

CHARACTERIZATION OF THERMAL PROPERTIES BEHAVIOUR OF CLAY IN EKITI
STATE, SOUTH WESTERN NIGERIA

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Abstract: Thermal quality of material is a useful property in building engineering. Today we deal with increasing requirements for quality of brick products, particularly in terms of thermal properties. These characteristics of products depend on many factors, such as conductivity. This paper presents results of the thermal properties of clay slabs, sampled at five different locations in Ekiti state. KD2 probe was used to determine the thermal properties of the slabs. Thermal conductivity, thermal diffusivity and specific heat capacity range from 0.12 to 0.17 W/mK; 6.62 to 10.9 m²/s and 8.5x10³ to 9.85x10³ J/kgK, respectively. The results are useful data for builders and agriculturists.

Key words: Thermal quality, brick products, thermal diffusivity, clay slabs.

1. Introduction

Each material has a characteristic rate at which heat will flow through it. The faster heat flows through a material, the more conductive it is. Clay is a special earth material with high content of ions. Its high ion exchange capacity might affect the amount of heat energy that flow through it. Conductivity is a material property given for homogeneous solids under steady state conditions. This property is important in the study of heat transfer, thus determining the values are vital in building engineering and agriculture. Determination of thermal properties of rocks using block method was examined and reported [1]. Long term systematic studies are also done on the influence of the structural morphology of a material in order to highlight the value of thermal conductivity [2]. Some studies have identified to a marked degree those factors which singly or in combination are of the greatest significance in the improvement of the overall thermal insulation capacity of a wall constructed from hollow bricks by increasing the cavity height in respect to its width [3,4].

Thermal properties of many agricultural and food products have been reported in the literature, and most of these data are compiled [5] and [6] for engineering research and design purposes. The thermal property data of clay in Ekiti state is not, however, available in the literature despite the fact that clay in this location is used in making pot or industry. Therefore, this research aims at presenting thermal characteristics of some locations in southwestern Nigeria.

Theoretical background of thermal conductivity

Generally, there are a number of ways to measure thermal conductivity; each of them is suitable for a limited range of materials, depending on the thermal properties and the medium temperature. There are different methods by which thermal properties of materials can be measured; steady-state and transient techniques.

i) Steady- state techniques: These perform measurement when the temperature of the material that is measured does not change with time. It makes the signal analysis straight forward (steady state implies constant signals). The steady-state techniques give only the thermal conductivity. The disadvantage of this method is that it is a well-engineered experimental set up.

ii) Transient techniques: These perform measurement during the process of heating up. The advantage is that measurements can be made relatively quickly. Transient methods are usually carried out by needle probes (inserted into samples or plunged into the ocean floor). This method gives either or both thermal conductivity and thermal diffusivity[7]. This method was employed in this research work.

Other methods used for measuring thermal conductivity are:

Divided Bar method (of various types) is the most common device used for consolidated rock samples [8].

Single probe method is based on the solution of the heat conduction for a line heat source in a homogeneous and isotropic medium, at a uniform initial temperature [9].

Derivation of heat equation (Using Divergence Theorem)

Physical experiments show that the rate of flow of heat is proportional to the gradient of the temperature. This means that the velocity, V of the heat flow in a body is expressed in the form

$$V = -K \text{ grad } U \quad (1)$$

Where $U(x,y,z,t)$ is temperature, t is time and K is called the thermal conductivity of the body (i.e K is a constant)

Using the above information, mathematical model can be set up for heat flow (heat equation).

Let T be a region in the body and S be its bounding surface. Then the amount of heat leaving per unit time is

$$\iint_S \mathbf{v} \cdot \mathbf{n} \, dA \quad (2)$$

Where $\mathbf{v} \cdot \mathbf{n}$ is the component of $\mathbf{v}$ in the direction of the outer unit normal vector $\mathbf{n}$ of S .

From (23) and the divergence theorem, we obtain

$$\iint_S \mathbf{v} \cdot \mathbf{n} \, dA = -k \iiint_T \text{div}(\text{gradu}) \, dx \, dy \, dz = -k \iiint_T \nabla^2 u \, dx \, dy \, dz \quad (3)$$

Where $\nabla^2 u = u_{xx} + u_{yy} + u_{zz}$ is the Laplacian of u . $\iint_S v \cdot n dA$

On the other hand, the total amount of heat H is

$$H = \iiint_V c \rho u dx dy dz \quad (4)$$

Where the constant c is the specific heat of the material of the body and ρ is the density (mass per unit volume) of the material.

Hence the time rate of decrease of H is

$$-\frac{dH}{dt} = -\iiint_V c \rho \frac{\partial u}{\partial t} dx dy dz \quad (5)$$

And this is equal to the above amount of heat leaving T .

From (24), we thus have

$$-\iiint_V c \rho \frac{\partial u}{\partial t} dx dy dz = -k \iiint_V \nabla^2 u dx dy dz$$

Simply

$$\iiint_V (c \rho \frac{\partial u}{\partial t} - k \nabla^2 u) dx dy dz = 0 \quad (6)$$

Since this holds for any region T in the body, the integrand, if (continuous), must be zero everywhere. Therefore (6) becomes

$$c \rho \frac{\partial u}{\partial t} = k \nabla^2 u$$

$$\frac{\partial u}{\partial t} = \left(\frac{k}{c \rho}\right) \nabla^2 u$$

$$\frac{\partial u}{\partial t} = \alpha^2 \nabla^2 u \quad (7)$$

$$\text{But } \sigma^2 = \frac{k}{c \rho} = \alpha$$

Where α is a constant (called thermal diffusivity) of the material while the partial differential equation is called the heat equation.

For one dimensional heat equation, we have

$$\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2} \quad (8)$$

Specific Heat Capacity

The amount of heat required to increase the temperature of 1g of material by 1°C is referred to as specific heat capacity. In other words, the specific heat capacity of a substance is the quantity of heat required to raise the temperature of unit mass (in kg) of the substance through unit temperature (in °C or K).

The specific heat capacity can also be defined as the amount of energy required to raise a unit mass of material by one unit of temperature at constant pressures. The equation governing this expression or statement is given as

$$c = \frac{Q}{m\Delta T} \quad (9)$$

Where c is the specific heat capacity, m is the mass of the substance, ΔT is the change in temperature and Q is the amount of heat energy taken by the substance.

The S.I unit specific heat capacity is $\text{Jkg}^{-1}\text{K}^{-1}$.

Thermal Diffusivity

Thermal diffusivity is a measure of how quick a body can change its temperature. It increases with the ability of a body to conduct heat (i.e thermal conductivity) and it decreases with the amount of heat needed to change the temperature of a body (i.e specific heat capacity).

According to the McGraw-Hill, thermal diffusivity is the quantity of heat passing normally through a unit area per unit time divided by the product of specific heat, density and temperature gradient transient. Its unit is m^2/s .

Thermal diffusivity is the way heat flow through materials to the other side and can be expressed as the rate of change of temperature in a transient heat transfer process [10]. The equation is given as follow:

$$\lambda = \frac{k}{\rho c} \quad (10)$$

Where λ = thermal diffusivity

K = thermal conductivity in W/mk

ρ = density in kgm^{-3}

C = specific heat capacity in $\text{Jkg}^{-1}\text{k}^{-1}$

Materials and Methods

Samples were collected from five different locations in Ekiti State-Ire (S1), Isan (S2), Orin (S3), Ara Ijero I (S4) and Ara Ijero ii (S5). The study area lies within latitudes $7^{\circ}23'$ and $7^{\circ}52'N$ and longitudes $4^{\circ}58'$ and $5^{\circ}31'E$, covering about 534 km^2) in the Southwestern sector of the Nigerian Basement Complex which formed the southern part of the Trans-Saharan mobile belt of Neoproterozoic (750 - 500Ma) age [11]. Clay, as collected from the deposit was soaked in de-ionized water and deleterious particles were separated by gravity sedimentation. Thereafter, the clay samples were sun dried for three days then placed inside the oven and further dried for a period of eight hours at a temperature of 500°C .

The dried clay was finally crushed down to smaller sizes and subsequently ground to fine sizes using the laboratory crusher and the ball mills respectively. It was then sieved. The sieved clay was mixed with de-ionized water and slabs of dimensions $4 \times 4 \times 1 \text{ cm}$ were formed. These set of slabs were dried and thermal property determined.

The measurements of thermal conductivity and thermal diffusivity were performed with a KD2 Thermal Analyzer instrument which is based on the transient hot-wire technique [12, 13]. Steady-state methods are not adequate to measure the thermal conductivity and thermal diffusivity of a clay brick, because the sample may experience desiccation during the long equilibration times required. In contrast, the transient hot-wire technique is most adequate, since it allows for an almost instantaneous measurement of thermal conductivity and thermal diffusivity, so that the resulting values can be unambiguously ascribed to the water content with which the clay brick was prepared.

The KD2 Pro allows an automated mode where the reading is displayed directly or a manual mode that can download the raw values from each reading for further analysis with a spreadsheet program as required by IEEE (Institute of Electrical and Electronic Engineering) and ASTM (American Society for Testing and Materials) standards. The governing equation for this instrument [14] is represented as:

$$\frac{dT}{dt} = \alpha \left(\frac{d^2T}{dr^2} + r^{-1} \frac{dT}{dr} \right) \quad (11)$$

where r is the radial distance (m), T is the temperature ($^{\circ}\text{C}$), α is the thermal diffusivity (m^2/s), and t is the time (s).

During measurements, the 60 mm long probe was put into the samples and the in-built microprocessor ensures temperature stability within 90 s before heating the probe for 30 s. Thermal conductivity and thermal diffusivity of the clay slab/brick were measured from the temperature rise before instantaneous display of results while specific heat capacity was calculated from the data obtained.

Results and Discussion

The thermal conductivity, thermal diffusivity and specific heat capacity values for natural clay collected from S1, S2, S3, S4 and S5, respectively are presented on Table 1. The measured results showed appreciable difference in their thermal behaviour.

Figure 1 showed relationship between thermal conductivity and location where samples were collected. There is significant variation in their thermal properties.. S1 has the highest value of thermal conductivity, followed by S2, next by S4 and the least value from S4. Figures 2 present relationship between thermal diffusivity and corresponding locations. The behaviour of these thermal properties is a factor to determine which of the locations is good for building.

Table 1: Thermal conductivity, Thermal diffusivity and Specific heat capacity of clay samples at 6400ppm when lead nitrate solution was added.

Location	Thermal conductivity W/mK	Thermal diffusivity m^2s^{-1}	Specific heat capacity $\times 10^{-3} \text{ Jkg}^{-1}\text{k}^{-1}$
S1	0.169	9.29	9.85
S2	0.148	6.62	12.2
S3	0.159	10.9	5.43
S4	0.118	9.91	8.53
S5	0.129	8.24	8.50

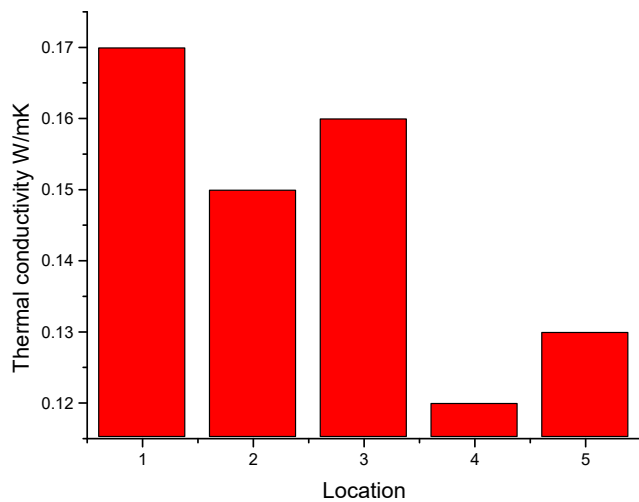


Figure 1: Thermal conductivity against sample location

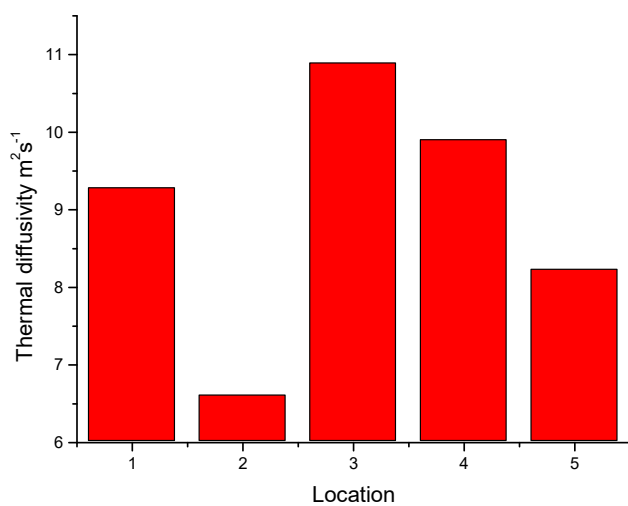


Figure 2: Thermal diffusivity against sample location

Conclusion

The study investigated the thermal characteristics of clay in different locations from Ekiti state. Clay from S2 had the least thermal diffusivity next by S5 and the S3 had the highest. In respect with thermal conductivity S4 has the least followed by S5 and S1 is the highest. The thermal conductivity of clay in all locations are relatively low (approximately, 0.14). In the light of this results, clay in these locations is preferable in building of houses and therefore recommended.

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