.23}$$

Rearranging equations (3.20) to (3.23), gives the expression
for Z_i^2 as follows:

$$Z_1^2 = Z_1 - Z_1 Z_2 - Z_1 Z_3 - Z_1 Z_4 \tag{3.24}$$

$$Z_2^2 = Z_2 - Z_1 Z_2 - Z_2 Z_3 - Z_2 Z_4 \tag{3.25}$$

$$Z_3^2 = Z_3 - Z_1 Z_3 - Z_2 Z_3 - Z_3 Z_4 \tag{3.26}$$

$$Z_4^2 = Z_4 - Z_1 Z_4 - Z_2 Z_4 - Z_4 Z_3 \tag{3.27}$$

Substituting Equations (3.24) to (3.27) into Equation (3.18) and setting f(0)= Y yields:

$$\begin{aligned} Y &= b_0 Z_1 + b_0 Z_2 + b_0 Z_3 + b_0 Z_4 + b_0 Z_5 + b_1 Z_1 + b_2 Z_2 + b_3 Z_3 + b_4 Z_4 + b_{12} Z_1 Z_2 + b_{13} Z_1 Z_3 \\ &+ b_{14} Z_1 Z_4 + b_{23} Z_2 Z_3 + b_{24} Z_2 Z_4 + b_{34} Z_3 Z_4 + \\ &+ b_{11}(Z_1 - Z_1 Z_2 - Z_1 Z_3 - Z_1 Z_4) + b_{22}(Z_2 - Z_1 Z_2 - Z_2 Z_3 - Z_2 Z_4) \\ &+ b_{33}(Z_3 - Z_1 Z_3 - Z_2 Z_3 - Z_3 Z_4) + b_{44}(Z_4 - Z_1 Z_4 - Z_2 Z_4 - Z_3 Z_4) \end{aligned} \tag{3.28}$$

Factorization of equation (3.28) yields:

$$\begin{aligned} Y &= (b_0 + b_1 + b_{11}) Z_1 + (b_0 + b_2 + b_{22}) Z_2 + (b_0 + b_3 + b_{33}) Z_3 \\ &+ (b_0 + b_4 + b_{44}) Z_4 + (b_0 + b_5 + b_{55}) Z_5 + (b_{12} - b_{11} - b_{22}) Z_1 Z_2 \\ &+ (b_{13} - b_{11} - b_{33}) Z_1 Z_3 + (b_{14} - b_{11} - b_{44}) Z_1 Z_4 \end{aligned}$$

$$+(b_{23}-b_{22}-b_{33})Z_2Z_3+(b_{24}-b_{22}-b_{44})Z_2Z_4+(b_{34}-b_{33}-b_{44})Z_3Z_4 \quad (3.29)$$

Let:

$$\alpha_i = b_0 + b_i + b_{ii} \quad (3.30)$$

And

$$\alpha_{ij} = b_{ij} + b_{ii} + b_{jj} \quad (3.31)$$

Using Equations (3.30) and (3.31), Equation (3.25) changes to:

$$Y = \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_{12} Z_1 Z_2 + \alpha_{13} Z_1 Z_3 + \alpha_{14} Z_1 Z_4$$

$$+\alpha_{23} Z_2 Z_3 + \alpha_{24} Z_2 Z_4 + \alpha_{34} Z_3 Z_4 \quad (3.32)$$

Equation (3.32) in generalized form is given by:

$$Y = \sum_{i=1}^{4} \beta_i Z_i + \sum_{1\le i\le j}^{4} \beta_{ij} Z_i Z_j \quad (3.33)$$

Where: Y is the response function at any observation point. Z_i *and* Z_j are the predictors and α_i *and* α_{ij} are the coefficients of the polynomial function.

Determination of the Coefficients of the Model

Let the n[th] point of observation be $y^{(n)}$.

Therefore, the vector of the corresponding set of variables becomes:

$$Z^{(n)} = [Z_1^{(n)}, Z_2^{(n)}, Z_3^{(n)}, Z_4^{(n)} \quad (3.34)$$

Different observation points will have different predictor at constant coefficients. At n[th] observation point, the response function, $Y^{(n)}$ corresponds with the predictors $Z_i^{(n)}$.

Implying that:

$$Y^{(n)} = \sum_{i=1}^{4} \alpha_i Z_i^{(n)} + \sum_{1\le i\le j}^{4} \alpha_{ij} Z_i^{(n)} Z_j^{(n)} \quad (3.35)$$

Where:

$$1 \le i \le j \le 4 \ and \ n = 1, 2, 3, \ldots, 15$$

Equation (3.31) can be written in a matrix form as:

$$[y^{(n)}] = [Z^{(n)}][\alpha] \quad (3.36)$$

The values of the constant coefficients α_i in Equation (3.36) are determined with the values of $Y^{(n)}$ *and* $Z^{(n)}$.

$$[\alpha] = [Z^{(n)}]^{-1}[Y^{(n)}] \quad (3.37)$$

The Zn matrix for trial and control mix ratiosare given in Table 3.5 and 3.6 respectively. The inverse of the Zn matrix based on the trial mix ratios is given in Table 3.7. The values of the fractional portions $Z^{(n)}$ were used to determine $Z^{(n)}$ matrix and $Z^{(n)}$ matrix inverse. These values of $Y^{(n)}$ matrix were determined from experiments. When the values of the matrices $Y^{(n)}$ and $Z^{(n)}$ are known, the values of the constant coefficients α_i can be determined using Equation (3.37).

Testing of the Adequacy of the Models

The predicted and the experimental values were tested for adequacy using the following hypotheses.

Null hypothesis H_o: There is no significant difference between the experimental and the predicted values at 5% level of significance.

Alternative hypothesis H_1: There is a significant difference between the experimental and predicted values at 5% level of significance.

The Null hypothesis (H_0) is the hypothesis that is being tested for validity. Alternative hypothesis (H_1) is accepted when the Null hypothesis has been rejected. The Null hypothesis (H_0) being true means that the difference between the predictive and experimental values is very small.

F- Statistic is used to test the adequacy of the predictive model as follows: follows:

Consider the sample variances for the observed and predicted cost values to be S_1^2 and S_2^2 and the population variances to be σ_1^2 and σ_2^2 respectively. If $S_1^2 = S_2^2$, it means that the population variances are the same and if $S_1^2 \neq S_2^2$ it means that the population variances are not the same. The acceptance of null hypothesis means that the sample variances at the given level of significance (α) are the same.

The F-statistics is given by:

$$F = S_1^2 / S_2^2 \tag{3.38}$$

S_1^2 is the larger value of the two sample variances

The variance is given by Equation (3.39).

$$S^2 = \frac{1}{n-1} * \sum_{i=1}^{n} \left(y - \bar{y} \right)^2 \tag{3.39}$$

And the mean, $\bar{y}$ of the sample response is given by:

$$\bar{y} = \sum \frac{y}{n} \quad \text{for } 1 \leq i \leq n \tag{3.40}$$

Where α = level of significance = 5%, v = degree of freedom = n-1

and n = number of observation at the control points, y = responses at control points

The null hypothesis is accepted if:

$$\frac{1}{F_{(\alpha)(V_2,V_1)}} \leq F \leq F_{(\alpha)(V_1,V_2)} \tag{3.41}$$

The component fractions based on trial and control mix ratios are presented in Tables 3.3 and 3.4 respectively.

Table 3: Component Fractions based on Trial Mix Ratios

Z_1	Z_2	Z_3	Z_4
0.05956	0.05141	0.01129	0.87774
0.07173	0.07764	0.00675	0.84388
0.06475	0.06115	0.01079	0.86331
0.08163	0.07959	0.02245	0.81633
0.06475	0.06259	0.00935	0.86331
0.06198	0.05595	0.01106	0.87102
0.06796	0.06214	0.01553	0.85437
0.06796	0.06874	0.00893	0.85437
0.07621	0.07852	0.01386	0.83141
0.07173	0.06878	0.01561	0.84388

Table 4: Component Fractions for Control Mix Ratios

Z_1	Z_2	Z_3	Z_4
0.07015	0.06770	0.01387	0.84829
0.07173	0.06962	0.01477	0.84388
0.06597	0.06212	0.01201	0.85990
0.06475	0.05881	0.01313	0.86331
0.07387	0.07343	0.01477	0.83793
0.06331	0.05915	0.01023	0.86730
0.07171	0.06996	0.01367	0.84466
0.06867	0.06772	0.01121	0.85241
0.06728	0.06453	0.01193	0.85627
0.07015	0.06737	0.01419	0.84829

Table 5: Zn Matrix for Trial Mix Ratios

Z_1	Z_2	Z_3	Z_4	Z_1Z_2	Z_1Z_3	Z_1Z_4	Z_2Z_3	Z_2Z_4	Z_2Z_5
0.05956	0.05141	0.01129	0.87774	0.00306	0.00067	0.05026	0.00058	0.04513	0.00991
0.07173	0.07764	0.00675	0.84388	0.00557	0.00048	0.06193	0.00052	0.06552	0.00570
0.06475	0.06115	0.01079	0.86331	0.00396	0.00070	0.05286	0.00066	0.05279	0.00932
0.08163	0.07959	0.02245	0.81633	0.00650	0.00183	0.07047	0.00179	0.06497	0.01833
0.06475	0.06259	0.00935	0.86331	0.00405	0.00061	0.05640	0.00059	0.05403	0.00807
0.06198	0.05595	0.01106	0.87102	0.00347	0.00069	0.05295	0.00062	0.04873	0.00963
0.06796	0.06214	0.01553	0.85437	0.00422	0.00106	0.05806	0.00097	0.05309	0.01327
0.06796	0.06874	0.00893	0.85437	0.00467	0.00061	0.05650	0.00061	0.05873	0.00763
0.07621	0.07852	0.01386	0.83141	0.00598	0.00106	0.06431	0.00109	0.06528	0.01152
0.07173	0.06878	0.01561	0.84388	0.00493	0.00112	0.06053	0.00107	0.05804	0.01317

Table 6: Zn Matrix for Control Mix Ratios

Z1	Z2	Z3	Z4	z1*z2	z1*x3	z1*z4	z2*z3	z2*z4	z3*z4
0.0701468	0.0676998	0.0138662	0.8482871	0.0047489	0.0009727	0.0591956	0.0009387	0.0574289	0.0117625
0.0717300	0.0696203	0.0147679	0.8438819	0.0049939	0.0010593	0.0616803	0.0010281	0.0587513	0.0124624
0.0659748	0.0621201	0.0120089	0.8598962	0.0040984	0.0007923	0.0569567	0.0007460	0.0534168	0.0103264
0.0647482	0.0588129	0.0131295	0.8633094	0.0038080	0.0008501	0.0542543	0.0007722	0.0507738	0.0113348
0.0738699	0.0734289	0.0147740	0.8379272	0.0054242	0.0010914	0.0640676	0.0010848	0.0615281	0.0123795
0.0633131	0.0591500	0.0102342	0.8673027	0.0037450	0.0006480	0.0534779	0.0006054	0.0513010	0.0088761
0.0717123	0.0699561	0.0136734	0.8446582	0.0050167	0.0009806	0.0611281	0.0009565	0.0590890	0.0115494
0.0686661	0.0677190	0.0112076	0.8524073	0.0046500	0.0007696	0.0587967	0.0007590	0.0577242	0.0095534
0.0672783	0.0645260	0.0119266	0.8562691	0.0043412	0.0008024	0.0570713	0.0007696	0.0552516	0.0102124

Table 7: Inverse of Zn Matrix basedon Trial Mix Ratios

34174.5	46958.7	155665.2	18171.6	75403.3	-176539.6	78691.1	-126433.0	-11514.1	-94574.9
49048.0	-40083.1	-102699.8	-6147.7	-3071.8	-34515.3	9422.1	112947.0	9866.5	5235.3
-16624.0	-22544.9	-101011.4	-13355.1	-46510.8	119957.2	-94945.7	65204.8	-9448.3	119277.9
-819.9	-1174.6	-3877.8	-446.3	-1876.7	4360.2	-1944.5	3166.3	295.2	2319.1
-176770.5	34019.0	29190.1	-11129.9	-111158.8	359336.1	-141534.6	-100810.8	-5158.4	124014.2
35893.9	-10376.4	20261.7	24066.3	16959.1	-137122.1	184908.9	70862.5	19105.5	-224558.0
-218.4	64.5	-207.6	-29.1	104.5	464.7	-141.2	-237.9	2.9	197.6
-41048.8	-10792.7	-6029.9	-11510.9	-7275.6	88838.0	-59520.1	-23851.3	16394.3	54795.9
-67532.6	11207.6	8569.9	-4738.3	-40692.9	135927.6	-55118.5	-35188.1	-3179.6	50743.5
-4969.8	-5102.5	7748.8	1630.5	353.3	-11026.1	44983.6	8394.0	16439.6	-58451.2

RESULTS

Results of the Laboratory Tests

The results of the sieve analysis of laterite, specific gravity of laterite, natural moisture content of laterite, liquid limit of laterite, plastic limit of laterite, oxide composition test of sawdust ash, oxide composition test of laterite are presented in Tables 1to 7 respectively. The particle size distribution curve for the laterite used is given in Figure 1. The results of the laboratory test on compressive strength, static modulus of elasticity and water absorption are presented in Tables to 1-10 respectively. The results of the F-statistic test of compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilised unfired clay brick are presented in Tables 11 to 13 respectively.

Table 1: Sieve Analysis Laterite

Sieve size (mm)	Mass of sample retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)	Zone (2) Limits
5	6	0.6	0.6	99.4	90-100
4.75	8	0.8	1.4	98.6	75-100
2.36	28	2.8	4.2	95.8	55-90
1.18	492	49.2	53.4	46.6	35-59
0.60	318	31.8	85.2	14.8	8-30
0.21	140	14	99.2	0.8	0-10
Pan	8	0.8	100	0	-

Table 2: Results of Specific Gravity of laterite

Sample Trial No	Trial 1	Trial 2	Trial 3
Weight of Density Bottle…..Gms (W1)	25	25	25
Weight of Bottle and Dry Sample (W_2)…..Gms	60.4	60.4	60.1
Weight of Bottle, Sample and Water (W_3)…..Gms	99.8	99.2	99.5
Weight of Bottle and Water (W4) …Gms	77.8	77	77.6
Mass of dry sample only W5 = (W2-W1)	35.4	35.4	35.1
Mass of water occupying same volume as the sample W6 = W4-(W3-W5)	13.4	13.2	13.2
Specific gravity = W5/W6	2.64	2.68	2.66
Average specific gravity	2.66		

Table 3: Results of Natural Moisture Content of Laterite

Sample Trial	Trial 1	Trial 2
Weight of Container (G)…… W_1	6.33	6.22
Weight of Container and Wet Soil (G)…… W_2	72.4	74.8
Weight of Container and Dry Soil (G)…… W_3	68.1	70.2
Mass of Water (M_w) = ($W_2 – W_3$)	4.3	4.6
Mass of Dry Soil (M_d) = ($W_3 – W_1$)	61.77	63.98
Moisture Content (W) = mw/md*100	6.96	7.19
Average natural moisture content	7.08	

Table 4: Results of Liquid limit of Laterite

Sample Trial	Trial 1	Trial 2
Number of blows	25	30
Weight of wet sample + Container (G) (W1)	30.76	30.85
Weight of soil +Container (G) (W2)	25.01	25.11
Weight of Container (G) (W3)	15.13	15.21
Mass of dry soil (W4)	9.88	9.9
Mass of water (W5)	5.75	5.74
Liquid Limit (LL) = W5/W4*100	58.20	57.98
Average Liquid Limit (%)	58.09	

Table 5: Results of Plastic Limit of Laterite

Sample Trial	Trial 1	Trial 2
Weight of wet sample + Container (G) (W1)	28.21	28.24
Weight of soil +Container (G) (W2)	26.24	26.08
Weight of Container (G) (W3)	10.13	10.21
Mass of dry soil (W4)	16.11	15.96
Mass of water (W5)	1.97	2.16
Plastic Limit (LL) = W5/W4*100	12.23	13.53
Average Plastic Limit (%)	12.88	

Table 6: Oxide Composition of Sawdust Ash

Oxide Name	Sample 1	Sample 2
SiO_2	65.74	64.85
Al_2O_3	6.67	6.25
Fe_2O_3	3.38	3.05
CaO	1.86	6.27
MgO	3.72	3.11
SO_3	2.44	2.8
K_2O	12.76	10.65
Na_2O	0.93	0.89
PK_2	2.50	2.13

Source: Author's experiment

Table 7: Oxide Composition of Laterite

Oxide Name	Amount Present (%)
SiO_2	26.94
Al_2O_3	30.86
Fe_2O_3	34.75
CO_2	7.45

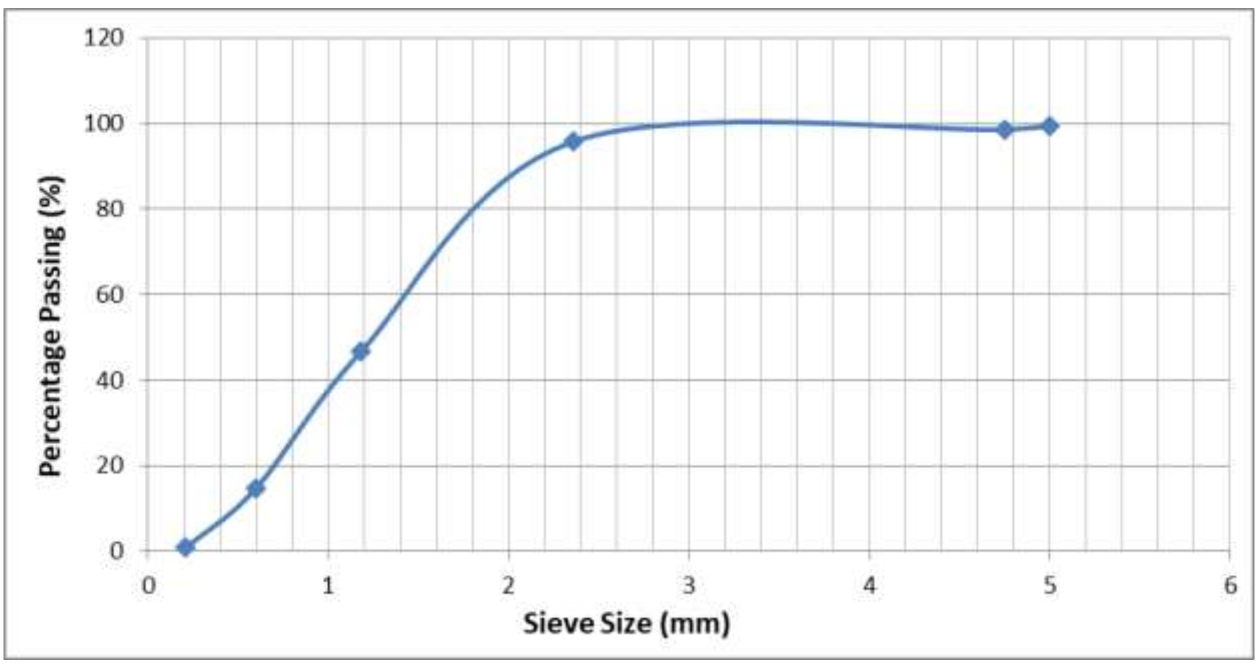

Figure 1: Particle Size Distribution Curve for Laterite

The coefficient of uniformity and coefficient of curvature are given by equations (4.1) and (4.2) as:

$$C_u = \frac{D_{60}}{D_{10}} \quad (4.1)$$

$$C_c = \frac{{D_{30}}^2}{D_{10} x D_{60}} \quad (4.2)$$

Where C_c =Coefficient of curvature, C_u =Coefficient of uniformity, D_{60} =Size of sieve at 60% passing = 0.50mm, D_{10} Size of sieve at 10% passing = 0.14mm, D_{30} Size of sieve at 30% passing = 0.30mm

From Figure 1, D60 = 1.10, D_{10} = 0.35, D_{30} = 0.80

Substitution of the above parameters yields the values of C_c and C_u follows.

$$C_c = \frac{0.80^2}{0.35x1.10} = 1.66$$

$$C_u = \frac{1.10}{0.35} = 3.14$$

Table 8: Compressive Strength Test Results at 28 Days Curing Age

ExptNo.	Replicates	Mass (Kg)	Volume (m_3)	Density (Kg/m^3)	Aver. Density (kg/m^3)	Failure Load (KN)	Compressive Strength (Mpa)	Average Comp. Strength (Mpa)
	A	3.65	0.0018	2027.78		110	3.67	
	B	3.7	0.0018	2055.56	1990.74	110	3.67	3.66
1	C	3.4	0.0018	1888.89		109	3.63	
	A	3.64	0.0018	2022.22		75	2.50	
	B	3.67	0.0018	2038.89	2035.19	75	2.50	2.50
2	C	3.68	0.0018	2044.44		75	2.50	
	A	3.66	0.0018	2033.33		66	2.20	
	B	3.56	0.0018	1977.78	1994.44	66	2.20	2.19
3	C	3.55	0.0018	1972.22		65	2.17	
	A	3.52	0.0018	1955.56		90	3.00	
	B	3.54	0.0018	1966.67	1977.78	90	3.00	3.00
4	C	3.62	0.0018	2011.11		90	3.00	
	A	3.46	0.0018	1922.22		68	2.27	
	B	3.66	0.0018	2033.33	1988.89	68	2.27	2.27
5	C	3.62	0.0018	2011.11		68	2.27	

	A	3.65	0.0018	2027.78		70	2.33	
	B	3.44	0.0018	1911.11	1988.89	70	2.33	2.44
6	C	3.65	0.0018	2027.78		80	2.67	
	A	3.48	0.0018	1933.33		120	4.00	
	B	3.65	0.0018	2027.78	1955.56	120	4.00	4.00
7	C	3.43	0.0018	1905.56		120	4.00	
	A	3.61	0.0018	2005.56		95	3.17	
	B	3.64	0.0018	2022.22	2012.96	95	3.17	3.17
8	C	3.62	0.0018	2011.11		95	3.17	
	A	3.64	0.0018	2022.22		130	4.33	
	B	3.66	0.0018	2033.33	2029.63	130	4.33	4.33
9	C	3.66	0.0018	2033.33		130	4.33	
	A	3.64	0.0018	2022.22		80	2.67	
	B	3.58	0.0018	1988.89	2001.85	80	2.67	2.67
10	C	3.59	0.0018	1994.44		80	2.67	
Control Points								
	A	3.67	0.0018	2038.89		100	3.33	
	B	3.57	0.0018	1983.33	2020.37	100	3.33	3.33
C1	C	3.67	0.0018	2038.89		100	3.33	
	A	3.66	0.0018	2033.33		76	2.53	
	B	3.66	0.0018	2033.33	2031.48	76	2.53	2.53
C2	C	3.65	0.0018	2027.78		76	2.53	
	A	3.64	0.0018	2022.22		125	4.17	
	B	3.64	0.0018	2022.22	2020.37	125	4.17	4.17
C3	C	3.63	0.0018	2016.67		125	4.17	
	A	3.66	0.0018	2033.33		70	2.33	
	B	3.62	0.0018	2011.11	2022.22	70	2.33	2.33
C4	C	3.64	0.0018	2022.22		70	2.33	
	A	3.64	0.0018	2022.22		83	2.77	
	B	3.65	0.0018	2027.78	2003.70	33	1.10	2.21
C5	C	3.53	0.0018	1961.11		83	2.77	
	A	3.56	0.0018	1977.78		65	2.17	
	B	3.55	0.0018	1972.22	1977.78	65	2.17	2.17
C6	C	3.57	0.0018	1983.33		65	2.17	
	A	3.66	0.0018	2033.33		110	3.67	
	B	3.57	0.0018	1983.33	2001.85	110	3.67	3.67
C7	C	3.58	0.0018	1988.89		110	3.67	
	A	3.67	0.0018	2038.89		90	3.00	
	B	3.67	0.0018	2038.89	2016.67	90	3.00	3.00
C8	C	3.55	0.0018	1972.22		90	3.00	

	A	3.689	0.0018	2049.44			118	3.93	
	B	3.65	0.0018	2027.78	68766.48		118	3.93	3.93
C9	C	364	0.0018	202222.22			118	3.93	
	A	3.56	0.0018	1977.78			80	2.67	
	B	3.54	0.0018	1966.67	1990.74		80	2.67	2.68
C10	C	3.65	0.0018	2027.78			81	2.70	

Table 8: Static Modulus of Elasticity Test Results at 28 Days Curing Age

Expt. No	Replicates	Density (Kg/m^3)	Compressive Strength f_{cu} (MPa)	Static Modulus of Elasticity (Gpa)	Average Static Modulus (Gpa)
	A	1927.78	3.67	9.703	
	B	1916.67	3.67	9.591	9.599
1	C	1911.11	3.63	9.501	
	A	1922.22	2.5	8.499	
	B	1911.11	2.5	8.401	8.450
2	C	1916.67	2.5	8.450	
	A	1911.11	2.2	8.054	
	B	1911.11	2.2	8.054	8.027
3	C	1905.56	2.17	7.971	
	A	1922.22	3	9.026	
	B	1900	3	8.819	8.922
4	C	1911.11	3	8.922	
	A	1911.11	2.27	8.138	
	B	1916.67	2.27	8.185	8.138
5	C	1905.56	2.27	8.091	
	A	1905.56	2.33	8.161	
	B	1900	2.33	8.113	8.337
6	C	1927.78	2.67	8.736	
	A	1916.67	4	9.868	
	B	1927.78	4	9.983	9.906
7	C	1916.67	4	9.868	
	A	1916.67	3.17	9.139	
	B	1922.22	3.17	9.192	9.157
8	C	1916.67	3.17	9.139	
	A	1900	4.33	9.954	
	B	1888.89	4.33	9.838	9.877
9	C	1888.89	4.33	9.838	

	A	1916.67	2.67	8.636	
	B	1922.22	2.67	8.686	8.686
10	C	1927.78	2.67	8.736	
Control Points					
	A	1927.78	3.33	9.397	
	B	1916.67	3.33	9.289	9.307
C1	C	1911.11	3.33	9.235	
	A	1922.22	2.53	8.533	
	B	1911.11	2.53	8.434	8.483
C2	C	1916.67	2.53	8.483	
	A	1911.11	4.17	9.946	
	B	1911.11	4.17	9.946	9.927
C3	C	1905.56	4.17	9.889	
	A	1922.22	2.33	8.304	
	B	1900	2.33	8.113	8.208
C4	C	1911.11	2.33	8.208	
	A	1911.11	2.77	8.690	
	B	1916.67	1.1	6.445	7.925
C5	C	1905.56	2.77	8.640	
	A	1905.56	2.17	7.971	
	B	1900	2.17	7.925	8.018
C6	C	1927.78	2.17	8.158	
	A	1916.67	3.67	9.591	
	B	1927.78	3.67	9.703	9.629
C7	C	1916.67	3.67	9.591	
	A	1916.67	3	8.974	
	B	1922.22	3	9.026	8.992
C8	C	1916.67	3	8.974	
	A	1900	3.93	9.641	
	B	1888.89	3.93	9.528	9.566
C9	C	1888.89	3.93	9.528	
	A	1916.67	2.67	8.636	
	B	1922.22	2.67	8.686	8.697
C10	C	1927.78	2.7	8.768	

Table 10: Water Absorption Test Results at 28 Days Curing Age

Expt. No.	Replicates	Dry Mass (Kg)	Wet Mass (Kg)	Water Absorption (%)	Average Water Absorption (%)
	A	3.65	3.75	2.74	
	B	3.7	3.82	3.24	4.25
1	C	3.4	3.63	6.76	
	A	3.64	3.76	3.30	
	B	3.67	3.75	2.18	2.91
2	C	3.68	3.8	3.26	
	A	3.66	3.72	1.64	
	B	3.56	3.61	1.40	1.95
3	C	3.55	3.65	2.82	
	A	3.52	3.62	2.84	
	B	3.54	3.63	2.54	2.35
4	C	3.62	3.68	1.66	
	A	3.46	3.57	3.18	
	B	3.66	3.74	2.19	3.26
5	C	3.62	3.78	4.42	
	A	3.65	3.72	1.92	
	B	3.44	3.63	5.52	3.39
6	C	3.65	3.75	2.74	
	A	3.48	3.65	4.89	
	B	3.65	3.74	2.47	4.10
7	C	3.43	3.6	4.96	
	A	3.61	3.7	2.49	
	B	3.64	3.73	2.47	2.58
8	C	3.62	3.72	2.76	
	A	3.64	3.7	1.65	
	B	3.66	3.72	1.64	1.82
9	C	3.66	3.74	2.19	
	A	3.64	3.73	2.47	
	B	3.58	3.67	2.51	2.40
10	C	3.59	3.67	2.23	
Control Point					
	A	3.67	3.77	2.72	
	B	3.57	3.68	3.08	2.75
C1	C	3.67	3.76	2.45	
	A	3.66	3.76	2.73	
	B	3.66	3.79	3.55	2.83
C2	C	3.65	3.73	2.19	

	A	3.64	3.78	3.85		
	B	3.64	3.72	2.20	3.02	
C3	C	3.63	3.74	3.03		
	A	3.66	3.77	3.01		
	B	3.62	3.76	3.87	3.39	
C4	C	3.64	3.76	3.30		
	A	3.64	3.74	2.75		
	B	3.65	3.69	1.10	1.94	
C5	C	3.53	3.6	1.98		
	A	3.56	3.69	3.65		
	B	3.55	3.68	3.66	3.46	
C6	C	3.57	3.68	3.08		
	A	3.66	3.78	3.28		
	B	3.57	3.62	1.40	3.42	
C7	C	3.58	3.78	5.59		
	A	3.67	3.78	3.00		
	B	3.67	3.76	2.45	2.76	
C8	C	3.55	3.65	2.82		
	A	3.68	3.78	2.72		
	B	3.65	3.73	2.19	2.55	
C9	C	3.64	3.74	2.75		
	A	3.56	3.67	3.09		
	B	3.54	3.64	2.82	2.70	
C10	C	3.65	3.73	2.19		

2 Mathematical Model Development for Compressive Strength

Substituting the values of $y^{(n)}$ shown in Table 4.8 into Equation (3.37) yields the coefficients values as follows:

$$\alpha_1 = -88784.5 \; \alpha_2 = 187770.4, \quad \alpha_3 = 8052.7, \quad \alpha_4 = 2284, \quad \alpha_5 = -342338.3, \quad \alpha_6 = 188439.7,$$

$$\alpha_7 = -446.5, \; \alpha_8 = -61586, \; \alpha_9 = -130491, \; \alpha_{10} = 41492.5,$$

Substituting the obtained coefficients into Equation (3.32) yields:

$$y = -88784.5Z_1 + 187770.4Z_2 + 8052.7Z_3 + 2284Z_4 - 342338.3Z_1Z_2 + 188439.7Z_1Z_3 - 446.5Z_1Z_4 - 61586Z_2Z_3 - 130491Z_2Z_4 + 41492.5Z_3Z_4 \quad (4.3)$$

Equation (4.3) is the regression model for the prediction of compressive strength of sawdust ash blended cement stabilised clay brick.

1. Test of Adequacy of the Compressive Strength Model

Equation (4.1) is tested for adequacy using F-statistics as follows:

The F-statistic test of compressive strength prediction model for sawdust ash blended cement stabilised clay brick is performed using Equation (3.39) and the results are presented in Table 11.

Table 11: F-statistic of Compressive Strength Test Results of Sawdust Ash blended Cement Stabilised Clay Brick

Control point	y_o	y_p	$y_o - \bar{y}_o$	$y_p - \bar{y}_p$	$(y_o - \bar{y}_o)^2$	$(y_p - \bar{y}_p)^2$
C_1	3.33	3.04	0.329	0.214	0.108241	0.045796
C_2	2.53	2.25	-0.471	-0.576	0.221841	0.331776
C_3	4.17	4.11	1.169	1.284	1.366561	1.648656
C_4	2.33	2.19	-0.671	-0.636	0.450241	0.404496
C_5	2.21	2.17	-0.791	-0.656	0.625681	0.430336
C_6	2.17	1.89	-0.831	-0.936	0.690561	0.876096
C_7	3.67	3.42	0.669	0.594	0.447561	0.352836
C_8	3	2.88	-0.001	0.054	1E-06	0.002916
C_9	3.93	3.69	0.929	0.864	0.863041	0.746496
C_{10}	2.67	2.62	-0.331	-0.206	0.109561	0.042436
	3.001	**2.826**			**Σ = 4.88329**	**Σ = 4.88184**

$$F_{0.05} = \frac{4.88329}{4.88184} = 1.000$$

The critical F-value at 5% level of significance obtained from statistical table is 3.179.

From Table 11, it can be seen that the critical F-value obtained from standard statistical table at 5% level of significance is 3.179 while the calculated F-value is 1.000. The critical F-value obtained is greater than the calculated F-value implying that the null hypothesis is accepted. Therefore, the regression equation is adequate for the prediction of compressive strength of sawdust ash blended cement stabilised clay brick.

2.2 Mathematical Model Development for Static Modulus of Elasticity

Substituting the values of $y^{(n)}$ shown in Table 4.9 into Equation (3.37) yields the coefficients values as follows:

$\alpha_1 = -40818.8$ $\alpha_2 = 201738.7$, $\alpha_3 = -28040.5$, $\alpha_4 = 1091.7$, $\alpha_5 = -454376.2$, $\alpha_6 = 287866$,

$\alpha_7 = -551.9$, $\alpha_8 = -1314447$, $\alpha_9 = -171409.4$, $\alpha_{10} = 46936.8$,

Substituting the obtained coefficients into Equation (3.32) yields:

$$y = -40818.8Z_1 + 201738.7Z_2 - 28040.5Z_3 + 1091.7Z_4 - 454376.2Z_1Z_2 + 287866Z_1Z_3 - 551.9Z_1Z_4 - 1314447Z_2Z_3 - 171409.4Z_2Z_4 + 46936.8Z_3Z_4 \quad (4.4)$$

Equation (4.4) is the regression model for the prediction of static modulus of elasticity of sawdust ash blended cement stabilised clay brick.

3 Test of Adequacy of the Static Modulus of Elasticity Model

The F-statistic test of static modulus of elasticity prediction model for sawdust ash blended cement stabilised clay brick is performed using Equation (3.39) and the results are presented in Table 12.

Table 12: F-statistic of Static Modulus of Elasticity Test Results of Sawdust Ash blended Cement Stabilised Clay Brick

Control point	y_o	y_p	$y_o - \bar{y}_o$	$y_p - \bar{y}_p$	$(y_o - \bar{y}_o)^2$	$(y_p - \bar{y}_p)^2$
C_1	9.307	8.35	0.4318	-0.113	0.18645124	0.012769
C_2	8.483	7.56	-0.3922	-0.903	0.15382084	0.815409
C_3	9.927	9.72	1.0518	1.257	1.10628324	1.580049
C_4	8.208	7.76	-0.6672	-0.703	0.44515584	0.494209
C_5	7.925	7.86	-0.9502	-0.603	0.90288004	0.363609
C_6	8.018	8.27	-0.8572	-0.193	0.73479184	0.037249
C_7	9.629	8.82	0.7538	0.357	0.56821444	0.127449
C_8	8.992	8.98	0.1168	0.517	0.01364224	0.267289
C_9	9.566	8.79	0.6908	0.327	0.47720464	0.106929
C_{10}	8.697	8.52	-0.1782	0.057	0.03175524	0.003249
	8.875	**8.463**			**Σ = 4.620**	**Σ = 3.808**

$$F_{0.05} = \frac{4.620}{3.808} = 1.213$$

The critical F-value at 5% level of significance obtained from statistical table is 3.179.

From Table 12, it can be seen that the critical F-value obtained from standard statistical table at 5% level of significance is 3.179 while the calculated F-value is 1.213. The critical F-value obtained is greater than the calculated F-value implying that the null hypothesis is accepted. Therefore, the regression equation is adequate for the prediction of static modulus of elasticity of sawdust ash blended cement stabilised clay brick.

2.4 Mathematical Model Development for Water Absorption

Substituting the values of $y^{(n)}$ shown in Table 4.10 into Equation (3.37) yields the coefficients values as follows:

$$\alpha_1 = -40818.8\ \alpha_2 = 201738.7,\quad \alpha_3 = -28040.5,\quad \alpha_4 = 1091.7,\quad \alpha_5 = -454376.2,\ \alpha_6 = 287866,$$

$$\alpha_7 = -551.9,\ \alpha_8 = -131444.7,\ \alpha_9 = -171409.4,\ \alpha_{10} = 46936.8,$$

Substituting the obtained coefficients into Equation (3.32) yields:

$$y = -40818.8 Z_1 + 201738.7 Z_2 - 28040.5 Z_3 + 1091.7 Z_4 - 454376.2 Z_1 Z_2 + 287866 Z_1 Z_3 - 551.9 Z_1 Z_4 - 131444.7 Z_2 Z_3 - 171409.4 Z_2 Z_4 + 46936.8 Z_3 Z_4 \quad (4.5)$$

Equation (4.5) is the regression model for the prediction of water absorption of sawdust ash blended cement stabilised clay brick.

2.5 Test of Adequacy of the Water Absorption

The F-statistic test of water absorption prediction model for sawdust ash blended cement stabilised clay brick is performed using Equation (3.39) and the results are presented in Table 13.

Table 13: F-statistic of Water Absorption Test Results of Sawdust Ash blended Cement Stabilised Clay Brick

Control point	y_o	y_p	$y_o - \bar{y}_o$	$y_p - \bar{y}_p$	$(y_o - \bar{y}_o)^2$	$(y_p - \bar{y}_p)^2$
C_1	2.75	2.85	-0.132	-0.032	0.017424	0.001024
C_2	2.83	2.78	-0.052	-0.102	0.002704	0.010404
C_3	3.02	2.94	0.138	0.058	0.019044	0.003364
C_4	3.39	3.43	0.508	0.548	0.258064	0.300304
C_5	1.94	1.98	-0.942	-0.902	0.887364	0.813604
C_6	3.46	3.45	0.578	0.568	0.334084	0.322624
C_7	3.42	3.36	0.538	0.478	0.289444	0.228484
C_8	2.76	2.75	-0.122	-0.132	0.014884	0.017424
C_9	2.55	2.45	-0.332	-0.432	0.110224	0.186624
C_{10}	2.7	2.83	-0.182	-0.052	0.033124	0.002704
	2.882	**2.876**			**Σ = 1.966**	**Σ = 1.887**

$$F_{0.05} = \frac{1.966}{1.887} = 1.042$$

The critical F-value at 5% level of significance obtained from statistical table is 3.179.

From Table 13, it can be seen that the critical F-value obtained from standard statistical table at 5% level of significance is 3.179 while the calculated F-value is 1.042. The critical F-value obtained is greater than the calculated F-value implying that the null hypothesis is accepted. Therefore, the regression equation is adequate for the prediction of water absorption of sawdust ash blended cement stabilised clay brick.

Discussion of Results

1. Physical Properties

The laterite used in this study is a reddish brown coloured material. The results of the sieve analysis and particle size distribution show that the laterite is well graded. The results of the sieve analysis are compared with the grading limits for fine aggregates as recommended by BSI (1983). It can be seen that the laterite used as fine aggregate belongs to zone 2. This implies that the laterite used was neither too coarse nor too fine and was therefore adequate for brick production. The value of coefficient of uniformity (C_u) is 3.14. This value is less than 4.0 recommended for well-graded sand. The value of coefficient of gradation (C_c) is 1.66. This value is between 1 and 3. Hence the laterite used as fine aggregate is well graded (BS 1377, 1990). The laterite has a natural moisture content of 7.08%. This fall within the range recommended by BS 1377 (1990) and it is therefore suitable for brick construction. Also, the liquid and plastic limit values are 58.09% and 12.88% respectively, with a plasticity index of 45.21%. This shows that the laterite has high plasticity (BS 1377, 1990).

Also, the specific gravity value of laterite used is 2.66. This value agrees with Shirley (1975), who reported that the specific gravities of normal density aggregates lie between 2.5 and 3.0. The results of the sieve analysis are compared with the grading limits for fine aggregates as recommended by BSI (1983) and observed that the laterite used belongs to zone 2. The results of the oxide composition of sawdust sample are shown in shown in Table 4.2. The results obtained from chemical analysis carried out on the sawdust ash are shown in Table 4.8. The summation of percentage of oxides, namely, SiO_2, Al_2O_3 and Fe_2O_3 is 72%. This value above 70% which is required for pozzolans according to ASTM C616 (2005) showing that sawdust ash is a good pozzolanic material and therefore can be used as partial replacement for cement in brick production.

Discussion

Structural Properties Sawdust Ash Blended Stabilized Unfired Clay Bricks

Compressive Strength

The effect of partial replacement of cement with sawdust ash on the compressive strength of cement stabilized clay brick is shown in Table 4. It can be observed from Table 4 that compressive strength decreases with increase in the percentage replacement of cement with sawdust ash. The reduced value of the compressive strength may be due to lower specific gravity value of sawdust ash compared to that of cement. The blending of the two materials caused a reduction in strength value of the end product since specific gravity is strength related. The reduced compressive strength value may also be due to the fact that sawdust ash has little binding properties compared to cement. After 28 days of water curing, the cement stabilized clay bricks produced from some mix ratios gave the maximum compressive strength value of 4.33N/mm^{2}that are above 3.5N/mm^2 as recommended by Deodhar (2009) which is the minimum value of compressive strength required for clay bricks and it is therefore suitable for masonry wall construction in low-cost housing construction (Deodhar, 2009).

Static Modulus of Elasticity

The effect of partial replacement of cement with cement stabilized clay brick on the static modulus of elasticity of concrete is as shown in Table 5. It can be seen from Table 5 that static modulus of elasticity decreases with increase in the percentage replacement of cement with sawdust ash. The reduced value of the static modulus of elasticity after 28 days curing age may also be attributed to sawdust ash having a very low specific gravity compared to cement. After 28 days of water curing, the cement stabilized clay bricks produced from some mix ratios gave the maximum static modulus value of 9.9273Gpa.

Water Absorption

The effect of partial replacement of cement with sawdust ash on water absorption of cement stabilized clay brick is as shown in Table 6. It can be observed from Table 6 that the water absorption increases with increase in the percentage replacement of cement with sawdust ash. This behaviour is not strange because the amount of calcium hydroxide produced during hydration of cement was not enough to react with silica contained in sawdust ash. This possibly left some sawdust ash pastes unreacted leading to the formation of voids for moisture penetration. The water absorption values are in the range of 1.82% to 4.25%. These values are below 20% which is the maximum percentage of water absorption that is required for good clay bricks (Deodhar, 2009).

Analysis of the Mathematical Models

The compressive strength, static modulus of elasticity and water absorption test results are presented in Tables 4 to 6 respectively. Mathematical models were developed to predict the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended stabilised clay bricks. A total of three computer programs in Basic language were written for quick prediction of compressive strength, static modulus of elasticity and water absorption of sawdust ash blended unfired cement stabilized clay brick. The compressive strength, static modulus of elasticity and water absorption models were tested for adequacy using F-statistics and were all found to be adequate. The null hypothesis was accepted for all the three mathematical models. The maximum value of compressive strength predictable by the model is 4.33N/mm^2. The maximum value of static modulus of elasticity predictable by the model is 9.927Gpa. The maximum value of water absorption predictable by the model is 4.25%. The computer programs and program outputs are found in Appendices A. The maximum value of compressive strength being 4.33N/mm^2, is above the minimum value of 3.5N/mm^2 recommended for masonry construction (Deodhar, 2009).

CONCLUSIONS

From the study, the following conclusions were made:

(i) The compressive strength and static modulus of elasticity of sawdust ash blended cement stabilized unfired clay brick decreased with increase in percentage replacement of cement with sawdust ash.

(ii) The maximum compressive strength value of 4.33N/mm^{2}showed that sawdust ash blended cement stabilized unfired clay brick is acceptable for construction of masonry walls and other simple construction works in low-cost housing construction.

(iii) The water absorption of sawdust ash blended cement stabilized unfired clay brick increased with increase in percentage replacement of cement with sawdust ash.

(iv) Three mathematical models were developed to predict the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay brick. These models can with the aid of computer programs written in Visual basic environment predict the value of the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay brick when the mix ratios are specified. These models can also generate the mix ratios for any specified the compressive strength, static modulus of elasticity and water absorption of sawdust ash blended cement stabilized unfired clay brick. The models developed were all tested for adequacy at 5% level of significance and were found to be adequate.

RECOMMENDATIONS

Based on the results obtained from this study, the following suggestions are made:

(i) The sawdust ash blended cement stabilized unfired clay brick should be used for construction of masonry walls in the Niger delta area of Nigeria to reduce the cost of brick production.

(ii) The government of Nigeria should embark on commercial production of sawdust ash blended cement stabilized unfired clay bricks in the Niger delta area of Nigeria.

(iii) The mathematical models developed in this study should be used as design codes and standards for sawdust ash blended cement stabilized unfired clay brick mix ratios.

REFERENCES

Aimen H., Bahaa, E., Ahmed, M., Seddik, H., Ayman, S. M. and Eman N. S. (2023). Effect of the Addition of Sawdust on Clay Brick Construction Properties and Thermal Insulation: *Experimental and Simulation Approaches Journal of Architectural Engineering* 30, 1.

Alecci, V., Stipo, G., La Brusco, A., De Stefano, M., & Rovero, L. (2019). Estimating elastic modulus of tuff and brick masonry: a comparison between on-site and laboratory tests. *Construction and Building Materials, 204*, 828-838.

Almusaed A, Alasadi A, Almssad A, (2022). A Research on the biophilic concept upon school's design from hot climate: A Case Study from Iraq. Advances in Materials Science and Engineering

Al-Waked, R. F., Fares, M. M., & Al-Nimr, M. A. (2017). Influence of drying conditions on the mechanical properties of clay bricks. Journal of Building Engineering, 10, 64-70.

Arif, A. F. M., Islam, R., & Uddin, M. M. (2019). Lightweight Clay Concrete: An Approach towards Low Cost and Sustainable Construction Material. International Journal of Advanced Engineering Research and Science, 6(11), 157-162.

Bishnu, P. B. and Diptasri, G. (2024). Development of Light Weight Bricks for Energy Efficient Buildings Using Rice Husk. *International Journal of Earth Sciences Knowledge and Applications* 6(1), 12 - 20.

Chatterjee, P., Ghosh, A., & Bhanja, S. (2023). Compressive stress-strain behaviour of masonry prisms made of low elastic modulus burnt clay bricks. *Journal* of Building Engineering, *78*, 107561.

Crespo-López L, Cultrone G, 2022. Improvement in the petrophysical properties of solid bricks by adding household glass waste. Journal of Building Engineering. 59:105039

Demir I (2005). An investigation on the production of construction brick with processed waste tea. Build. Environ. 41:1274-1278.

Fernando PR (2017) Experimental Investigation of the Effect of Fired Clay Brick on Partial Replacement of Rice Husk Ash (RHA) with Brick Clay. Adv Recycling Waste Manag 2: 120

Garzon-Roca, J., Marco, C. O., & Adam, J. M. (2013). Compressive strength of masonry made of clay bricks and cement mortar: Estimation based on Neural Networks and Fuzzy Logic. *Engineering Structures, 48*, 21-27.

Guadagnuolo, M., Aurilio, M., Basile, A., & Faella, G. (2020). Modulus of elasticity and compressive strength of tuff masonry: Results of a wide set of flat-jack tests. *Buildings*, 10(5), 84.

Hisham, A., Omrane, B., Chokri, S., Mohamed, A. K. and Rayed, A. (2021). Effects of incorporating wood sawdust on the firing program and the physical and mechanical properties of fired clay bricks. *Journal of Building Engineering* 35, 102106

Kadir AA, Sarani NA. An overview of wastes recycling in fired clay bricks. International Journal of Integrated Engineering. 2012;4(2):53-69.

Lamia Bouchhima, Mohamed Jamel Rouis and Mohamed Choura, "A Study of Pressure Influences of Phosphogypsum-Based Bricks" International Journal of Civil Engineering & Technology (IJCIET), Volume 4, Issue 3, 2013, pp. 143 - 154, ISSN Print: 0976 - 6308, ISSN Online: 0976 - 6316..

Lopez, V., Llamas, B., Juan, A., Moran, J. M. & Guerra, I. 2007. eco-efficient concrete: impact of the use of white ceramic powder on the mechanical properties of concrete. Biosystems Engineering, 96, 559-564.

Miri, M. (2005). Modelling of repair techniques for masonry arch bridges. Ph.D. Thesis, Cardiff University, England.

Raheem, A. A., Momoh, A. K. and Soyingbe, A. A. (2012). Comparative Analysis of Sandcrete Hollow Blocks and Laterite Interlocking Blocks as Walling Elements. *International Journal of Sustainable Construction Engineering & Technology* (ISSN: 2180-3242) 3(I1), 79-88.

Rahmi, K., Hilma, Tamiami, F., Muhammad, A., Putra, H., Farhan, A. and Sally, I. R. (2024). Utilizing Of Wood Sawdust Ash in Eco-Friendly Interlocking Bricks: A Sustainable Approach. E3S Web of Conferences 519, 04006

Sampson, A., Kankam, C. K., Adinkrah-Appiah, K. A., Russell, O. Banahene, O. J. and Okai, D. (2024). Influence of Burnt Sawdust Ash from Timber Species on the Chemical Strength Properties of Laterite-interlocking Blocks. *Journal of Materials Science Research and Reviews*, 7 (2). 252-261.

Yu-Ming, H., Chao-Shi, C., Chen-Chung, C. and Jian-Wen, L. (2024). Utilizing Industrial Sludge Ash in Brick Manufacturing and Quality Improvement. *Materials*, 17(11), 2568.