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Development of Thermo-Regulated and Eco-Friendly Bricks for Thermo-Regulated Houses using Anthill Clay

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ABSTRACT

This study investigated the development of thermo-regulated and eco-friendly bricks for thermo-regulated houses using anthill clay. Anthill Clay samples obtained from two tropical climatic locations were crushed, properly mixed with adequate water and varied proportions of Cement (0 - 20%), and subjected to standard laboratory experiments. The anthill clay samples for chemical composition, particle size distribution using sieve analysis and Atterberg limits tests were drawn before the compounding of the mixture for other tests. Specimens prepared using anthill clay and anthill-cement mix were tested, for physical, mechanical and thermal properties. The results of chemical composition, particle size distribution, atterberg limits and natural moisture content, showed that the Anthill Clay is a fireclay composed of inorganic coarse silt materials with mild plasticity. The chemical composition revealed that the clay contained residual carbon on ignition of 1.2% which is from the organic matter used by the white ants (termites) in compounding the clay, it is also responsible in regulating the amount of heat that enters the anthill. The effects of Cement on the anthill clay were visible on the dry density with an optimum value of 1878 kgm-3 at 10% additive. The Linear shrinkage and water absorption showed an inversely proportional effect to increasing additive amounts with optimum values of 1.86% and 4.22% at 10% additive respectively. The compressive strength increased with a maximum value of 9.04 Nmm-2 at 20% additive and an optimum value of 3.75 Nmm-2 at 10% additive, while the abrasion index decreased with a minimum value of 0.162units at 20% additive. The thermal conductivity had a direct proportional increase with % cement increase in the bricks, with a minimum value of 0.621W/mK at 0% additive with acceptable values at the other additive percentages. Based on the need to develop a thermo-regulated-eco-friendly brick with improved functional properties and thermoregulatory ability, the optimum product was achieved at 10% admixture (Anthill Clay + Cement 10%) which adhered to all recommended standards of the selected properties for clay bricks. The anthill clay does not emit CO_2 and hence the control was from the quantity of cement added. This percentage proportion of the additive is suitable for the production of Anthill Clay brick for building thermo-regulated houses and agricultural storage structures, in urban and most especially in rural areas that are capable of withstanding the recent global warming effects in Nigeria and the world.

Introduction

Global warming and its attendant effects have become a world problem today. The year 2015 has been declared an El-nino year (El Niño, oceanic and atmospheric phenomenon in the Pacific Ocean, during which unusually warm ocean conditions appear along the western coast of Ecuador and Peru, causing climatic disturbances of varying severity.), most parts of the world are experiencing one or both of the following: extreme temperatures, drought, storms, floods, etc. In the month of May, 2015 not less than 2500 people in India lost their lives due to heat waves in that country with temperatures reaching 48°C. In the same month and year, in the USA State of Texas – Houston, not less than 25 people lost their lives to floods and storms excluding millions of Dollars worth of properties destroyed in the natural disaster [1-2]. This incidence was preceded by extensive drought in the area. The Philippines and Australia have also been having their share of the effects of global warming. North- Korea is currently experiencing drought and this is threatening the availability of food (UN, 2015) [3]. Nigeria is another country where some part of the country is yet to receive rain for farming activities even after the month of May, 2015. The temperatures in most part of the country are as high as 37°C and sometimes more [4]. This year has been declared by Nigerians as the hottest year as compared to last year. The years 2012 and 2013 in Nigeria witnessed serious floods that destroyed lives and properties worth billions of Dollars. These disasters informed this research work. The world today needs thermo-regulated houses for comfort; houses that will not be easily soaked by water during flooding. Strong houses that will not be pulled down easily by storms. This can only be achieved by the development of intelligent materials and by mimicking and copying from bio-systems [5].

The anthill is an interesting structure built by the white ants called termites (ecosystem engineers). Studies have shown that even when the external environmental temperature is up to 37°C, temperature within the anthill hardly exceed 27°C. The same studies revealed that this same clay releases less CO_2 and the use of this clay for building barns for storage of agricultural

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products in Northern Nigeria dates back to several centuries of history. The same material is used by the locals for building of thatch huts for habitation [5-7]. Studies have also shown that around 1926 the colonial masters used the material for building thermo-regulated houses at Yandev Agricultural Farm Centre in Benue State of Nigeria. These were specially built with bricks made from the clay. The house was roofed with zinc sheets followed by a thick layer of thatch grass called ''acho'' in the local dialect. These roofs lasted for close to 70 years because the last of these houses were seen in the 1990s. These houses were cool and comfortable to live in [6-8]. The greatest draw-back of the anthill clay is that of wetability which often reduces its strength making it prone to quick collapse when used in buildings, particularly in the presence of too much rain [6, 9].

Studies have shown that this draw-back can be overcome by two ways. One is by firing of the anthill clay between the temperature range of 700°C and 1200°C. The second method is by mixing the clay with additives [9-11]. These additives include: cements, slake lime, rice husk ash, coal ash, dicalcium silicate γ phase (γ- $2CaO.SiO_2$), calcined periwinkle, etc. The use of some of the additives reduces the wetability but increases CO_2 emission during brick making. Zero CO_2 emission can be achieved by mixing the anthill clay with γ-$2CaO.SiO_2$ and coal ash [10]. This is particularly important in producing eco-friendly bricks. In a work carried out by Higuchi et al, [10] the authors developed a new ecological concrete with CO_2 emissions below zero. This ecological concrete is named CO_2-SUICOM (CO_2 Storage under Infrastructure by Concrete Materials). This concrete is based on two typical features. One is using a special additive (the dicalcium silicate γ phase: γ-$2CaO.SiO_2$) and coal-ash instead of cement. These materials have very low level of CO_2 emissions, and γ-$2CaO.SiO_2$ hardens concrete by reaction with CO_2. The other feature of this concrete is that CO_2 in the exhaust gas of a power plant can be captured [10].

In a work by Makunza and Wambuka, [12] the researchers developed thermal insulator paving bricks for global warming control. Their study explored the possibility of employing coconut and grass fibers in paving bricks to create insulation in the paving materials. To this effect paving bricks were manufactured by using local traditional methods. To start with, the engineering properties of the insulated paving bricks were determined and it was established that they satisfied the quality requirements as stipulated in ASTM C 902 "Specification for Pedestrian and Light Traffic Paving Brick", thus making them suitable for use. The heat flow test results showed that the paving bricks which were composed of grass layers and coconut fibers demonstrated lower thermal conductivity as they took longer time to absorb heat and shorter time to lose it in comparison to normal solid paving bricks. Anthill structure behaves in a similar manner as the paving bricks developed by Makunza and Wambuka [12]. The use of anthill clay in many applications is possible due to the capacity of anthill clay to maintain a permanent shape after moulding because of its plasticity and less prone to cracking attributes compared to ordinary clay. In addition, its low thermal conductivity, reduced solar heat flow and temperature fluctuation within an enclosure [13-15] is appropriate in constructing thermoregulatory facilities.

The objective of this work is to develop thermo-regulated and eco-friendly bricks for thermo-regulated houses to counter global warming.

Materials and Method

Materials and Equipment

The materials for this study were Anthill Clay (primary), Cement (secondary) and distilled water. Samples of the primary material were collected from different locations in the selected study area, Uyo and Port Harcourt, while the additive sample was obtained from the concrete laboratory in the University of Uyo, Akwa Ibom State. The grade of additive used in the experiment was Cement grade 42.5 with high alumina content for general purpose engineering applications. Other materials were: distilled water, releasing agent (engine oil), filter papers, cellotape, writing materials, chemical reagents, cleaning cloth and fumigation chemicals (DDT).

Selection of the study area was based on the temperature and vegetative requirements suitable for the natural formation of Anthill Clay, the availability of the material and proximity. The study areas are characterized by a tropical climate between latitude 5^0 & 8^0 north and longitude 4^0 & 6^0 east of the Greenwich meridian. The mean temperature ranges from 28^0C to 37^0C, while the minimum monthly temperature ranges from 17^0C to 24^0C (see Plates 1 – 5).

Plate 1. Anthill Clay in a Semi-urban area

Plate 2. Anthill Clay in a rural area at Ebukulu Waterside Borokiri, Port Harcourt

Plate 3. Anthill Clay in an urban area along NLNG Road, Port Harcourt

Plate 4. Anthill Clay in a rural area at Ikot Okubo, Uyo

Plate 5. Anthill Clay in the University of Uyo, Nwaniba Campus, Uyo

Equipment

The equipment used in the research were laboratory based as shown in Plates 6 – 11. They were as follows: Atomic absorption spectroscope, Ignition burner, Analytical weighing balance (0.1g sensitivity) and weight box, Multi-purpose digital pH meter, Reciprocating shaker, Dispensing bottles, pipettes, beakers, Erlenmeyer and volumetric flasks (125ml), Thermometer (Hand thermo flash, max. 40^0C and Digital Sensor, 200^0C), Water distillation unit and evaporation dishes (aluminium), Drying oven (controlled at 105 -110^0C) and hot plate (150^0C). Others were Refrigerator and desiccators, I.S set of sieves, metal cans (lid), glass plate, measuring cylinder, oven, measuring pan, limit device, grooving tools and spatula, cylindrical steel mould, rammer, trowel, mixing pan, water cans, steel straight edge, steel ruler, Brick mould 215 x 102.5 x 65mm [16], Detachable steel moulds of 100 x 100 x 100mm, Computerized universal testing machine (DIGIMAX 3 Control, capacity of 3000KN), and Electrical furnace (max. 1200^0C).

Plate 6. Sets of International Standard Sieves

Plate 7. Oven with Temperature Meter of Range Sieves

Plate 8. Limit device, spatula, grooving tool, cylinder, lid and glass plate (Atterberg Limits)

Plate 9. Detachable wooden brick mould of size 215 x 102.5 x 65mm

Plate10. Detachable steel moulds, effective size 100 x 100 x 100mm

Plate 11. Thermometer, hot plate, brick specimen and cold plate

Method

Specimen Preparation

The combined Anthill clay samples were obtained in lump forms, it was pulverized into powdery form and air dried, this was done in the soil mechanics laboratory (see Plate12). From the processed sample, a specimen of 50mg in weight was sieved out and placed in plastic containers for chemical testing. Samples were then divided into six equal batches of 3000mg in weight, each for control and admixtures as shown in Table 2.1.

Table 2.1. Anthill Clay and Cement Mixing Design

Combined Sample	Control	Admixture (Anthill Clay + Cement)				
	A	B	C	D	E	
Anthill Clay Proportion (%)	100	95	90	85	80	
Cement Proportion (%)	0	5	10	15	20	

The processed Anthill clay sample was mixed with water and left to cure for two days before specimen preparation for the intended experiments, so as to allow the water to evenly distribute through the clay. This was done after the natural moisture content determination. From the mixing design; 12 No(s) cube specimens were produced manually from steel moulds of specification 100 x 100 x100 mm effective size for mechanical testing, 12 No(s) cylindrical specimens from a proctor mould (100 mm internal dia. by 116.6mm height) were obtained from standard compaction tests for use in the physical tests, while 6 No(s) brick specimens were made manually by pressing and extrusion from the brick mould of specification 215 x 102.5 x 65 mm [16]. Even distribution of blows in mould was ensured via compaction of the samples with a rammer of size 250 x 13 x 13mm, in adherence to British Standard [17]. The moulded bricks were carefully extruded in good shape from the detachable mould after 3 days, the specimens were then placed on a clean, hard flat surface allowed to dry under natural atmospheric temperature and pressure for 21 days. The brick specimens were later utilized in both physical and thermal testing. All the test specimens used in the laboratory tests are shown in Plate 13 – 15.

Lumps of Anthill clay

Processed sample

Air drying of sample

Plate 12. Sample Preparation in the Soil Mechanics Engineering Laboratory, University of Uyo

Plate 13. Cubed Test Specimens Prepared for Mechanical Property Testing (unconfined compressive test).

Plate 14. Cylindrical Test Specimens Prepared from Compaction Test for Physical Property Testing

Plate 15. Samples Prepared in Brick Moulds and Brick Specimens for Thermal Property Testing

Experimental Procedure

The purpose of this research is to develop a thermo-regulated eco-friendly brick using just an optimum quantity of Cement to minimize CO_2 emission. The optimum mixture was expected to be achieved, so for this reason varying additive percentages, ranging from 5% to 20% with proportional mass weights of the Anthill Clay (shown in Table 1) and adequate volume of water were used throughout the entire experimental program. This mix matrix was adopted for the combined samples collected from the selected locations respectively.

Based on the objectives of the study, the engineering properties of the primary material was investigated first from the prepared control specimen (Anthill Clay only). This was followed by the investigation of the admixture specimen (Anthill Clay + Cement), prepared from the combined samples collected from the selected locations. The test specimens were grouped into categories such as control (Anthill Clay only) and Admixture (Anthill Clay + Cement). These specimens were subjected to laboratory tests such as chemical, physical, mechanical and thermal.

The tests are briefly described below:

Chemical Composition

The chemical composition (mineral content) in oxide form of the control sample was tested using a standard atomic absorption spectroscopy (SAAS) and ignition loss method was used to check the organic content. The pH levels were tested using a multipurpose digital pH meter and the process CO_2 was checked using qualitative method of passing the gas into slaked-lime.

Sieve Analysis

The particle size analysis was used to measure the percentage of the varying grain sizes contained within the control specimen (Anthill Clay). The wet sieving procedure was utilized because of the clayey and silt particles present in the experimented material. The process is shown in Plate 16.

Collection of retained sample

Retained sample

Weighing of sieved sample

Plate 16. The Sieve Analysis of Anthill Clay sample.

Moisture Content Determination

The control sample (combined Anthill clay sample) was subjected to the oven drying method to obtain the natural moisture. An oven temperature of 110ºC was maintained for a period of 24 hours for proper drying to constant mass. After drying, the containers were carefully removed from the oven. The various weights required for the determination of the moisture content were measured using weighing balance and recorded. Plate 17 show samples inside the oven.

Plate 17. Containers with Samples in the Oven Set at 110^{0}C for 24 Hours Drying

Atterberg Limits and Indices

The tests carried out for this experiment measured the plastic limit, liquid limit and plastic index of the control sample (Anthill Clay). This tests were conducted according to IS standard. The plastic limit of the control sample was determined at the point where the thread-rolled specimen with calculated amount of water began to crumble that point indicated the plastic attributes of the clay and the quantity of water at that point was noted. For the liquid limit:

100g of the sample passing through 425 micron sieve was mixed thoroughly with distilled water in the evaporating dish to form a uniform paste. A portion of the paste was then placed in the cup of the liquid limit device. The mix was levelled to obtain a maximum depth 10mm. The groove tool was then drawn through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup. The handle of the apparatus was then rotated at a rate of about 2 rev/sec and the number of blows were counted till the two parts of the control sample came into contact at the bottom of the groove.

Standard Compaction Test

The standard proctor test also known as light compaction test, which involves the tamping compaction method was used for the experiment. The weight of the hammer for tampering was 2.6 kg, the height was 0.3m and the numbers of equal layers to be compacted were 3 No.s. The compactive energy in the selected proctor test was 60.45 kg-m

The samples were then compacted using the 2.6 kg rammer falling from a distance of 300 mm. Each layer was subjected to 29 vertical drops (blows) of the rammer. The compacted sample mould was weighed and the wet density determined. Moisture cans were filled with the samples from the three layers. It was then weighed and taken for oven drying. The remaining sample in the mould was removed and placed back in the mixing pan. 2% percent water was added to the initial water content of the sample after it was broken loose from the mould. These steps were repeated based on the wet density until a peak value was reached. This value was observed at the fall in weight of mould containing wet sample after final compaction process. The moisture content and dry density of the sample was calculated using appropriate formulas and the data tabulated were used to plot the graph of dry density against moisture content. These procedure was carried out on the control samples and the admixtures as shown in Plate 18.

The resultant cylindrical test specimens were air dried for further testing. Readings of calibrated equipment were taken precisely, avoiding parallax errors.

3kg of air dried sample

Addition of H_2O

Mixing of control sample

Mixed sample divided into 3 layers

Filling of the layered samples and compaction

Cylindrical test specimen

Dried test specimens

Plate 18. Preparing, Mixing, Weighing, Compaction and the Resultant Cylindrical Test Specimens

Linear Shrinkage

Shrinkage test was done in line with the recommendations of the standard in ref. [17] The cylindrical test specimens obtained from the compaction test were measured in length using a precision steel ruler and veneer caliper. They were air dried for 21 days and their respective measurements taken after the drying process as shown in Plate 19.

Plate 19. Measuring the Reduction in Size of the Brick Specimen after 21 Days of Air Drying

Water Absorption

This test was done in accordance to Standard specification (IS 3495, 1992). The cylindrical test specimens were completely dried in an oven at temperature 110^{0}C for 48 hours and their weights measured (W_1). After which they were completely submerged in a bucket of clean cold water at temperature 29^{0}C for 5 hours. The specimens were removed and traces of water were wiped out using absorbent material. The specimens were immediately weighed 3 minutes after damping (W_2) as shown in Plate 20. The water absorption was then calculated with the formula:

$$Water\ Absorption\ (\%) = \frac{W2 - W1}{W1}\ x\ 100 \quad \text{- - - - - - - - - -} \quad (1)$$

Where;

W_2 = weight of wet specimen, W_1 = weight of oven dried specimen after 5 hours.

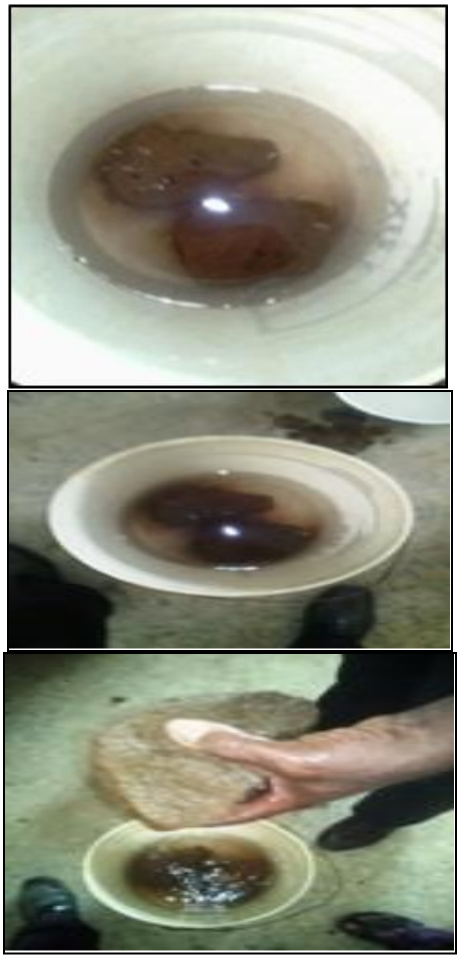

Plate 20. Cold Water Absorption Performed on the Test Specimens

Compressive Strength

The failure response of the prepared specimens to loading was tested in accordance with American Standard specification [18]. The cube shaped specimens obtained from a mixed mass of 2 kg of the control sample and admixtures, were air dried for 28 days, then placed between two plates of the compression strength tester. An axial load was applied at uniform rate of 14 N/mm^2 per minute until the maximum load at failure was realized. The crushing process is as shown in Plate 21, the computerized universal testing machine (DIGIMAX 3 control, capacity of 3000KN) which was used is also shown.

28 Days air dried specimens

weighing of specimen

crushing of specimen

Plate 21. Preparation of Cube Specimens, Weighing and Final Crushing Process

Thermal Conductivity

The thermal conductivity measurement test was conducted according to an adapted experimental procedure of international standards [19]. The specific steady state technique used in this research is known as the "Guarded Hot Plate Method". The scheme of guarded hot plate is shown in Figure 2.1.

The brick specimens were placed between two plates. One plate (hot plate) was heated to a temperature of 150^0C and the other plate (cold plate) was immersed in water to a temperature lower than the hot plate. The cold plate was of equal cross section with the brick specimens while the hot plate was of smaller cross sectional area. This was ensured to avoid heat transfer via radiation from the hot plate to the cold plate. Also insulation was effected by forming the set up in ceramic sink. The sink was covered with a ceramic tile for complete insulation. The temperature of the plates was monitored until they had a constant value. The steady state temperatures, the thickness of the sample and the heat input to the hot plate were used to determine thermal conductivity.

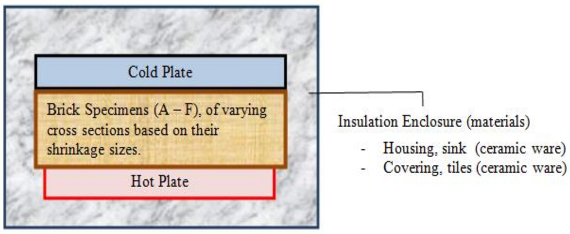

Figure 2.1. Schematic Representation of the Guarded Hot Plate Method Set up Utilized for Thermal Conductivity Test

Results and Discussion

Results

The results obtained are outlined based on investigations of the specimens' properties such as chemical, physical, mechanical and thermal properties.

Chemical Composition of the Anthill Clay Sample

The figure 3.1 below is the chemical composition chart of the anthill clay sample. While the pH value, the % composition of sand, silt and clay is also stated below.

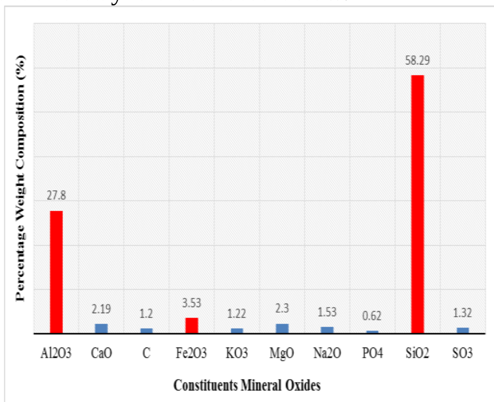

Fig 3.1. Chemical Composition Chart of Anthill Clay Sample

The pH value of the Anthill clay sample was 6.40 units, while the composition of the others were sand (59.6%), silt (3.60%) and clay (36.8%) respectively.

Physical Test

Sieve Analysis

The particle size distribution results obtained are shown in Table 3.1. The grain size curve as shown in Figure 3.2 was plotted to derive the values for the coefficient of uniformity (Cu) and curvature (Cc) respectively.

Table 3.1. Particle Size Distribution of Anthill Clay Sample

BS Sieve No.	Particle Size (mm)	Mass Retained (g)	Percentage (%)	Cumulative % Finer (passing)	Cumulative % Retained
2360 µ	2.360	0.000	0.000	100.000	0.000
1180 µ	1.180	7.800	0.780	99.220	0.780
600µ	0.600	166.650	16.670	82.550	17.450
425µ	0.425	132.300	13.230	69.320	30.680
300µ	0.300	166.350	16.640	52.680	47.320
150µ	0.150	121.250	12.130	40.550	59.450
75µ	0.075	45.000	4.500	36.050	63.950

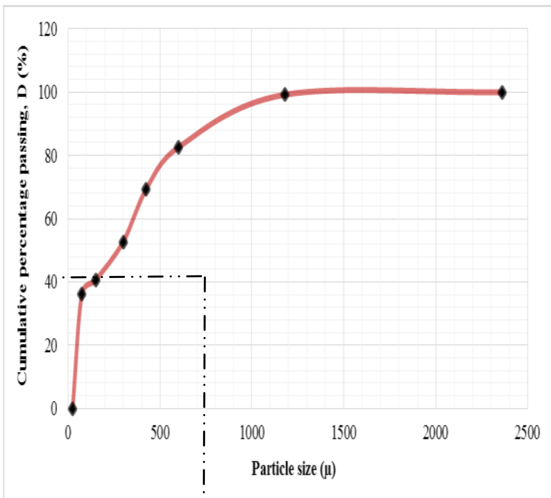

Fig 3.2. Particle Size Distribution Curve Graph for Anthill Clay Sample

From the graph, the calculated coefficient of uniformity and curvature will be;

$$Cu = \frac{D60}{D10} = \frac{0.340}{0.030} = 11.3\text{units}$$

$$Cc = \frac{D60}{D30} = \frac{0.0038}{0.0102} = 0.373\text{units}$$

Moisture Content Determination

The natural moisture content of the Anthill clay sample was determined as 28.92%

Atterberg Limits

Liquid limit analysis graph is shown in Figure 3.3. The plastic limit of the anthill clay occurred at 25.89% water content

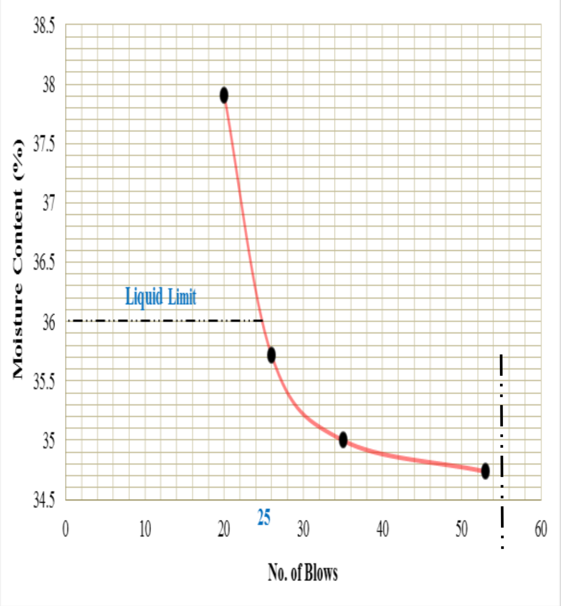

Fig 3.3. Graphical Analysis of the Liquid Limit of Anthill Clay Material

Figure 3.3 indicates a water content corresponding to 25 blows, this value of 36.0% is the liquid limit (LL) of the Anthill clay material.

Therefore the Plasticity Index (PI) will be; PI = LL – PL = (36.000 – 25.877) = 10.123 units.

Standard Compaction

Figure 3.4 is the graph of maximum dry density versus variation in % cement of anthill clay cement mix.

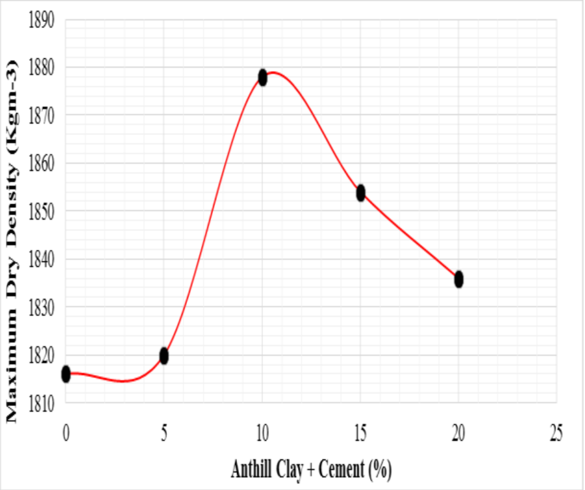

Fig 3.4. Graph of Maximum Dry Density Versus % Cement in Anthill Clay-Cement Mix

Linear Shrinkage

Figures 3.5 and 3.6 are shrinkage property chart for various percentages of cement in anthill clay-cement mix bricks and graph of total shrinkage versus percent variations of cement in anthill clay-cement mix bricks respectively.

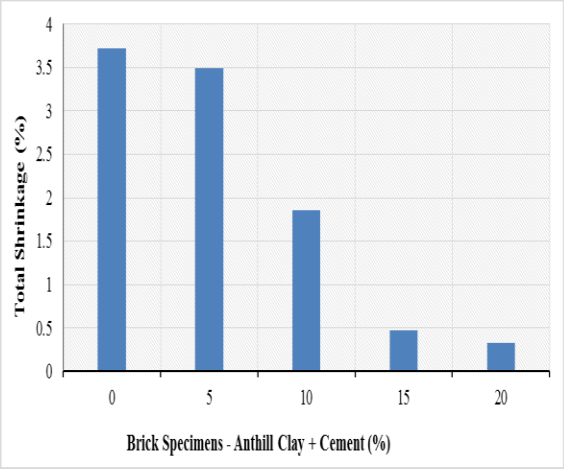

Fig 3.5. Shrinkage Property Chart for various Percentages of Cement in Anthill Clay- Cement Mix Bricks

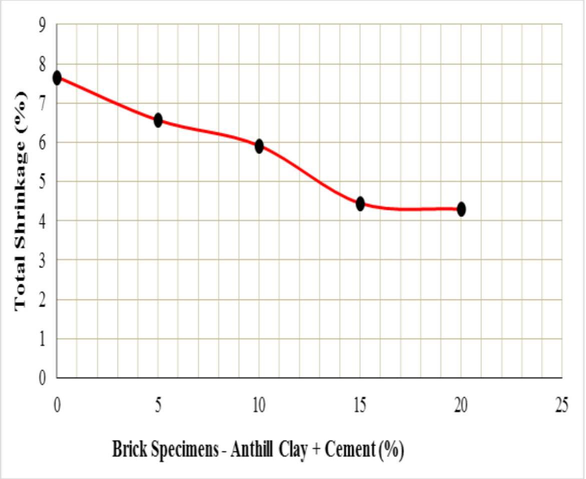

Fig 3.6. Graph of Total Shrinkage Versus Percent variations of Cement in Anthill Clay-Cement Mix Bricks

Water Absorption

Figure 3.7 is water absorption versus percent variation of cement in anthill clay-cement mix bricks

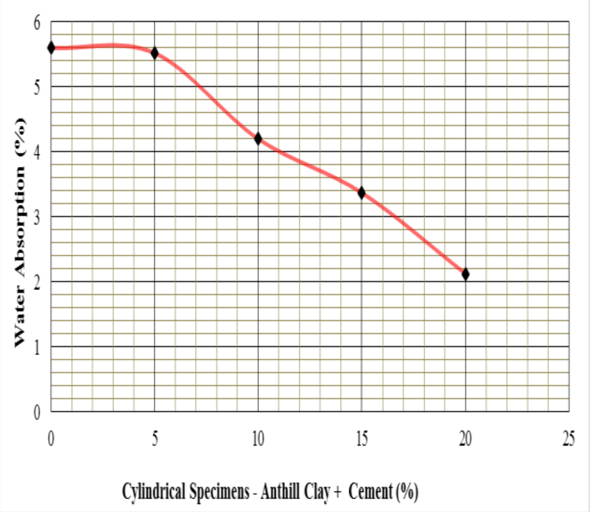

Fig 3.7. Water Absorption Versus Percent variation of cement in Anthill Clay-Cement Mix Bricks

Compressive Strength

Figures 3.8 and 3.9 are compressive strength versus % cement of anthill clay-cement mix bricks and abrasive index versus % cement of anthill clay-cement mix bricks respectively.

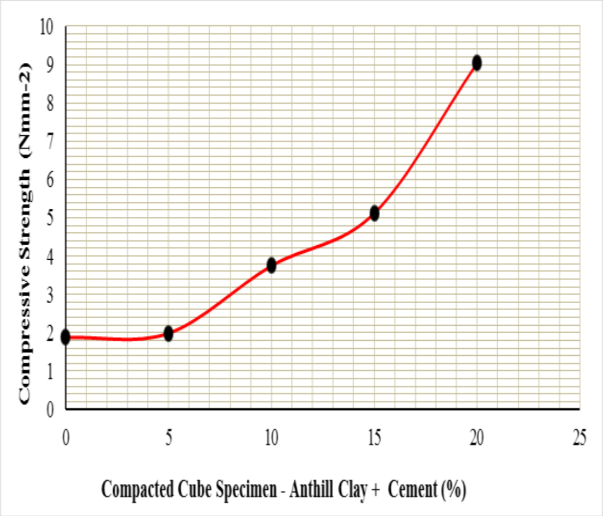

Fig 3.8. Compressive Strength Versus % Cement of Anthill Clay- Cement Mix Bricks

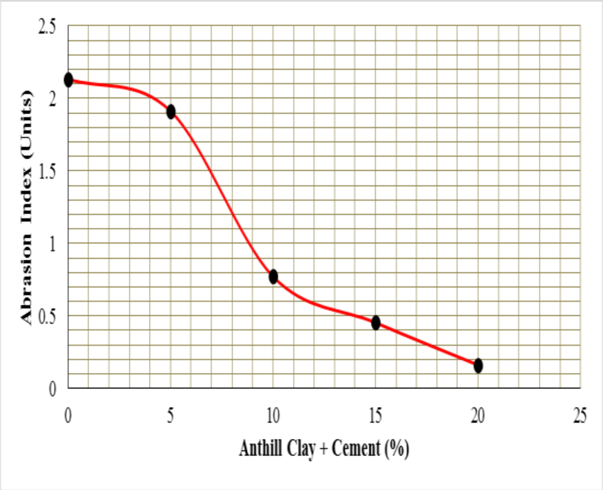

Fig 3.9. Abrasive Index Versus % Cement of Anthill Clay-Cement Mix Bricks

Thermal Conductivity

Figures 3.10 and 3.11 are thermal conductivity versus % cement of anthill clay-cement mix bricks and bar chart of thermal conductivity versus dry density of various anthill clay-cement mix bricks respectively.

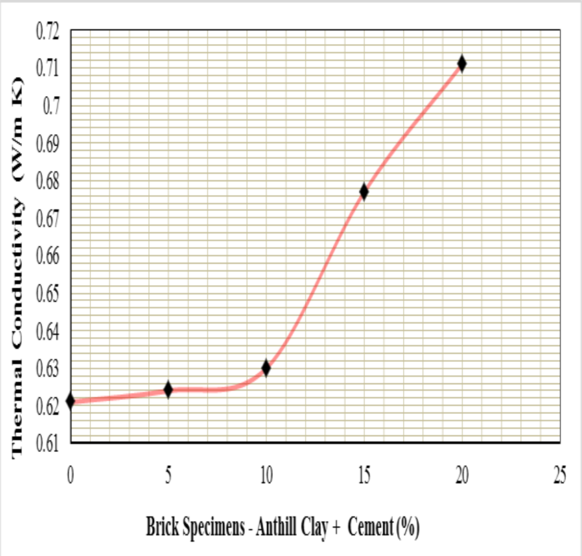

Fig 3.10. Thermal Conductivity versus % Cement of Anthill Clay-Cement Mix Bricks

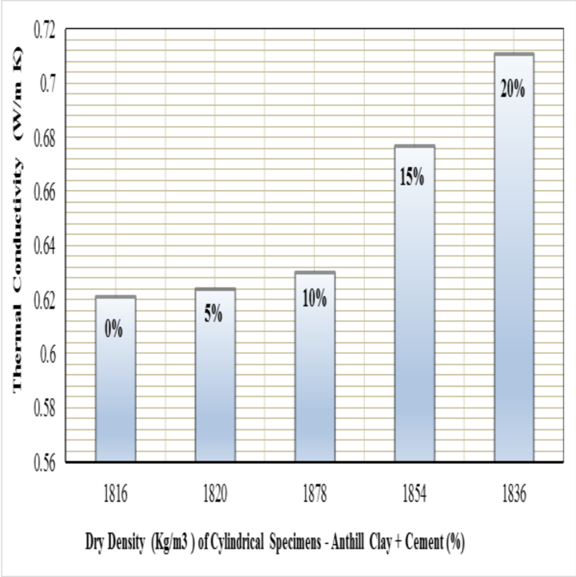

Fig 3.11. Bar Chart of Thermal Conductivity Versus Dry Density of various Anthill Clay-Cement Mix Bricks

Discussion

Chemical Composition of Anthill Clay Sample

Figure 3.1 shows that in the chemical composition of the anthill clay Silica (SiO_2) has the highest composition of 58.29%, followed by Alumina (Al_2O_3) with 27.8%. The result also shows that of the total anthill clay analysed 59.6% is sand 3.6% is silt and 36.8% is clay. The clay quantity is reasonably high and that gives it its plastic property [20]. The iron oxide content of the clay is 3.53%, and the pH level is 6.4 which make it slightly acidic. These implies that the clay sample belongs to the family of aluminosilicates and semi-acid refractory since the alumina value falls within standard classification [21]. The classification of the clay may be limited to siliceous fireclay and slightly acidic [22]. It also conforms to the fireclay standard [23] and the category of mild- plastic fireclay [24]. The result shows the combined percentage of SiO_2, Al_2O_3 and Fe_2O_3 to be 89.62%, which satisfies the ASTM requirement of pozzolanic materials of 70% minimum. MgO composition was found to be 2.30% which is less than 4% maximum requirement, while CaO and SO_3 composition are 2.19% and 1.23% respectively, and are within the recommended range of ASTM C6I8-78 [25]. The composition of Fe_2O_3 in the Anthill clay is responsible for the deep brownish colour of the material. The presence of carbon in the chemical analysis of the Anthill clay sample is from the organic matter used by the termites (ecosystem engineers) in building the anthill [26]. According to Batjes [27], the organic matter contributes to the thermoregulatory tendency of the Anthill and it plays a key role in the carbon cycle which is important in global climatic models. It improves the physical properties of soil thereby increasing the cation exchange capacity and water holding capacity of the Anthill clay. The chemical composition and structure of the Anthill clay determines its natural properties, reaction to external factors and serves as an integral part of the material [13]. This implies that for bricks produced from anthill clay to have the same properties as the clay, similar chemical composition to that of the clay material must be maintained.

The chemical analysis result can aid in achieving the synthesis of the anthill clay, hence overcoming any challenges in terms of availability. Previous works have also shown that results of chemical analysis have been used in making blends of similar clays [20, 28], this can also be adopted in the use of anthill clay for brick production.

Particle Size Distribution

The percentage passing as shown in Table 1 has a value less than 50% for the 75µ IS sieve which implies the composition of coarse silt particles in the anthill clay material. Deduced from figure 3.2 the values of coefficient of uniformity Cu and coefficient of curvature Cc are 11.3 and 0.373 respectively. Based on this figures the anthill clay is referred to as a well graded and uniform engineering clay material. The result showed that the clay content of the anthill clay sample was 36.05%, and so it belongs to the group of silt-clay materials since the value is more than 35% (passing No. 150 sieve) refer Table 1. This is in accordance with the American Association of State Highway and Transportation Officials (AASHTO) in [5]. Table 1 showed that the bulk of the retained particle size is on five sieves (600, 425, 300, 150, 75 µm), this is an indication that the clay will give good compaction and strength properties when moulded into bricks [29].

Moisture Content Determination

The natural moisture content of the clay material is 28.916%. Although this amount contributes to the clay strength properties it is not equivalent to one fourth of the whole clay sample tested (250g). Hence the classification of the material as a mild – plastic clay and medium grained is acceptable in relation to the inference of the chemical composition and sieve analysis of the Anthill Clay. High-plastic clays will have moisture content more than one quarter of the total weight of the tested clay sample. The Anthill clay structure derives its strength from its natural moisture content and so do any other clay material. This is due to the ability of the water molecules to hold the sand, clay, silt and organic matter together [20, 14].

Atterberg Limits

The liquid limit of the anthill clay from figure 3.3 is 36.0% corresponding to 25 numbers of blow, this value is greater than 35 and less than 50, classifying it as an inorganic clayey silt material with medium compressibility of plasticity 25.887 % based on the crushing strength (IS: 1498-1970, amended 1987). The plasticity index was 10.123% which implies that the clay sample can be described as having medium plasticity (LL>35%) according to BS: 1377 (1975) [30]. This means that the clay sample has good cohesion and hence can maintain proper compaction to enhance its strength and durability. These properties also explain why anthills do survive harsh weather conditions for centuries if not destroyed by mechanical means. This was evident in some of the Anthills surveyed during the work; most of them had a record of 30 years of existence.

Effects of Cement on the Physical Properties

The effects of the additive on anthill clay material were observed for the following physical tests, and their products are explained in comparison to standards.

Standard Compaction

Figure 3.4 shows that the maximum dry density of 1878 kg/ m^3 occurs at 10 % cement content in the clay-cement mix. The corresponding maximum dry density of 1878kg/m^3 is higher than 1780 kg/m^{-3} as obtained by Olaoye and Anigbogu in [5], meeting the minimum requirement of 1810 kgm^{-3} recommended by NBRRI(Nigerian Building and Road Research Institute) in [5]. The graph however showed that after the maximum dry density of 1878 kg/m^3 corresponding to 10% cement addition to the anthill clay further cement additions led to decrease in the dry maximum density. The dry maximum density for the control sample without cement was 1816 kg/m^3 this density value is higher than 1089 kg/m^3 known for undisturbed clay types such as dry excavated clay [31]. Therefore the value of 1878 kg/m^3 is an indication of good property improvement of the anthill clay material on the addition of 10% cement. According to Gooding [32] good compaction of the clay mixture leads to improved physical and mechanical properties of bricks [32].

Linear Shrinkage

Figures 3.5 and 3.6 shows the positive effects of the additive in all the varied proportions (0 – 20%). The figures showed that as the cement content of the anthill clay bricks was increased from 0 to 20% the total shrinkage continued to decrease with the lowest value of 4.3% occurring at 20%. The highest shrinkage value of 7.7% occurred at 0% cement. This clearly indicates that the addition of the cement reduced the shrinkage problem associated with anthill clay bricks. Cement has the ability of resisting water absorption as it forms chemical bonds with the particles of the clay resulting in the formation of a gel-like substance which is also said to be responsible for the continuous curing of cement and thereby contributing to the strength of the material. The bonds formed impede further shrinkage [33]. The values of the total shrinkage in Figures 3.5 and 3.6 are within the acceptable range expected of clay bricks; in which shrinkage is expected to be less than 7% [34]. This is due to the binding property of the additive reducing the ability of the Anthill clay to release most of its absorbed moisture in the presence of increased temperature. All the varied proportions of the additive proved to be effective in reducing the shrinkage problem of the Anthill clay making it suitable for building and other functional purposes. This shrinkage tendency of the Anthill clay is a limiting property in the clay as an engineering material. Shrinkage present in materials used for building structures can be dangerous leading to contraction, internal stress and cracking [11, 35].

Water Absorption

Figure 3.7 shows that as the cement content in the bricks increase the water absorption capacity of the bricks decreases. Water absorption of the bricks and cement content has an inverse proportion. Anthill clay brick without cement has the highest water absorption value of 5.6% and anthill clay brick with 20% cement had the lowest value of water absorption of 2.1%. Cement has the ability of resisting water absorption as it forms chemical bonds with the particles of the clay resulting in the formation of a gel-like substance which is also said to be responsible for the continuous curing of cement and thereby contributing to the strength of the material [33]. According to standard, values within the range of 4.5% to 7% are recommended for structural bricks in BS EN 771-1 in [5]. This implies that the addition of cement in varied proportions improves the functional requirement of Anthill clay. It makes the clay a suitable structural brick material for construction of storage structures (silos) and shelter houses with minimal water absorption, even under intense precipitation occurrence of a period of 5 hours.

Effects of Cement on the Mechanical Properties

Compressive Strength and Abrasive Index

Figure 3.8 shows that the compressive strength is directly proportional to the increase in cement content of the bricks, as the cement was increasing so was the compressive strength. The highest value of 9.04 N/mm^2 compressive strength occurred at 20 % cement content in the brick, while the lowest value of 1.88 N/mm^2 compressive strength occurred at 0% cement content in the bricks. The rise in compressive strength as clearly depicted in Figure 3.8, is an indication that the varied proportions of the additive improved the clay material in terms of strength requirements. The results from 5-10% cement conforms to the compressive strength range of 3 to 3.5Nmm^{-2} recommended by the Nigeria Building and Road Research Institute, NBRRI in [5].

Figure 3.9 shows an inverse relationship between cement content of the bricks and the abrasive index, as the cement content increases the abrasive index decreases thus agree with figure 3.8 the bricks become stronger to resist abrasion and scratching. The highest abrasive index of 2.13 occurred at 0% cement in the brick and the lowest value of 0.162 abrasive index occurred at 20% cement in the brick. The curve depicts a downward sloping graph, with a visible decrease in the abrasion tendency at 10 to 20% of the additive. The abrasive index values corresponding to 15-20% cement in the bricks are within the allowable maximum limit of 0.50 as specified in the ASTM C902. According to BS in [5], bricks must have good compressive strength and low abrasive index to be able to withstand loading, abrasion and wear in building structures. The results obtained adhere to standard clay bricks requirements and are also similar to the outcomes of the research work by Olowu, et al [36]. The ability of the cement to improve both the compressive strength and the abrasive index of the anthill clay bricks can be explained in terms of cement being able to resist water absorption as it forms chemical bonds with the particles of the clay resulting in the formation of a gel-like substance which is also said to be responsible for the continuous curing of cement and thereby contributing to the strength of the material [33].

Effects of Cement on the Thermal Properties

Thermal Conductivity

Figure 3.9 shows that thermal conductivity is directly proportional to cement content in the anthill clay bricks, as the cement content of the bricks is increasing so also is the thermal conductivity increasing, showing a steady rise of the curve. The highest thermal conductivity value of 0.71 W/mK occurred at 20% cement while the lowest value of 0.62 W/mK thermal conductivity occurred at 0% cement content in the brick. The results are within the acceptable standard values of 0.6 – 0.8W/mK for structural clay bricks (ASTM C177-97 Standards, 2000) in [5]. However, 10% cement content brick will be preferred because of its optimum properties and closeness to 0.62 W/mK value of the 0% cement brick. This is an added advantage to fully utilize the thermoregulatory properties of the anthill clay. Figure 3.10 shows that the density in this case does not control the thermal conductivity but it is the cement added to the anthill clay that does. It can be seen in the figure that the thermal conductivity kept increasing mean while the density got to its highest peak of 1878 kg/m^3 at 10% cement and then started decreasing down to 1836kg/m^3 at 20% cement brick. Theories on the relationship between thermal conductivity of clay bricks and density of the bricks, say the denser the brick the higher the thermal conductivity and the porous the brick the lower the thermal conductivity of the bricks [21]. The result therefore agrees with the existing theory. Anthill clay (0% Portland cement) being the control specimen has the lowest thermal conduction ability which is a desirable functional requirement with regards to thermoregulation in the aspects of storage (food produce) and shelter (habitation). But total concentration on this natural property, neglecting other engineering properties renders standardization of the Anthill clay material futile. Hence the selection of brick specimens 5 – 10%, considering other parameters is a technical choice. Also Figure 3.10 shows a non-dependence of the thermal property on the maximum dry densities of the samples despite the optimum density value being at 10% additive as explained above. This is also partly due to physical properties of the anthill clay (mild –plastic) and that of the cement (hydraulic material) which introduces conducting elements in the mix (electrolytes) according to Bogue [37]. From the results, the plasticity of the Anthill clay tends to reduce the heat flow rate in the admixture, while the hydraulic nature (chemically reactive) due to the composition of Tricalcium Silicate ($3CaO{:}SiO_2$, C_3S) aids the flow rate resulting in the increase in thermal conductivity values indicated in Figure 3.10.

CO_2 Emissions

The conceptual intensions of this work were to improve on the engineering properties of the anthill clay in order to develop a thermoregulatory and eco-friendly bricks that would be used in building agricultural storage facilities, and thermoregulatory houses to counter global warming effects. The bricks were to have zero CO_2 emission by using dicalcium silicate cement and coal ash as cement to absorb CO_2 during the production process of the bricks [10]. The inability to source for dicalcium silicate and coal ash lead to the use of high alumina cement, which was however used in very small quantities (5 – 20%) in order to increase the water resistance of the clay and consequently its strength. The quantity of cement used was small and so the relative CO_2 emission expected was less as was indicated in slake lime test, thereby making the bricks environmentally friendly.

Conclusion

The study 'Development of Thermo-Regulated and Eco-Friendly Bricks for Thermo-Regulated Houses using Anthill Clay' has been extensively carried out and the following conclusions are drawn from the study:

1. The anthill clay has a unique chemical composition and the inclusion of organic matter in the form of grass, fibre and others help in defining the properties of the anthill clay including its ability to take in less heat and also give out less heat leading to its thermo regulatory property.
2. The shrinkage problem of anthill clay bricks can be addressed with the addition of cement, preferably 10% cement for optimum properties to be attained in the bricks.
3. The highest maximum dry density of 1878 kg/m^3 occurred at 10% cement indicating good compaction which also have to do with the other properties of the clay, like particle size distribution, and its Atterberg's limit values.
4. The problem of excessive water absorption of the clay can be solved by addition of cement since the water absorption decreased with increasing quantity of cement.
5. The compressive strength of the bricks increases with increase in cement content of the anthill clay bricks while the abrasive index of the anthill clay bricks decreases with increase in cement content of the bricks.
6. The thermal conductivity of the anthill clay increases with increase in cement content of the anthill clay bricks, while the maximum dry density of the bricks increases with thermal conductivity.
7. Based on the above conclusions and for eco-friendliness the best brick composition will be 10% cement anthill clay brick since the anthill clay does not emit CO_2. The use of 10% cement will minimize CO_2 emission.

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