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Determination of Thermal Conductivity of Interlocking Compressed Stabilized Earth Block (CSEB)

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Abstract: Over the years, the Nigerian Building and Road Research Institute (NBRRI) has been involved in the research and development of an interlocking Compressed Stabilized Earth Block (CSEB), produced from laterite stabilized with cement of not less than 5% weight using a minimum compaction effort of 3N/mm^2. This investigation concerned itself with the determination of Thermal Conductivity of the NBRRI interlocking CSEB with the aim of ascertaining its performance for a wide range of application such as its Thermal comfort for the building occupants when in used towards achieving sustainability in construction. Several laboratory and workshop activities were carried out in the formulation, molding, curing and testing of the Blocks using standard procedures. Geotechnical properties of the laterite showed a Plastic Limit (PL) of 33.06, Liquid Limit (LL) of 59.00 and Plasticity Index (PI) of 25.94. The laterite is classified as silty sand, while at 5% stabilization of the laterite, the blocks proved to have an average Coefficient of Thermal Conductivity (k_{avg}) of 0.4841 Wm^{-1}K^{-1}. Therefore, NBRRI CSEB can be concluded to be environmentally friendly and energy efficient walling material.

Keywords: Laterite, Thermal Conductivity, CSEB, NBRRI

1. Introduction

Several concerns such as climate change and resource depletion are continually being raised with regards to construction posing serious environmental challenges and also using up more than its fair share of resources. Therefore the development of alternative indigenous building materials that can mitigate these challenges became necessary. In that light, the Nigerian Building and Road Research Institute (NBRRI) undertook research and development of an interlocking Compressed Stabilized Earth Block (CSEB) technology to address some of these challenges in the Building Construction sector of Nigeria. These Blocks are produced from laterite stabilized by cement of not less than 5% by weight using a minimum compaction effort of 3N/mm^2.

From time immemorial man has always been in the business of using earth (soil) as a construction material. Earth is an effective, economical and most abundant construction material available for housing globally [1]. The earth blocks technology has been utilized in housing one-third of the world's population [2]. [3] also agreed that 30% of the world's population lives in homes constructed of earth. Earth building techniques was commonly used in Nigeria until the influx of Portland cement into the country after independence when sandcrete wall construction became common.

A Compressed Earth Block (CEB) also known as a pressed earth or compressed soil is a building material made primarily from damp soil compressed at high pressure to form a block. CEBs use mechanical press to form, out of an appropriate mix of fairly moist inorganic subsoil, non-expansive clay and aggregate. If they are stabilized with a chemical binder such as Portland cement, they are called Compressed Stabilized Earth Blocks (CSEBs) or Stabilized Earth Blocks (SEBs). Typically, around 21MPa is applied in compression, and the original soil volume is reduced by about half [4].

In order to ensure that Earth Blocks obtain thermal comfort in the building, special attention must be given to the earth material which is used to build thermally comfortable structures. It is one of the most important and most common in the world, it is suitable as building material and has low thermal properties, and the compressed earth blocks are model for that [5]. To confirm the foregoing assertion, this particular research was aimed to carry out an investigation of the Thermal Conductivity of NBRRI CSEB technology to give the respective indices for the level of thermal comfort for building occupants by first characterizing the laterite obtained.

2. Materials And Methods

This section includes the primary materials/equipment used and the methods employed for this investigation.

2.1 Materials

The primary materials used in this work included: cement, water and laterite which was locally sourced in Jos – Plateau State. These materials were what were used in molding the blocks CESBs.

2.2 Equipment

The equipment used for this investigation includes set of Sieves (BS: EL 79), Semi-Automated Block Machine Machine design and constructed by NBRRI, weighing Balance (11-D0630/06), Measuring Cylinder (LG-5510-108), Compressive Strength Testing Machine (ELE International 2000kN Capacity), Thermometer Thermocouple (4-Channel K-Type Digital LCD), Digital Caliper, Cone Penetrometer and Lee's Disc Apparatus.

2.3 Methods

2.3.1 Physical Properties Tests of Laterite Sample

A repeated Cone and Quartering procedure was carried out on the laterite sample discarding two opposite quarters to ensure homogeneity, until the desired amount of sample for the tests were obtained [6].

Physical properties tests were carried out on the Laterite (soil) sample which included: Sieve Analysis to determine the particle size distribution; Atterberg limits tests (i.e. liquid and plastic limits) to determine the plastic index of the soil sample and was carried out in accordance to the specifications of BS 1377 [7].

The particle size distribution was determined by washing 2001.8g of the Laterite sample in the BS/ISO 3310 Sieve Size 0.075mm and then oven dried. The dry sample was manually shook downward through a set standard sieves for about 10 minutes. The amount of sand remaining on each sieve was weighed, and the weights were used to compute the grain size distribution. All tests procedures were carried out in accordance with the established British Standards (BS) and African Regional Organization for Standardization (ARSO) ARS 683:1996 [8].

2.3.2 Block Molding

The laterite was prepared by sieving it through BS/ISO 3310 Sieve Size 5mm to remove gravel, lumps of clay and some organic materials etc. Then the sieved laterite was mixed with cement at the ratio of 19:1 respectively. To achieve the desired satisfactory mixing, the laterite was spread in a thin layer and covered with another thinner layer of the cement before it was thoroughly mixed until the mixture attained a uniform colour. The mixture was sprinkled with water and mixed further for homogeneity. The adequacy of moisture was checked severally by squeezing the mixture within the palm to produce balls. Water was continually added until when balls were able to form but without having the soil sticking to the palm. The stabilized soil was then fed into the NBRRI Semi- Automated Machine and compressed at 20MPa. The produced Blocks were then cured for 21 days [6], [9], [10].

Plate 1: Extrusion of Blocks from the Machine

Plate 2: Stacking of NBRRI Blocks for Curing

2.3.3 Thermal Conductivity Test

The Lee's Disc Method was employed for the determination of the Thermal Conductivity of the NBRRI Interlocking CSEB [11].

Plate 3: Determination of Cooling Rate using Lee's Disc Apparatus

3. Results And Discussion

3.1 Physical Characterization of Laterite

3.1.1 Particle Size Distribution

Table 1 and Figure 1 below show the result of the Particle Size Distribution Test and the Particle Size Distribution Curve respectively.

Table 1: Particle Size Distribution Test Results

Sieve Size (mm)	*Mass Retained*	*Percentage Retained*	*Percentage Passing*
20	0.00	0.00	100.00
14	16.89	3.35	96.65
10	8.32	1.65	95.00
6.3	20.33	4.03	90.97
5	7.93	1.57	89.39
3.35	14.80	2.94	86.46
2.36	17.35	3.44	83.02
2	6.75	1.34	81.68
1.18	45.97	9.12	72.56
0.6	62.89	12.48	60.08
0.425	26.73	5.30	54.78
0.3	21.97	4.36	50.42

0.212	19.10	3.79	46.63
0.15	13.60	2.70	43.93
0.075	16.04	3.18	40.75
0	205.43	40.75	0.00

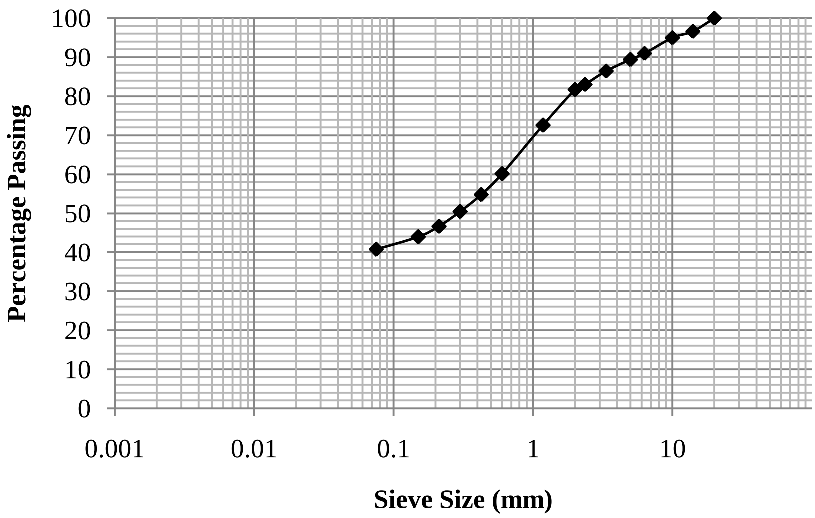

Figure 1: Particle Size Distribution Curve

Particle size distribution, also known as gradation as shown in Table 1, refers to the proportions by dry mass of a soil distributed over specified particle-size ranges. Gradation of soil is used to classify soils for engineering and agricultural purposes, since particle size influences how fast or slow water or other fluid moves through a soil [12]. From Fig. 1, it can be concluded that the laterite is well graded [13]. A well graded soil has higher compressibility than poorly graded soil. That means the laterite has fewer voids and is suitable to be used as CSEB material.

3.1.2 Atterberg Limit Test

The following results present the behaviour of soil at varying moisture content enabling the classification of the soil used for the investigation.

Table 2: Plasticity Index

LIQUID LIMIT					
Test No	1	2	3	4	5
Cone Penetration (mm)	12.61	16.98	18.9	23.21	27.95
Mass of Can (g)	26.58	18.89	19.07	26.88	18.98
Mass of Wet Soil + Can (g)	33.1	28.4	29.49	37.56	36.23
Mass of Dry Soil + Can (g)	30.84	24.96	25.60	33.41	29.27
Mass of Dry Soil (g)	4.26	6.07	6.53	6.53	10.29
Mass of Moisture Loss (g)	2.26	3.44	3.89	4.15	6.96
Moisture Content (%)	53.05	56.67	59.57	63.55	67.64
PLASTIC LIMIT					
Test No	A	B	C	D	E
Mass of Wet Soil + Can (m_2) g	36.10	34.26	24.47	32.45	30.15
Mass of Dry Soil + Can (m_3) g	33.10	31.77	22.78	30.75	29.21
Mass of Can (m_1)	22.66	26.59	18.92	26.65	26.60

Mass of Moisture (m_2-m_3) g	3.00	2.49	1.69	1.70	0.94
Mass of Dry Soil (m_3-m_1) g	10.44	5.18	3.86	4.10	2.61
Moisture Content w=(m_2-m_3)/(m_3-m_1)*100%	28.74	48.07	43.78	41.46	36.02
PLASTIC LIMIT (PL)	33.06				
LIQUID LIMIT (LL)	59.00				
PLASTICITY INDEX (PI) = LL-PL	25.94				

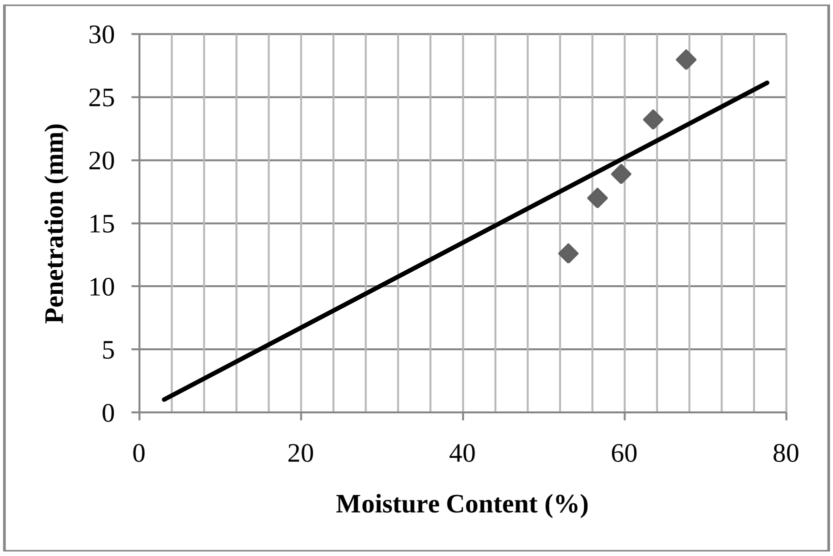

Figure 2: Liquid Limit (LL)

The composition of a particular laterite and its plasticity index affect the laterites suitability for block production. [14] reported that a suitable laterite soil for blocks production would be composed of clay 15-20 percent, contain silt roughly 25-40 percent by volume and roughly 40-70 percent by volume of sharp sand. The soil plasticity is said to depend primarily on the function of the clay content. Soil with Plasticity Index up to 20-30 is suitable for use in the production of building blocks. Based on the Unified Soil Classification System (USCS) [6], the soil has a high Liquid Limit($35< LL<75$) of 59, a Plasticity Index of 25.95 and from the grading curve, the soil consists of 40.75% fines (silt-clay), 48.65% fine/medium/course sand and 10.6% fine gravel. The soil can therefore be said to be predominantly sand with silt and therefore classified as silty SAND.

3.2 Thermal Conductivity Test

k – Coefficient of Thermal Conductivity
D – Diameter of Sample
d – Thickness of Sample
M – Mass of Brass Disc C = 0.9956 kg
C – Specific Heat Capacity of Brass = 380 J/kg^{0}C
R – Slope of Cooling Curve at Mean Temperature at θ_2
θ_1 – Steady Temperature of Brass Base B
θ_2 – Steady Temperature of Brass Base C

$$k \times \frac{\pi D^2}{4} \times \frac{\theta 1 - \theta 2}{d} = MCR$$

$$k = \frac{4dMCR}{(\theta 1 - \theta 2)\pi D^2} \ (Wm^{-1}K^{-1})$$

Table 1: Dimensions of Samples

Sample 1		*Sample 2*	
Diameter, D (mm)	*Thickness, d (mm)*	*Diameter, D (mm)*	*Thickness, d (mm)*
111.74	16.66	110.92	14.88

Table 2: Steady Temperatures Measured Using Two Thermometers

	Sample 1		*Sample 2*	
Temperature (^0C)	θ_1	θ_2	θ_1	θ_2
Before Interchanging	92.4	64.3	92.2	64.0
After Interchanging	92.3	64.4	92.0	64.2
Mean Temperature	92.35	64.35	92.1	64.1

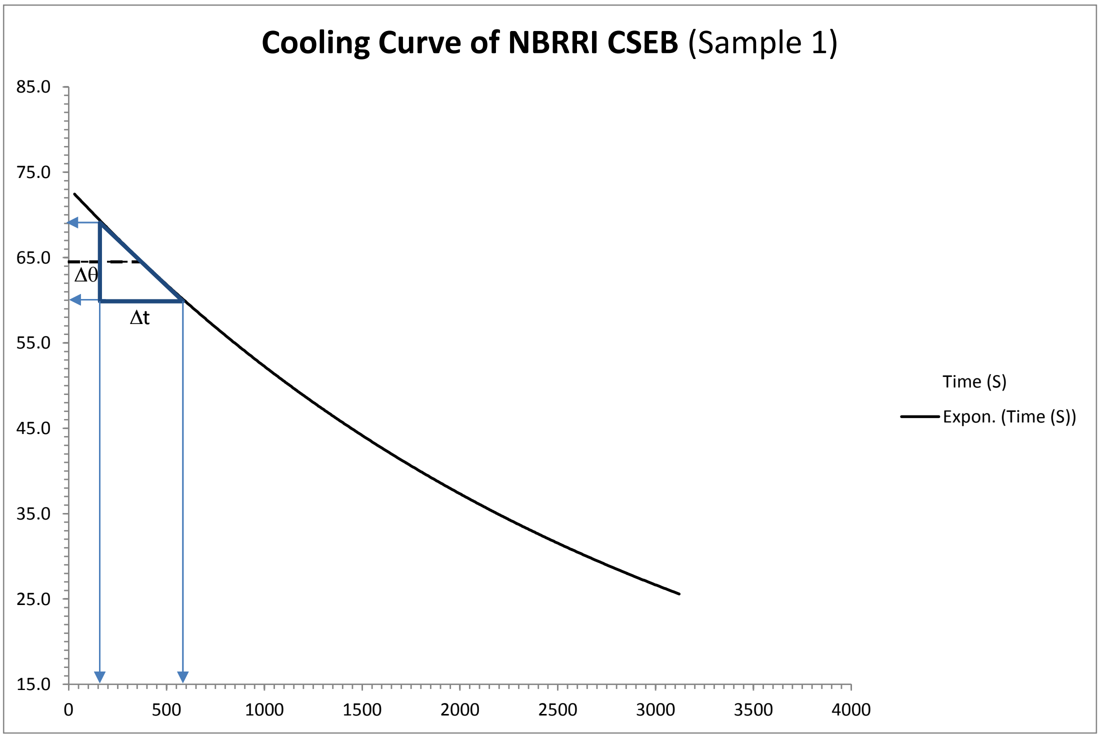

Figure 3: A Plot of Temperature (C) against Time (S)

R_2 from Figure 3 $= \frac{\Delta\theta}{\Delta t} = \frac{69-60}{580-160}$

$= \frac{9}{420}$

$k_1 = \frac{7}{22} \text{ x } 4 \text{ x } \frac{9}{420} \text{ x } \frac{0.01666 \text{ x } 380 \text{ x } 0.9956}{(0.11174)^2 \text{x } 28}$

$\therefore\ k_1 = 0.4916 Wm^{-1}K^{-1}$

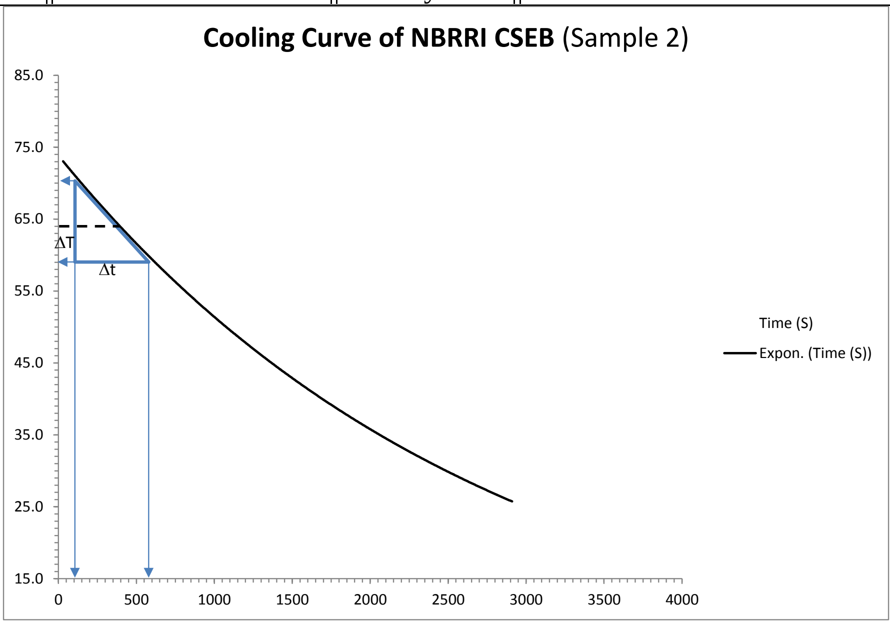

Figure 4: A Plot of Temperature (C) against Time (S)

R_2 from Figure 4 $\frac{\Delta\theta}{\Delta t} = \frac{70-59}{580-100}$

$= \frac{11}{480}$

$k_2 = \frac{7}{22} \text{x } 4 \text{ x } \frac{11}{480} \text{ x } \frac{0.01488 \text{ x } 380 \text{ x } 0.9956}{(0.11092)^2 \text{x } 28}$

$\therefore\ k_2 = 0.4765 Wm^{-1}K^{-1}$

Mean (k_{avg}) $= \frac{k1+k2}{2} = \frac{0.4916+0.4765}{2} = 0.4841 Wm^{-1}K^{-1}$

From the test result obtained above, the coefficient of thermal conductivity of NBRRI CSEB is 0.4841 $Wm^{-1}K^{-1}$. This is a bit higher compare to what was obtained from wood (0.15 - 0.2 $Wm^{-1}K^{-1}$), rubber (0.15 $Wm^{-1}K^{-1}$) and a related CEB of 0.127 $Wm^{-1}K^{-1}$ from Malaysia [15], [16]. Yet, lower than the range of 0.85 – 1.4 $Wm^{-1}K^{-1}$ for concrete, 34.6 $Wm^{-1}K^{-1}$ for Lead and 48.5 $Wm^{-1}K^{-1}$ for mild steel [13]. Therefore, NBRRI CSEB with a Coefficient of Thermal Conductivity of 0.4841 $Wm^{-1}K^{-1}$ is within the best 50th percentile for the range Coefficient of Thermal Conductivity of Building Bricks (0.35 – 0.7) $Wm^{-1}K^{-1}$. This low value of Thermal Conductivity guarantees efficient use of energy and comfort of occupants within a building, as the lower the coefficient value, the best performance of the material in term of thermal conductivity [15].

4. Conclusion

The NBRRI interlocking CSEBs were successfully formulated, moulded and cured according to specified provisions and standards. An average Thermal Conductivity of 0.4841 $Wm^{-1}K^{-1}$was established which clearly makes the NBRRI CSEB an environmentally friendly and energy efficient alternative to conventional concrete which has a Thermal Conductivity of (0.85 – 1.4) $Wm^{-1}K^{-1}$.

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