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Analysis of Thermal and Electrical Properties of Laterite, Clay and Sand Samples and Their Effects on Inhabited Buildings in Ota, Ogun State, Nigeria

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Abstract. Buildings are faced with situations bothering on effects of heat and electric current flow on occupants. Thermal comfort as well as the quantity of current expected in buildings is of paramount importance. Core materials used in erecting buildings were considered during this study. This study is meant to analyze the thermal and electrical properties of laterite, clay and sand samples thereby picking out the most suitable for inhabited buildings. Each sample of laterite, sand and clay was placed in the sample chamber of Lee's disc apparatus and sufficient heat was passed to the samples through the conical chamber. The in and out temperatures of the specimens were determined. The cooling curves of temperature against time were employed to determine their thermal conductivities while the resistivity was obtained through the thermocouple and multi-meter. A very low thermal conductivity of $3.5 \times 10^{1} kgms^{-2}\Theta^{-1}$ and high resistivity of $0.0337\Omega m$ were obtained for laterite samples. The results obtained revealed that the samples considered have different thermal conductivities, electrical resistivity and rates of cooling. The rate of cooling of laterite sample showed that it has low temperature fluctuations when it absorbs heat. The salt content of laterite sample in Ota was observed to be very minimal due to small quantity of current flowing through buildings constructed with such laterite sample analyzed. The electrical and thermal conductivity of laterites show they can easily withstand high current and intense heat much more than clay and sand. Based on the thermal and electrical properties of laterites obtained, it is therefore imperative to establish the need to embrace it as local building material while sand and clay could be used in the production of pipes, roof tiles and interior floor where the heat conductivity is of secondary concern. Laterite based buildings using NBRRI interlocking should be encouraged more in Nigeria especially those living in hot regions.

KEYWORDS: Laterite, clay, sand, thermal conductivity, resistivity, Ota.

1.0 INTRODUCTION

1.1 Laterites are soil types rich in iron and aluminum, formed in hot and wet tropical areas (Tardy, 1997). Nearly all laterites are rusty-red because of iron oxides. They develop by intensive and long-lasting weathering of the underlying parent rock. Tropical weathering is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils (Tardy, 1997). The majority of the land areas with laterites ore are between the tropics of Cancer and Capricorn (Tardy, 1997).

Historically, laterite was cut into brick-like shapes and used in monument building (Norton, 2000). Since the mid-1970s trial sections of bituminous-surfaced, low-volume roads have used laterite in place of stone as a base course. Thick laterite layers are porous and slightly permeable, so the layers can function as aquifers in rural areas. Locally available laterites are used in an acid solution, followed by precipitation to remove phosphorus and heavy metals at sewage treatment facilities (Norton, 2000).

Laterites are a source of aluminum ore; the ore exists largely in clay minerals and the hydroxides, gibbsite, boehmite, and diaspore, which resembles the composition of bauxite (Norton, 2000). In Northern Ireland they once provided a major source of iron and aluminum ores (Prudence, 1996). Laterite ores also were the early major source of nickel.

Plate 1- Showing laterite

Francis Buchanan-Hamilton first described and named a laterite formation in southern India in 1807 (Norton, 2000). He named it laterite from the Latin word *later*, which means a brick; this rock can easily be cut into brick-shaped blocks for building (Norton, 2000). Laterites can be either soft or easily broken into smaller pieces, or firm and physically resistant. Laterites are formed from the leaching of parent sedimentary (sandstones, clays, lime stones); metamorphic rocks (schists, gneisses, migmatites); igneous rocks (granites, basalts, gabbros,peridotites); and mineralized proto-ores; which leaves the more insoluble ions, predominantly iron and aluminum (Norton, 2000). An essential feature for the formation of laterite is the repetition of wet and dry seasons. The mineralogical and chemical compositions of laterites are dependent on their parent rocks. Laterites vary significantly according to their location, climate and depth. Laterites are widely used to build blocks, build roads, as aquifers in water supply, water treatment etc.

Plate 2: Road built with laterite in Ota

Clay is a natural resource, which means it is not made by humans. It comes from the earth. Clay is in fact all around us; it is part of the earth's crust and the surface on which we tread. It is usually found in little pockets that appear a couple of feet below the ground.

Clay is originally formed from granite rock**,** which makes up a large part of the earth's crust. Over millions of years of weathering, (through coming into contact with sunlight, rain and ice).Granite rocks have gone through a physical change, being broken down into smaller and smaller particles (Owate and Edike , 1986). It is this process that transforms granite rock into clay. Primary clay has remained in the same place for millions of years, never moving from the position where it began life as granite rock. The color of primary clay is white. Primary clay is not very plastic and not the best clay for being molded and shaped. Secondary clay is the kind of clay which we have been using. It is a very plastic like material, being able to be worked into various shapes and forms. Secondary clays unlike primary are not found in the same place as where they started life as granite Rock. Rather other millions of years, they have been moved and carried around by flowing water, usually settling in the side of riverbeds (Owate and Edike , 1986). Also secondary clay differs from primary clays in terms of color. Whereas Primary clay is only white, secondary clay comes in a variety of colors ranging from red to yellow and black to grey. The reason for these different colors is due to the fact that they have been moved around. What happens is that on their journey they come in contact and mixed with different minerals. These different minerals have mixed with the clay and are responsible for producing the different colors. This paper is targeted at determining the thermal and electrical properties of laterite, clay and sand samples thereby picking out the most suitable for inhabited buildings. It will encourage the general public on the need to embrace laterites in their building construction and to sensitize builders and other professionals on the need to use Nigerian building and road research institute (NBBRI) interlocking blocks from laterites for their buildings.

2.0 LITERATURE REVIEW

Here I will be discussing the technical terms involve. Thermal conductivity of a material is the property of the material to conduct heat (Nelkon, 2008). It can also be described as how easily heat can be transported through a material. A low thermal conductivity indicates a heat insulating material (Dindale, 1986). Heat is transferred at higher rates across materials of high thermal conductivity than across materials of low thermal conductivity. It depends on the state of the material, which is a function of the chemical composition and physical structure. Corresponding materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. Thermal conductivity of materials is temperature dependent. The reciprocal of thermal conductivity is thermal resistivity (Nelkon, 2008). Thermal conductivity is measured in watts per (mk) or with dimensions of $ML^{1}T^{-2}\Theta^{-1}$

2.1 Thermal energy

This is the total potential energy and kinetic energy of an object or sample of matter that results in the system temperature (Nelkon , 2008). It is represented by the variable **Q**, and can be measured in Joules. This quantity may be difficult to determine or even meaningless unless the system has attained its temperature only through warming (heating), and not been subjected to work input or output, or any other energy-changing processes. Because the total amount of heat that enters an object is not a conserved quantity like mass or energy, and may be destroyed or created by many processes, the idea of an object's thermal energy or "heat content," something that remains a measureable and objective part of the internal energy of a body, cannot be strictly upheld (Bamigbala, 2001). The idea of a thermal part of object's internal energy is therefore useful only as an ideal model, in special cases where the total integrated energy of heat added or removed from a system happens to stay approximately constant as heat is conducted through the system.

2.2 Electrical resistivity

This is also known as resistivity, specific electrical resistance, or volume resistivity and quantifies how strongly a given material opposes the flow of electric current (Nelkon, 2008). A low resistivity indicates a material that readily allows the movement of electric charge. Resistivity is commonly represented by the Greek letter ρ (rho). The SI unit of electrical resistivity is the ohmmeter (Ω·m) although other units like ohm·centimeter (Ω·cm) are also in use (Nelkon, 2008). As an example, if a 1m×1m×1m solid cube of material has sheet contacts on two opposite faces, and the resistance between these contacts is 1Ω, then the resistivity of the material is 1Ω·m, using the relation that resistivity equals the product of resistance and cross- sectional area divided by its length.

2.3 Electrical conductivity or specific conductance

This is the reciprocal of electrical resistivity, and measures a material's ability to conduct an electric current (Nelkon, 2008). It is commonly represented by the Greek letter σ (sigma), but κ (kappa) (especially in electrical engineering) or γ (gamma) are also occasionally used. Its SI unit is Siemens per meter ($S \cdot m^{-1}$). Many resistors and conductors have a uniform cross section with a uniform flow of electric current and are made of one material. In this case, the electrical resistivity ρ (Greek: rho) is defined mathematically as:

$$\rho = R\frac{A}{\ell},$$

Where

R is the electrical resistance of a uniform specimen of the material (measured in ohms, Ω)

ℓ is the length of the piece of material (measured in meters, m)

A is the cross-sectional area of the specimen (measured in square meters, m^2).

The reason resistivity is defined this way is that it makes resistivity a *material property*, unlike resistance. All copper wires, irrespective of their shape and size, have approximately the same *resistivity*, but a long, thin copper wire has a much larger *resistance* than a thick, short copper wire (Nelkon, 2008). Every material has its own characteristic resistivity – for example, rubber's resistivity is far larger than copper's.

2.4 Specific Heat Capacity, *c*

The specific heat capacity of a substance, *c*, is the amount of energy needed to raise the temperature of 1g of a substance by 1°C (Kumar, 1975). Specific heat capacity is a physical characteristic property. Different substances have different specific heats. Water has a very high specific heat: it takes 4.19 J to raise the temperature of 1 g or 1 ml of water by 1°C. Most metals, on the other hand, have much lower specific heats. Copper's value is only 0.39 J/ (g C). When I get hard boiled eggs ready for breakfast, I sometimes place water in a pot but forget the egg. If I remember within 30 seconds or so, it is still safe to place my hand in the water, but it would be a bad idea to touch the pot itself. Metals warm up faster than water does, so that's what a high specific heat implies: the higher the *c* value, the more difficult it is to warm up that substance (Kumar, 1975). By the same token, high specific heat substances also lose their heat slowly, while metals cool off quickly. The high specific heat capacity of water helps temper the rate at which air changes temperature, which is why temperature changes between seasons is gradual, especially near large lakes or the ocean. Water is the reason why Toronto is milder than Montreal (Kumar, 1975). If water's specific heat was lower than it actually is, life would not be possible. The rate of evaporation would be too high, and it would be too difficult for the evolutionary precursors of cells to maintain homeostasis.

2.5 Heat capacity, or thermal capacity

This is the measurable physical quantity that specifies the amount of heat required to change the temperature of an object or body by a given amount (Nelkon, 2008). The SI unit of heat capacity is joule per kelvin, J/K. Heat capacity is an extensive property of matter, meaning it is proportional to the size of the system. When expressing the same phenomenon as an intensive property, the heat capacity is divided by the amount of substance, mass, or volume, so that the quantity is independent of the size or extent of the sample. The molar heat capacity is the heat capacity per mole of a pure substance and the specific heat capacity, often simply called specific heat, is the heat capacity per unit mass of a material (Nelkon, 2008). Occasionally, in engineering contexts, the volumetric heat capacity is used. Temperature reflects the average randomized kinetic energy of particles in matter, while heat is the transfer of thermal energy across a system boundary into the body or from the body to the environment (Nelkon, 2008).

2.6 Multi –meter

This is a devise used to measure voltage, resistance and current in electronics & electrical equipment (Nelkon, 2008). It is also used to test continuity between to 2 points to verify if there is any break in circuit or line. There are two types of meter namely Analog & Digital multi- meter. Analog has a needle style gauge while Digital has an LCD display.

2.7 Measuring Voltage

Voltage (V) is the unit of electrical pressure; one volt is the potential difference needed to cause one amp of current to pass through one ohm of resistance as verified by Ohm (Nelkon, 2008). Voltage is broke up into 2 sections AC & DC. Alternating Current (AC) is house voltage (220v-ac) while direct current (DC) is battery voltage (12v-dc). On switched meters, use one value higher than your expected value, be very careful to not touch any other electronic components within the equipment and do not touch the tips to each other while connected to anything else to measure voltage connect the leads in parallel between the two points where the measurement is to be made. The multi- meter provides a parallel pathway so it needs to be of a high resistance to allow as little current flow through it as much as possible.

2.8 Measuring current

Current in ampere is the flow of electrical charge though a component or conductor (Nelkon, 2008). Current is measured in amps or amperes. Disconnect power source before testing, disconnect completed circuit at end of circuit, place multi-meter in series with circuit, reconnect power source and turn ON and select highest current setting and work your way down.

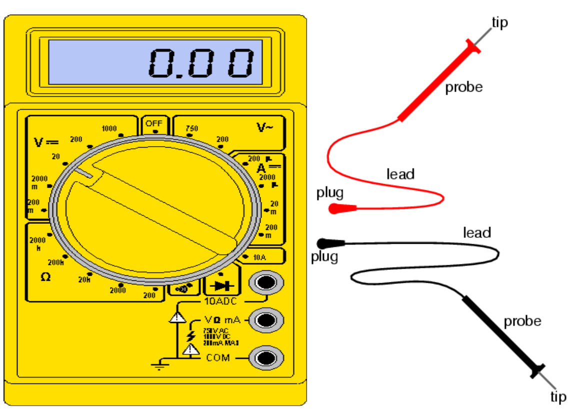

Plate 3: Multi- meter

APPARATUS AND MATERIALS USED

- Cylindrical slabs made of copper or brass for conduction
- Retort stand, stop clock, conveyor pipe, thermocouple, beam balance
- Cork, veneer caliper, electrical wire,
- Boss head
- Threads for suspension
- 2 thermometers
- Source of heat(switching device or Bunsen burner)
- Steam conical chamber

Plate 4: Photograph of thermal and electrical conductivity measurement setup

3.0 METHODOLOGY

Laterite, clay, and sand samples were taken from three different locations in Ota at a depth of about 0.8meters. Close to 0.018kg of each sample was dried, crushed, sieved and then molded into cylindrical shapes of about 9.5mm diameter and about 6.3mm in thickness. Lee's Disc apparatus was set up as shown in figure 1with thermometers in separate holes in slabs A and B. The apparatus was divided into three parts namely: heat generation section, sample chamber and electrical determination section. The heat generation section has a heat conducting container with conical shape. The container was filled with some amount of water, it then undergoes heat until it boils and gives off steam. A valve was then opened to allow the passage of steam into the chamber containing the molded sample.

The steam was passed into the chamber to allow the heat to reach the sample and the temperatures in and out of specimen were determined at regular intervals of time. Temperatures Θ_1 and Θ_2 from sample chamber at steady state at about 30seconds were taken. This is the temperature at which heat gained by the specimen from slab A equals the heat loss by the specimen to slab B. Thermometers T_1 and T_2 are interchanged at steady state and then recorded. Cylindrical slab A is then removed and a Bunsen flame is applied at the slab surface until T_2 recorded the temperature up to 15°C higher than the temperature at the steady state. Temperatures were taken at 30seconds interval until the temperatures also fall to about 15°C. The temperatures are recorded at interval of 30 seconds to have about six set of values obtained from the test. The result obtained by drawing a tangent to the cooling curve at Θ_2 is used to determine the thermal conductivity of the specimens.

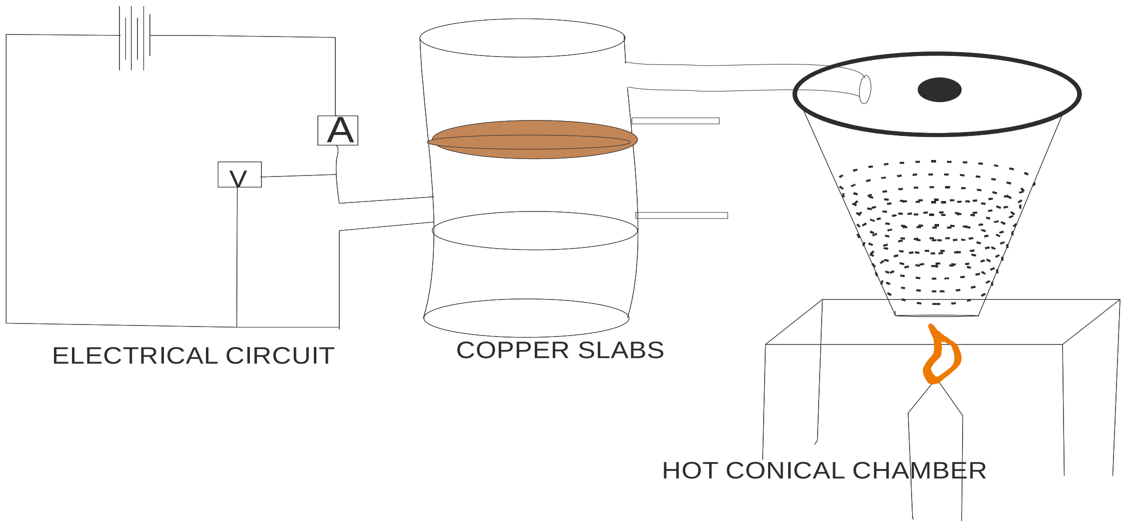

Figure 1- Experimental set up

The rate at which heat is conducted across the specimen is expressed by (Tyler, 1975) as:

$$Q = K \frac{\pi D^2}{4} \frac{(\theta_1 - \theta_2)}{d}$$

While the rate of loss of heat from the lower face and the sides of slab B is:

$$Q = mc\ (d\theta\ /dt)_2$$

$$\text{Therefore } K = \frac{mc\ (d\theta/dt)}{\pi D^2\ (\theta_1 - \theta_2)/4d}$$

Where,

- K is the apparent thermal conductivity in watts per mk

- D is the diameter of the specimen
- d is the thickness of the specimen
- Θ_1 and Θ_2 are steady state temperatures from thermometers T_1 and T_2
- m gives mass of sample
- c is the specific heat capacity of copper slab
- t is the time taken during heat gained and heat loss
- $\pi D^2/4$ is the cross-sectional area of the specimen
- veneer caliper
- micrometer screw gauge
- beam balance
- stopwatch

Hence, equating the two equations above and substituting their values we have β= 1/k also called thermal resistivity with mk/watt as its unit. The multi-meter is used to determine the amount of current and voltage in the experiment thereby calculating the resistance value. Using ohm's law which states that V= IR and β=RA/d where V, I, R, β, A and d are the voltage, current, resistance, resistivity, area and thickness respectively.

Plate 5: A photograph showing preparation of samples for the test

4.0 OUTCOMES AND CONSIDERATION

Table 1- table showing temperatures against time for each sample

[redacted]	0s	30s	60s	90s	120s	150s
	82.00	80.00	78.00	76.00	75.00	74.00
	84.00	82.00	80.00	78.00	76.00	75.00
	98.00	97.00	96.00	95.00	94.00	93.00
	95.00	94.00	93.00	92.00	91.00	90.00
	97.00	93.00	89.00	85.00	81.00	77.00
	95.00	92.00	89.00	86.00	83.00	80.00

Different samples taken from Ota town have gone through laboratory test and their thermal conductivities have been determined with a view to ascertain their potency in building applications. Table 1 above reveals their cooling temperatures with time of slab A with the samples. Comparing the rates of cooling of the samples in the cylindrical slab A, the results show that at regular interval of 30secs, the absorbed power of heat is directly proportional to the power of emission of heat by the samples. It can be deduced from the results that buildings constructed with laterite materials are subjected to low temperature fluctuations which could make building to stand the test of time. Sand materials have a relatively higher temperature fluctuation compared with that of laterites. Clay materials have the highest temperature fluctuations in all and most likely are instrumental to the gradual weakening of building materials. This is confirmed by (Milkin, 1980) that high daily temperature fluctuations cause thermal movement in materials thus weakening them. The thermal conductivity and resistivity of the samples are determined and shown in Table 2. Thermal conductivities are obtained using the rate of cooling of cylindrical slab A with the samples, the mass, thickness, diameters of each sample, temperatures and specific heat capacity of copper.

Using the model obtained above by Tyler in 2009 and putting all the values, thermal conductivity K can be calculated. Using sand 1 as an example

$\pi = 3.142$

Diameter (D) of the sample= 9.5mm

$\Theta_1=82°C$, $\Theta_2=80°C$

Thickness (I) =6.3mm

Mass (m) = 0.018kg

Specific heat capacity of copper= 400Jkg^{-1}k^{-1}

$d\Theta/dt$= slope from the graph

$K=8.5 \times 10^1 kgms^{-2}\Theta^{-1}$

The calculated values of the thermal conductivities of each sample reveal the extent at which they transfer heat absorbed by them. The results show that the greatest thermal conductivity of 1.07 x10^{1}kgms$^{-2}\Theta^{-1}$was obtained for gray clay, a value of 1.06 x 10^2 kgms$^{-2}\Theta^{-1}$ for white clay, a value of 8.5 x 10^{1}kgms$^{-2}\Theta^{-1}$ for sand 1, a value of 9.6 x 10^{1}kgms$^{-2}\Theta^{-1}$was obtained for sand 2 sample, a value 3.6 x 10^{1}kgms$^{-2}\Theta^{-1}$was obtained for laterite 1 and a value of $3.5 \times 10^{1} kgms^{-2}\Theta^{-1}$ for laterite 2. It therefore indicates that laterites are better insulating material for housing projects because of their lowest thermal conductivities while clay materials conduct heat at the highest rate and their absorbent power takes a longer period to reach the steady state.

Table 2– Calculated thermal conductivities for different samples

SAMPLES	THERMAL CONDUCTIVITY ($kgms^{-2}\Theta^{-1}$)	RESISTIVITY(Ωm)
SAND 1	$8.5 \times 10^{1} kgms^{-2}\Theta^{-1}$	0.0258
SAND 2	$9.6 \times 10^{1} kgms^{-2}\Theta^{-1}$	0.0251
LATERITE 1	$3.6 \times 10^{1} kgms^{-2}\Theta^{-1}$	0.0331
LATERITE 2	$3.5 \times 10^{1} kgms^{-2}\Theta^{-1}$	0.0337
GREY CLAY	$1.07 \times 10^{2}\ kgms^{-2}\Theta^{-1}$	0.0181
WHITE CLAY	$1.06 \times 10^{2}\ kgms^{-2}\Theta^{-1}$	0.0184

The law of floatation which states that high density objects sink in water and low density ones float on water (Nelkon, 2008) was used to determine the degree of sedimentation of the samples. The sand samples settled faster in water than other samples while the clay settled much slower than others. The multi-meter values of current and voltage were used to determine the resistivity of each sample. Laterite samples have highest resistivity value of 0.0337Ωm, followed by sand samples of resistivity value of 0.0258Ωm. It was noticed that the clay samples have the least value of 0.0184Ωm. In view of the above result, it will be appropriate to discuss the effects of resistivity on these samples. It will also be of great importance to differentiate between resistance and resistivity. Resistance is generally the value of the opposition to the flow of electric current in ohms while resistivity is the quality of a material to oppose the flow of current (Nelkon, 2008). The higher the objects resistivity, the less electricity will be flowing through. Resistance is a value while resistivity is a quality. Resistance is specific to a particular item while resistivity is common to all forms of a particular temperature; everything made of that material at that temperature has the same resistivity (Nelkon, 2008). The resistivity value for laterite sample indicates that the smallest amount of current is passed through it when compared with others. Also, clay will allow the highest amount of current to pass through due to its low resistivity value. It further suggests that laterites samples have a negligible amount of salt content when compared with others. This confirms the law that the lower the salt content, the lower the electrical conductivity (Nelkon, 2008). The greatest resistivity value of laterites shows that inhabitants living in houses built with laterites stand a chance of not experiencing high flow of electric current during hot and cold weathers.

The thermal conductivities according to the table reveal that laterites samples have the lowest thermal conductivity while clay samples have the highest. This is an indication that laterites are heat insulating material.

To calculate resistivity of the samples:

$\rho = R\frac{A}{\ell}$, Where R is resistance in ohms, A is the area in square meters and L is the thickness in meters.

GRAPHICAL ILLUSTRATIONS OF SAMPLES TEMPERATURES AGAINST TIME.

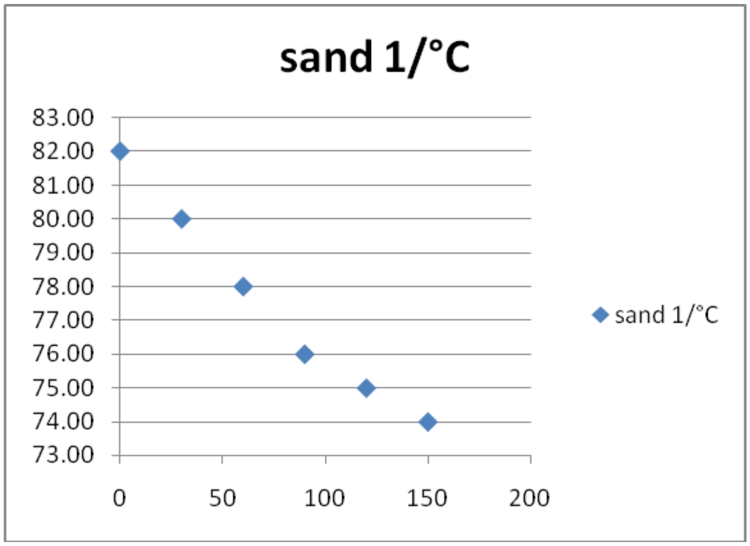

FIGURE 1- Graph of Sand 1(°C) against time (seconds)

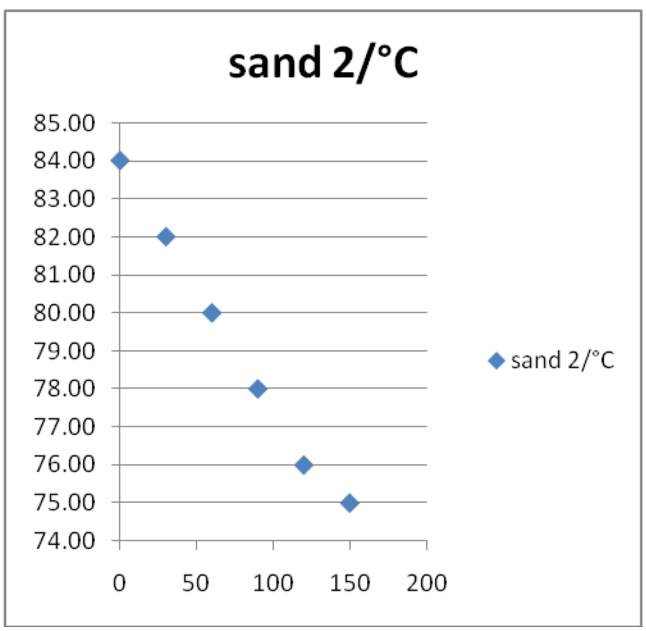

FIGURE 2- Graph of Sand 2(°C) against time(seconds)

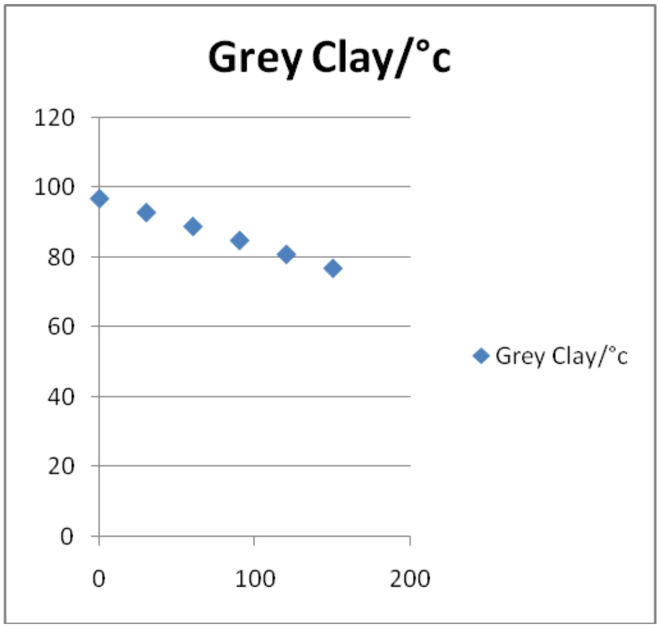

FIGURE 3- Graph of laterite 1(°C) against time (seconds)

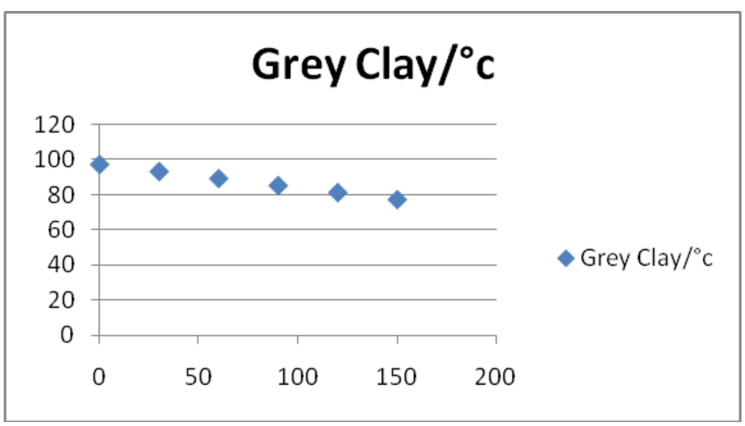

FIGURE 4- Graph of laterite 2(°C) against time (seconds)

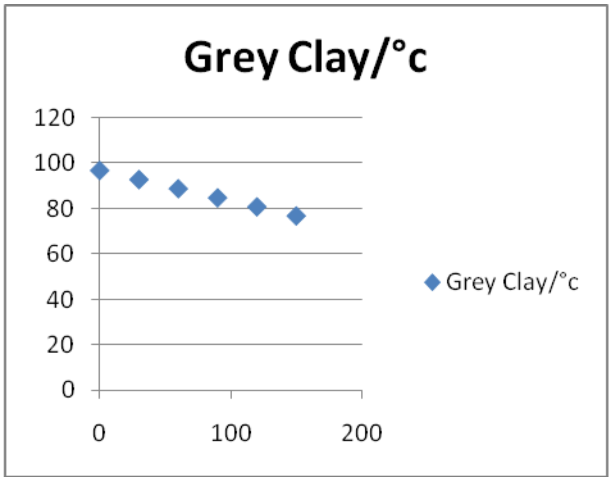

FIGURE 5- Graph of Grey Clay (°C) against time (seconds)

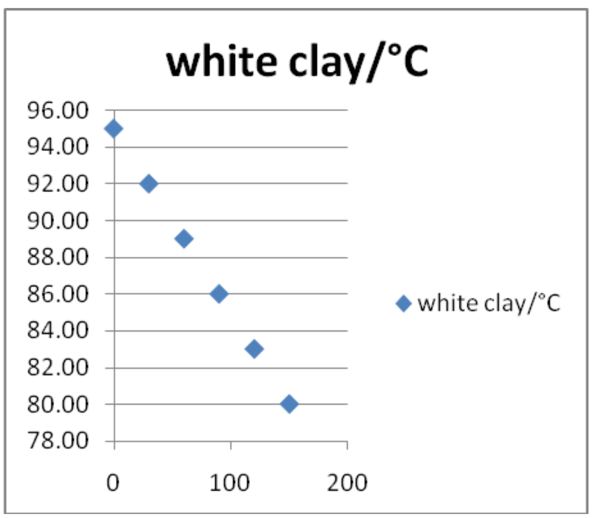

FIGURE 6- Graph of white Clay (°C) against time (seconds)

The graphs from figure 1 to 6 show the cooling curves of temperature against time reveal that Laterite samples have the most uniform graph of temperatures against time while clay has the least. This indicates that in times of heat or cold laterites have the greatest tendency of regulating the temperature to favor inhabitants while other samples do not have such ability to regulate temperatures.

5.0 INDUSTRIAL APPLICATIONS OF THE RESULT

In Nigeria, laterite based materials are currently emerging as a new generation of building materials. The electrical and thermal conductivity of laterites show they can easily withstand high current and intense heat much more than clay and sand. Laterites have the highest resistivity value showing the greatest quality not to carry high current during the year. The thermal conductivity of laterite also shows that heat fluctuations in such buildings are quite small and that the low thermal conductivity of laterites shows they serve as heat insulating material for buildings. Base on the above premise, laterite materials for buildings in the tropic have a high electrical resistance and they should thus be used as local building material. Besides, clay and sand samples could be used in the production of pipes, roof tiles and interior floor where the heat conductivity is of secondary concern. Lastly, laterites are known to be generally accessible, affordable and of low cost of production in building applications.

6.0 CONCLUSION

Laterites are complex materials of practical and academic interest because of their variety of applications in construction industries and engineering fields. In this study the thermal and electrical properties of samples of laterite, clay and sand are analyzed. The results have revealed that these samples have different values of thermal conductivity and rate of cooling. This is shown in Tables 1 and 2 above. Also, laterites have some characteristics that make it suitable for local building in the tropic. The study provides useful information on the determination of thermal and electrical properties to ascertain which of the samples under test has higher conductivity and predict the sample type that is suitable in the production of other building materials. This study has shown that laterite samples have the lowest thermal conductivity and emissive power while the white clay samples have the highest thermal conductivity and emissive power. Laterites have the highest resistivity which is an indication that only small amount of current flows through such buildings. This paper should be an eye opener for builders, architects and engineers to determine the most suitable materials for their building work and also for factories and manufacturing companies where heat is a major tool for production.

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