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Investigating the suitability of selected laterite deposits for bricks and required fired temperature

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Abstract

Seven laterite samples derived from Akure, Ondo, Owo, Oshogbo, Ilesha, Ado-Ekiti and Ijan Ekiti in South-west Nigeria were study for bricks production. Grain size analysis was conducted in accordance with ASTM **(**2007a) D 422-63 and the plot of the soils particle size on the ideal particle size chart adapted from McNally (1998) revealed that Loc.1, Loc.2, and Loc.3 soils can be used for making solid bricks while Loc.6 and Loc.7 soils can be used for none. Unconfined compressive strength and water absorption properties of the laterites were study at 600^{o}C, 700^{o}C, 800 ^{o}C, 900 ^{o}C and 1000 ^{o}C respectively while linear shrinkage was study at 1000 ^{o}C. The unconfined strength of the soils is very high even at 600^{o}C and increased continuously with firing temperature. The linear shrinkage of the soils varies from 1.4 to 13.6 when oven dried but when the soils were fired to 1000^{o}C, the linear shrinkage fall between 0.7 and 4.1. The water absorption capacity of the soils decreased with increased fired temperature. Loc.1, Loc.2, and Loc.3 soils can be used for making solid bricks while Loc.6 and Loc.7 soils can be used for making perforated bricks while others (Loc.4 and Loc.5) can be used for either of the two if properly stabilized (fired above 1000 ^{o}C) and base on the results of the unconfined compressive strength and water absorption capacity; Loc.2 and Loc.7 soils can be used for making bricks if fired at 600^{o}C while Loc.1 soil will be useful for bricks if fired at 900^{o}C while the rest of the laterites will be suitable for bricks if fired at temperature higher than 1000^{o}C.

Keywords: Laterite, bricks, particle size analysis, ideal particle size chart, firing temperature, unconfined compressive strength, water absorption capacity, linear shrinkage.

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1 Introduction

Laterite is abundantly available in the tropical region in which Southwest of Nigeria is located. Lateritic soil when use for engineering constructions reduces the cost of project. Sandcrete blocks constitute important building materials widely used today for walls of our domestic, industrial or commercial buildings but the cost of sancrete blocks continues to increase due to high cost of cement and demand for this material. Laterite bricks were made by the Nigeria Building and Road Research Institute (NBRRI) and used for the construction of a bungalow with cement of 5%, sand of 45% and this resulted in a savings of about 30 – 47% when compared with use of sandcrete blocks (Menasseh and Agbede, 2002). Lateritic soils require no blasting, no crushing unlike rock aggregate, and it can be mined using spade and jigger thus have low mining cost and this resulted in reduction in project cost. Laterites are poorer conductors of heat and so, houses constructed with them are generally cooler than those made with concrete blocks (Ushie and Anike, 2010).
There are different types of bricks: facing, solid and perforated bricks among others. Each structural product has an ideal particle size, in terms of the proportions of sand and coarse silt, fine silt and clay fraction in the body (Reeves *et al*., 2006). In other word, the proportion of sand, coarse silt, fine silt and clay determine the type of product that should be made from the soil. Soil with high percentage of sand and coarse silt is good for making solid bricks while one with high percentage of fine silt is suited for making roofing tiles but soil with very high percentage of clay content is not suited for either bricks or tiles. Soil with reasonable proportion of sand, coarse silt, fine silt and low percentage of clay content is best for perforated bricks. This paper examines laterites properties at different firing temperature. The results obtained will enable the determination of firing temperature required of the selected laterites for bricks production.

Geology of the Sample Localities
The geology of Ondo State consists of two regions: region of sedimentary rocks in the south, and the region of Precambrian Basement Complex rocks in the north. The sedimentary rocks are mainly of the PostCretaceous sediments. The basement complex is mainly of the medium grained gneisses. These are strongly foliated rocks frequently occurring as outcrops.

Osun State is underlain by metamorphic rocks of the basement complex, which outcrop over many parts. Rocks of basement complex found here are schists associated with quartzite ridges found in Ilesha. Other parts of the state are underlain by undifferential metamorphic rocks.

Ekiti State is underlain by metamorphic rocks of the Precambrain basement complex. These basement complex rocks show great variations in grain size and in mineral composition. The rocks are quartz gneisses and schists consisting essentially of quartz with small amounts of white micaceous minerals.

Figure 1 presents the Geological Map of Nigeria showing the study areas and Figure 2 presents the sampling location map showing sample localities.

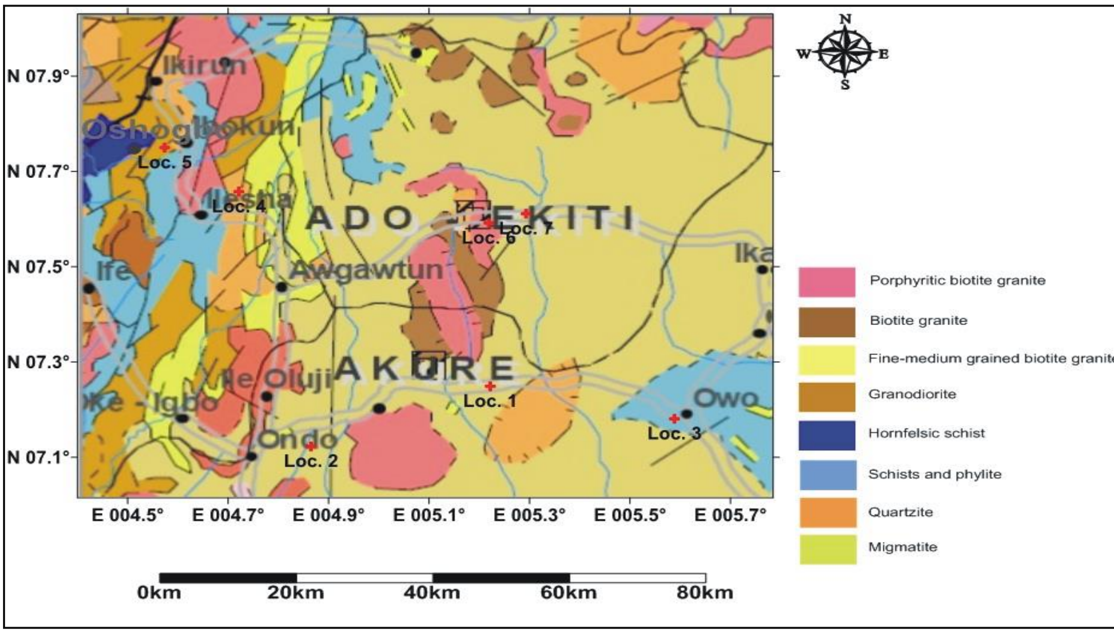

Fig 1: Geological Map of the Study Area

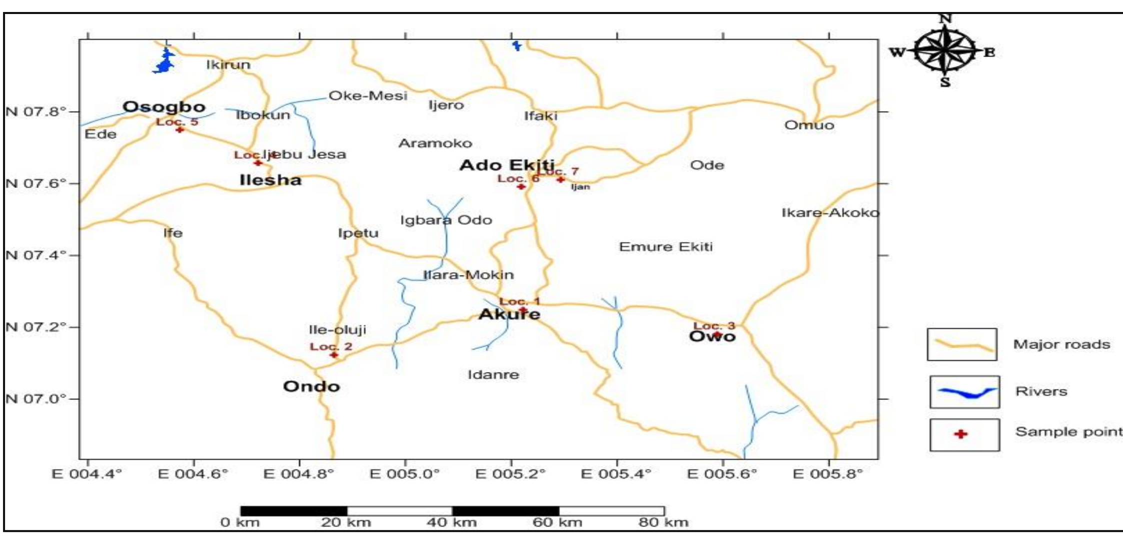

Fig. 2: Sampling Location Map Showing Samples Localities

2 Materials and Methods

2.1 Sampling

The study covers laterite deposits in Ondo, Osun and Ekiti States as representatives of Southwest Nigeria. The coordinates of locations in Ondo state: Akure ($07^0$14.94' N and $5^0$13.32' E); Ondo ($07^0$7.38' N and $04^0$51.9' E) and Owo ($07^0$10.85' N and $05^0$35.32' E); Osun state locations coordinate: Oshogbo ($07^0$44.99' N and $04^0$34.42' E) and Ilesha ($07^0$39.45' N and $04^0$43.29' E); and Ekiti state locations coordinate: Ado-Ekiti ($07^0$35.50 N and $05^0$13.13' E) and Ijan-Ekiti ($07^0$36.67 N and $05^0$17.58'E). The seven samples were obtained at depth between 1 and 3m and identified (Table 1). Samples were collected with the aid of digger, shovel, and clean polythene bags.

Table 1: Description of laterite samples

Sampling location	Sampling location code	Route (road)	Sample depth (m)	Sample colour
Behind Sunview hotel, Alagbaka Akure.	Loc.1	El-Shaddai road	2	Yellowish red
Igbo-Oja Ondo.	Loc.2	Ipetu-Ondo road.	3	Mottled yellowish red.
Adjacent Achiever University, Owo.	Loc.3	Owo-Ute-Uhen road	3	Yellowish.
Aladiye, Ilesha	Loc.4	Ilesha-Oshogbo road.	1	Reddish brown.
Opposite major garage, Oshogbo	Loc.5	Oshogbo-ilesha road.	2	Reddish
Opposite Yemtech Engineering, Ado-Ekiti	Loc.6	Ado-Ikere road.	2	Brownish red.
Odo-Ijan, Ijan-Ekiti	Loc.7	Ado-Ijan road.	1	Brownish red

2.2 Laboratory Tests

The tests carried out on the samples were particle size analysis, unconfined compressive strength, linear shrinkage and water absorption test. The laboratory procedures of the tests were carried out according to ASTM standard

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2.2.1 Determination of Grain Size Analysis

The grain size distribution of each of the soil was determined using grain size analysis according to ASTM **(**2007a) D 422-63. The test was carried out using a set of sieves and hydrometer. The sieves were clean and assembled in ascending order of sieve number with No. 4 sieve at top and No. 200 sieve at bottom while the pan was placed below No. 200 sieve. The weight of the dry laterite sample was recorded and carefully poured into the top sieve while the cap was placed over it. The sieve stack was placed in the mechanical shaker and shake for 10 minutes. The stack was then removed from the shaker and the weight of each sieve with its retained soil was carefully weighed and recorded. The weight of the bottom pan with its retained fine soil was weighed and recorded as well. Hydrometer test was conducted on the fine soils from bottom pan of the mechanical sieve set according to ASTM **(**2007a) D 422-63.

2.2.2 Unconfined Compression Test

This test was conducted in accordance with ASTM D 2166. Then the sieved soil was mixed with workable water to enhance adhesion of the soil. Then the soil was filled into a Shelby tube sampler of diameter 10.2 cm and the soil was compacted using proctor of 2.38 kg. The specimen was then extruded from Shelby tube sampler and cut into sizes of approximately 10.2 cm. Then the specimens were then group into two; first group were placed and dried in the oven at 105^{o}C for 24 hours while the second group were not dried in the oven. After oven dried the first group, those to be tested for their oven dry compressive strength were selected and the rest to be fired were sub-group into five for their respective firing temperature (that is 600^{o}C, 700^{o}C, 800^{o}C, 900^{o}C and 1000^{o}C group respectively). Then the specimen (un-dried, dried and fired) was carefully placed in the compressive device and load was applied continuous until the load (load dial) started to decreases on the specimen significantly and the load holds constant for at least four deformation dial readings.

2.2.3 Linear Shrinkage

The linear shrinkage of soil samples was determined in this study according to ASTM C67 standard procedure. The laterites samples were sieved using 425 μm sieves and then mixed with workable water and were filled into moulds of length 144 mm and were then dried in the oven for 24 hours at 105^{o}C to complete drying. Then soils specimen were then removed from the oven, allowed to cool off and the specimen were remove from the mould and the lengths of each specimen was measured. Then the oven dry specimens were then placed in the "Gallenkamp" Muffled furnace capable of (24 x 103) cm^3 chamber and fired at 1000^{o}C to drive away all undesirable water. The specimens were then removed from the furnace, allowed to cool off and the lengths of the specimen were measured. The linear shrinkage of each sample were determine using Equation 3.26.

$$LS = \left(1 - \frac{Lo}{Lf}\right) \times 100, \% \qquad (1)$$

Where: LS is the linear shrinkage; L_o is the original length of specimen in mm; and L_f is the final length of specimen after drying (and after fired) in mm.

2.2.4 Water Absorption Test

Water absorption test was conducted to determine the amount of water that can leach through the fired laterite bricks, this test was determine according to ASTM C373-88 standard procedure. The laterites samples was pulverized and passed through 4.76 mm sieves. The soils samples were then mixed with workable water and were melded into ellipsoidal shape. The ellipsoidal shape specimens were then oven dried at 105^{o}C for 24 hours and allowed to cool down at room temperature for an hour. Then the oven dried samples were then group into five for their respective firing temperature (that is 600^{o}C, 700^{o}C, 800^{o}C, 900^{o}C and 1000^{o}C group respectively) and then fired using "Gallenkamp" Muffled furnance capable of (24 x 103) cm^{3} chamber. The first group were fired at 600^{o}C, second group were fired at 700^{o}C, third group were fired at 800^{o}C, forth group was fired at 900^{o}C, and last group was fired at 1000^{o}C respectively to drive away all undesirable water. The specimens were then removed from the furnace after firing and allowed to cool off. After the samples had cooled down the mass of each dried specimen was determined using weighing balance and the values are recorded as the dry mass (M_d). Each dried specimen was then submerged in cold water for 24 hours after which the specimens were taken out of the water and their surfaces were wiped with pieces of cloth to remove excess water. The new mass was determined by weighing the soaked specimen and recording as saturated mass (M_s). The percentage water absorption was determined using Equation 3.27.

$$A = \frac{(Ms - Md)}{Md} \text{ x } 100\ \% \qquad (2)$$

Where, A = % water absorption; M_d is dry mass; and M_s is saturated mass.

3 Results and Discussions

3.1 Grain Size Analysis Results

The summaries of grain-size analysis test results conducted on the samples are shown in Tables 2 and 3.

Table 2: Summary of grain-size distribution of soils samples (Loc.1 – Loc.7)

Sample	% Gravel size particles (mm	% Sand size particles (mm)	% Silt size particles (mm)	% Clay size particles (mm)	% Fine to medium silt particle size (mm)	% Coarse silt and sand particle size (mm)
Loc.1	10.6	47.2	26.6	15.6	16.4	68
Loc.2	3.7	48	26.8	21.5	16.5	62
Loc.3	34.0	48.7	9.4	8.0	3	89
Loc.4	4.6	23.6	15.7	56.1	9.9	34
Loc.5	8.6	39.0	14.4	38.0	9	53
Loc.6	10.6	41.2	16.1	32.1	9.9	58
Loc.7	6.7	46.4	14.5	32.4	9.6	58

The composition of the soil is one of the characteristics that greatly affect the suitability of soil for production of bricks. An ideal soil should be composed of soil with combine: clay content of (15-20%); silt content of approximately 25-40 percent; and sand content of approximately 40-70 percent (Onaolapo, 2010). Base on grain size analysis results shown in Table 2, Loc.1 soil is an ideal soil because it has the composition of an ideal soil. Loc.2, Loc.3, Loc.6 and Loc.7 are nearly ideal because they meet one or two of the three ideal soil compositions. Loc.4 and Loc.5 soils are not an ideal soil because they did not meet any of the ideal soil composition ranges. As a result of this, all the soils are good material for brick production except Loc.4 and Loc.5 soils which are poor material and should not be mine and used for bricks production if not stabilize. In the same development, The plot of the soils particle sizes composition shown in Table 2 on the ideal particle size chart adapted from McNally (1998) shown in Figure 3, revealed that Loc.1, Loc.2, and Loc.3 soils can be used for making solid bricks while samples Loc.6 and Loc.7 soils can be used for making perforated bricks but Loc.4 and Loc.5 soils are not suitable because there product will be liable to excessive shrinkage on firing.

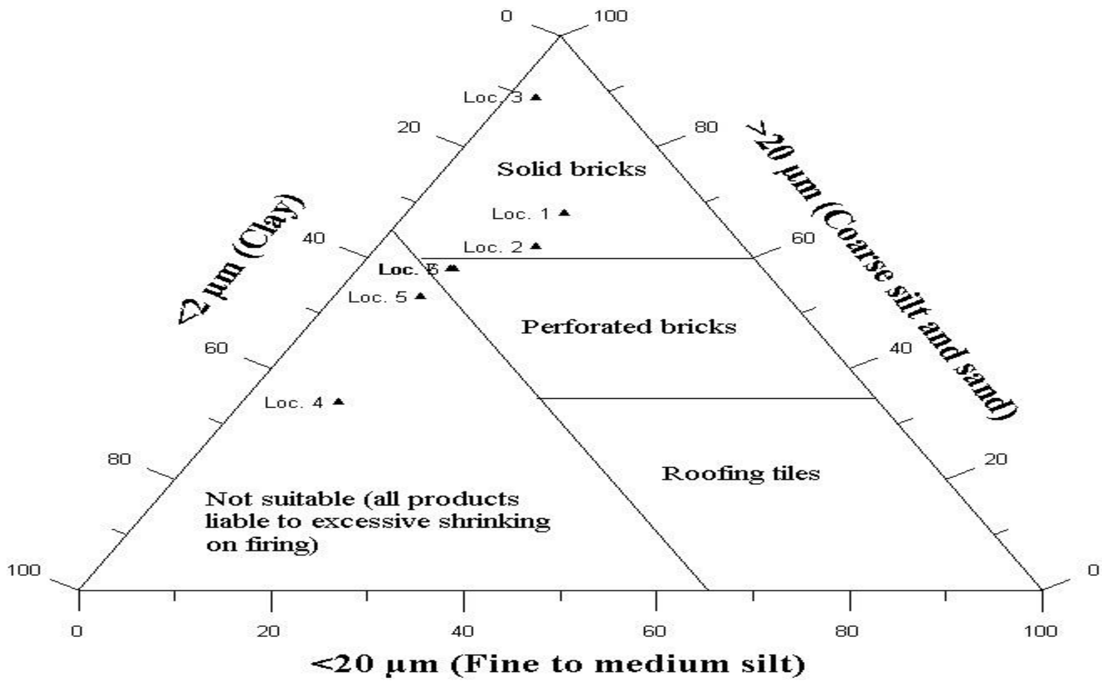

Fig. 3: Suitable Bricks types for the Laterites

3.2 Unconfined Compressive Strength

Table 3: Summary of unconfined compressive strength

Sample	Oven dry UCS Results (kPa)	Fired (600 ^{o}C) UCS Results (kPa)	Fired (700 ^{o}C) UCS Results (kPa)	Fired (800 ^{o}C) UCS Results (kPa)	Fired (900 ^{o}C) UCS Results (kPa)	Fired (1000 ^{o}C) UCS Results (kPa)
Loc.1	3452.96	4562.95	4747.56	4844.61	4992.04	5093.97
Loc.2	3650.90	4824.40	5019.47	5121.95	5277.71	5385.35
Loc.3	3816.46	5047.01	5250.98	5358.09	5520.92	5633.43
Loc.4	3471.96	4588.03	4773.65	4871.22	5019.45	5121.94
Loc.5	3453.96	4564.27	4748.93	4846.01	4993.48	5095.45
Loc.6	3312.64	4381.02	4558.35	4651.61	4793.25	4891.20
Loc.7	3366.41	4452.10	4632.27	4727.00	4870.90	4970.41

Unconfined compression test was carried out on the soils samples to assess their compressive strength in order to determine the maximum amount of compressive load a material can withstand before fracturing if used for bricks production. Also the relationship between the compressive strength of the laterites and the firing temperature were deduced by determine their compressive strength at different firing temperature and plotted it against each other (Figures 4 to 10)

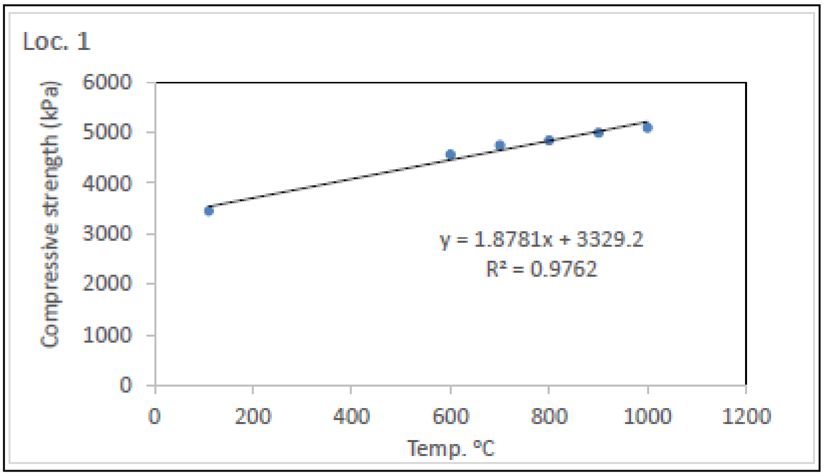

Fig. 4: Compressive Strength against the Fired Temp. (Loc.1)

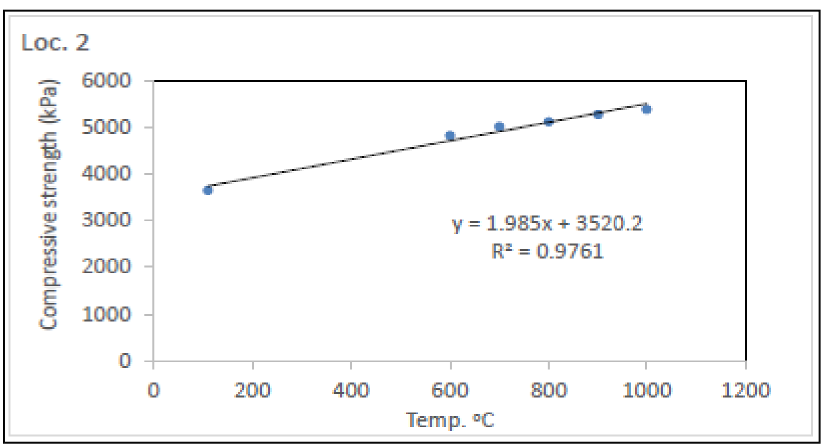

Fig. 5: Compressive Strength against the Fired Temp. (Loc.2)

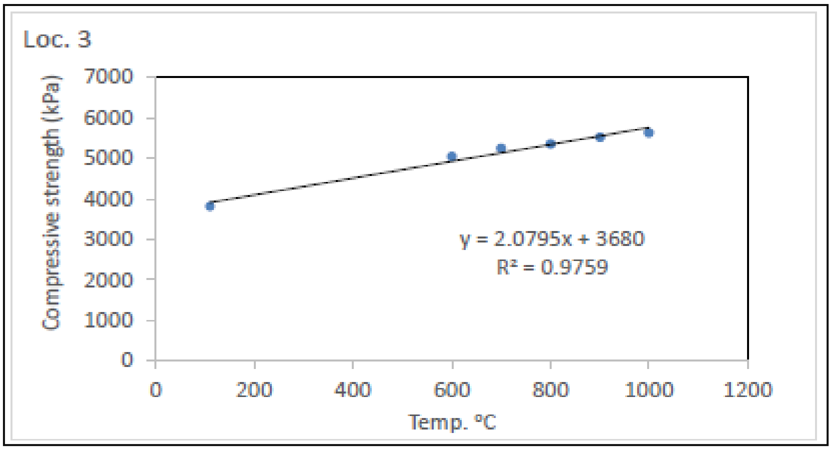

Fig. 6: Compressive Strength against the Fired Temp. (Loc.3)

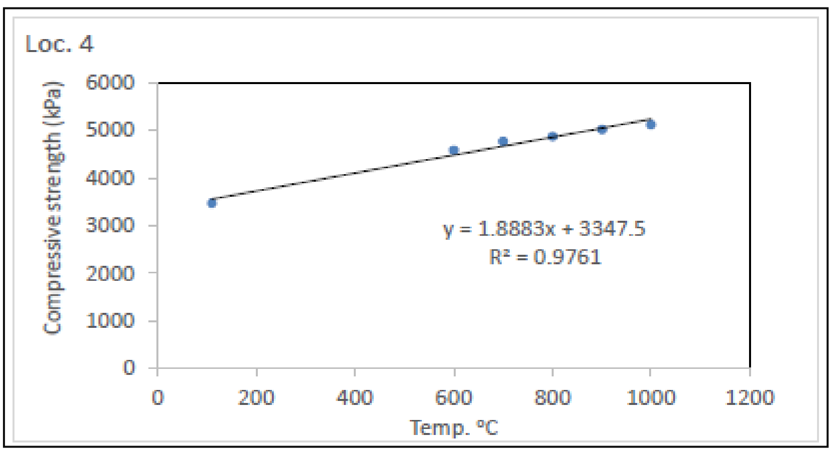

Fig. 7: Compressive Strength against the Fired Temp. (Loc.4)

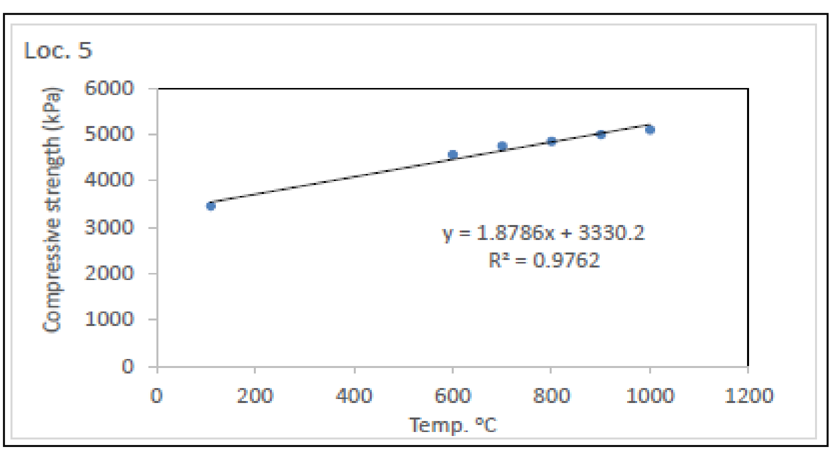

Fig. 8: Compressive Strength against the Fired Temp. (Loc.5)

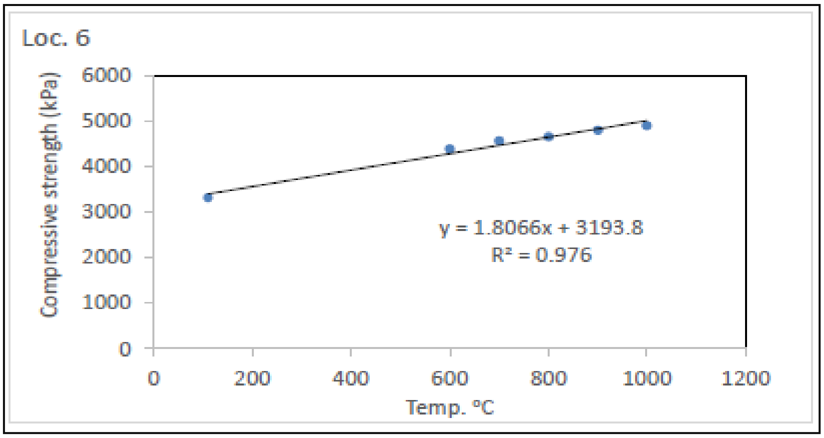

Fig. 9: Compressive Strength against the Fired Temp. (Loc.6)

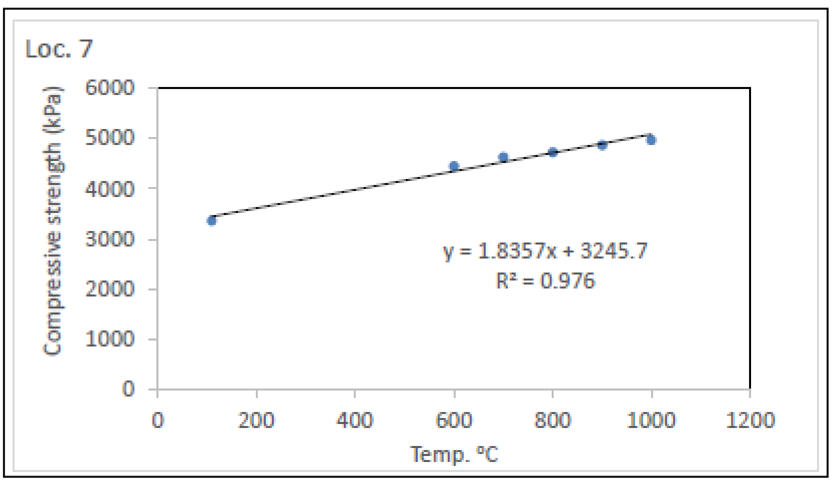

Fig. 10: Compressive Strength against the Fired Temp. (Loc.7)

The compressive strength of the laterites increases with fired temperatures as shown in Table 3 and graphical representation shown Figures 4 to 10. The Increment in compressive strength with fired temperature is due to decrease in porosity and increase in bulk density of the laterite (Bhatnager and Geol, 2002).

Nigeria Building and Road Research Institute (NBRRI) specified a minimum compressive strength of 1.65 N/mm^2 (1650kP) for bricks for building construction. None of the soil meets the specification when not fired but when fired; all the soils meet the NBRRI specification (Table 4) and therefore can be used for bricks production.

3.3 Linear Shrinkage

The summary of the results of the linear shrinkage test conducted on the samples after oven dried at 105^{o}C is shown in Table 4 while the summary of the results of the linear shrinkage test conducted on the samples after fired at 1000^{o}C is shown in Table 5.

Table 4: Summary of Linear Shrinkage Results (Loc.1 – Loc.7)

Sample	Loc.1	Loc.2	Loc.3	Loc.4	Loc.5	Loc.6	Loc.7
Original Length, L_o (mm)	140	140	140	140	140	140	140
Final Length, L_f (mm)	134	133	138	121	126	127	128
Linear Shrinkage = (1-(L_f/L_o))*100	4.3	5.0	1.4	13.6	10.0	9.3	8.6

Table 5: Summary of Linear Shrinkage Results of Fired Laterites at 1000^{o}C (Loc.1 – Loc.7)

Sample	Loc.1	Loc.2	Loc.3	Loc.4	Loc.5	Loc.6	Loc.7
Original Length, L_o (mm)	134	133	138	121	126	127	128
Final Length, L_f (mm)	132	131	137	116	122	124	125
Linear Shrinkage = (1-(L_f/L_o))*100	1.5	1.5	0.7	4.1	3.2	2.4	2.3

Shrinkage in soils occurred as chemical and mechanical bound water is lost. McKeen (1976) specified that if soil linear shrinkage is greater than 5 (> 5), such soil has critical degree of expansion, but if less than 5 (≤ 5), such soil has non-critical degree of expansion. Base on the linear shrinkage results shown in Table 4, Loc.1, Loc.2 and Loc.3 soils have non-critical degree of expansion while other has critical degree of expansion.

The lower the linear shrinkage, the lesser the tendency for the soil to shrink when desiccated (Jegede, 1997). Comparing linear shrinkage results shown in Tables 4 and 5, linear shrinkage decreases with firing at 1000^{o}C and all the laterite soils have non-critical degree of expansion after fired at 1000^{o}C, hence Loc.1 to Loc.3 soils can be used for making bricks with firing temperature lesser than 1000^{o}C while others can only be used if fired to 1000^{o}C.

3.4 Water Absorption Capacity

Table 6: Summary of Water Absorption Capacity Results (Loc.1 –Loc.7)

Sample	Water absorption capacity of sample fired at 600 °C (%)	Water absorption capacity of sample fired at 600 °C (%)	Water absorption capacity of sample fired at 600 °C (%)	Water absorption capacity of sample fired at 600 °C (%)	Water absorption capacity of sample fired at 600 °C (%)
Loc.1	13.30	13.02	12.73	12.42	12.14
Loc.2	12.10	11.85	11.59	11.30	11.05
Loc.3	14.10	13.80	13.50	13.16	12.87
Loc.4	16.30	15.96	15.61	15.22	14.88
Loc.5	15.10	14.78	14.46	14.10	13.79
Loc.6	13.90	13.61	13.31	12.98	12.69
Loc.7	12.30	12.24	11.97	11.67	11.41

Water absorption capacity of soil is a property which depends on the level of porosity present in the soils. High values of water absorption capacity of some soils indicate that the soils were highly porous and the water absorption capacity decreased significantly when the temperature increased due to the formation of the amorphous phase at high firing temperatures (Cultrone *et al*., 2004).

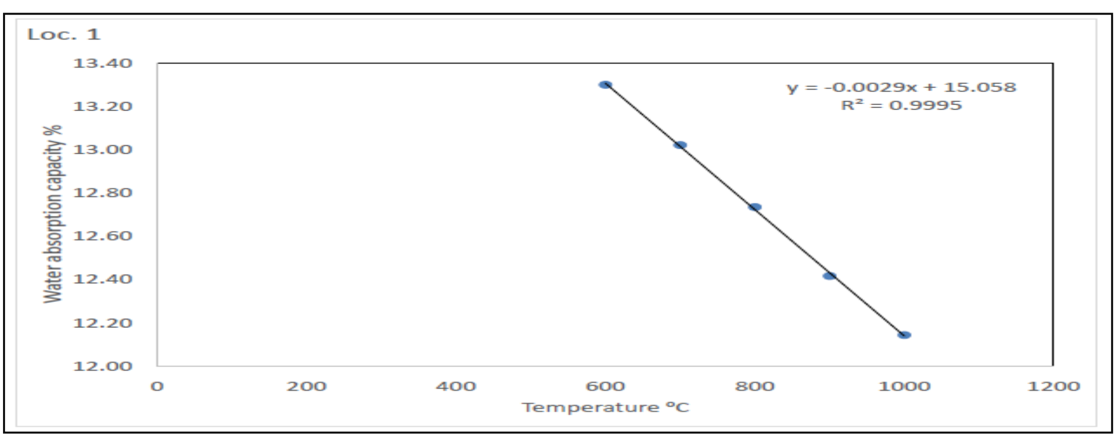

Fig. 11: Water absorption capacity against Fired Temp. (Loc.1)

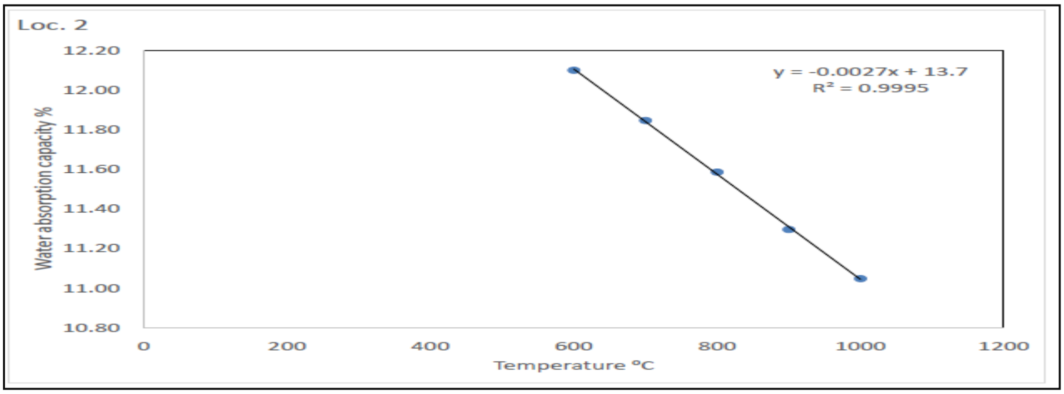

Fig. 12: Water absorption capacity against Fired Temp. (Loc.2)

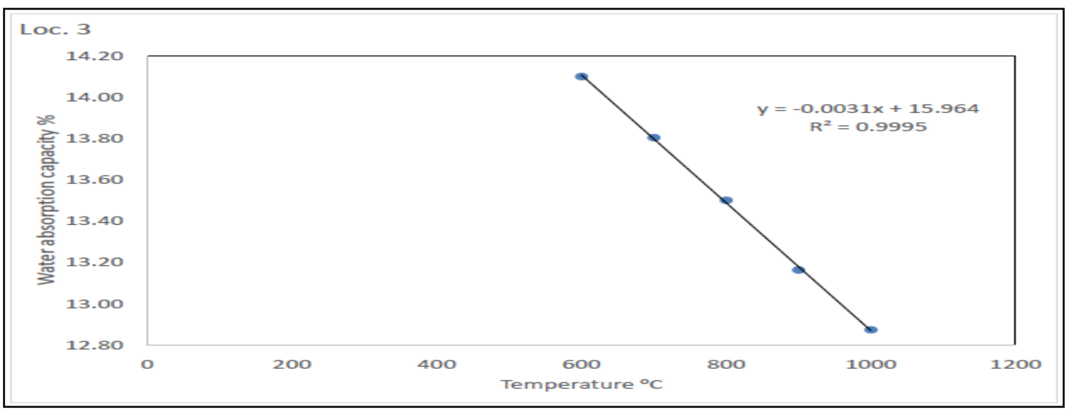

Fig. 13: Water absorption capacity against Fired Temp. (Loc.3)

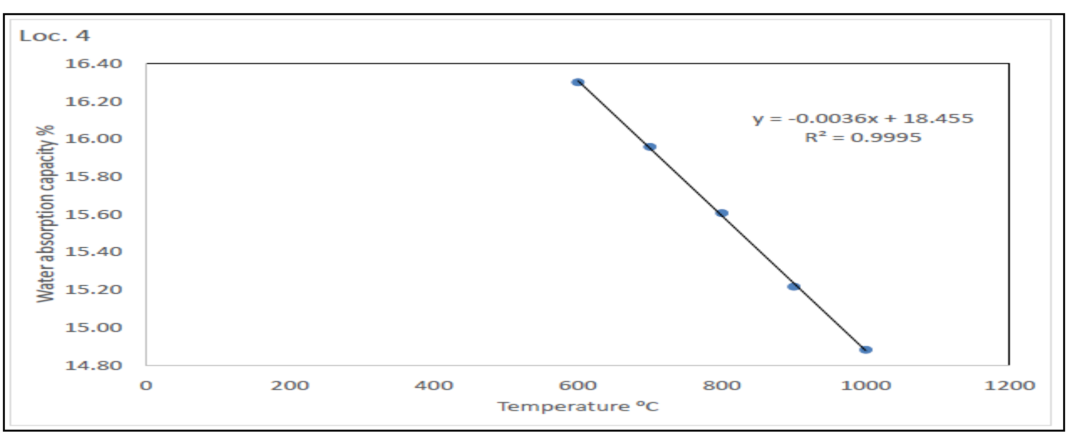

Fig. 14: Water absorption capacity against Fired Temp. (Loc.4)

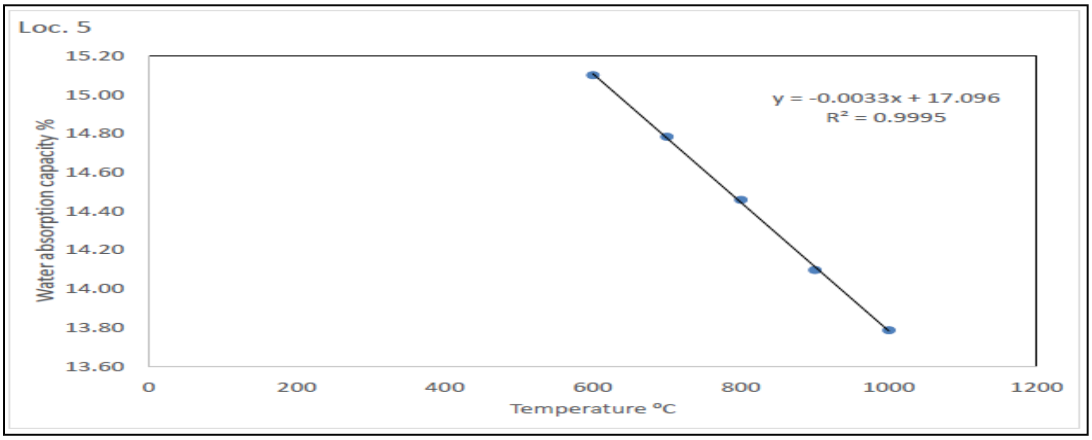

Fig. 15: Water absorption capacity against Fired Temp. (Loc.5)

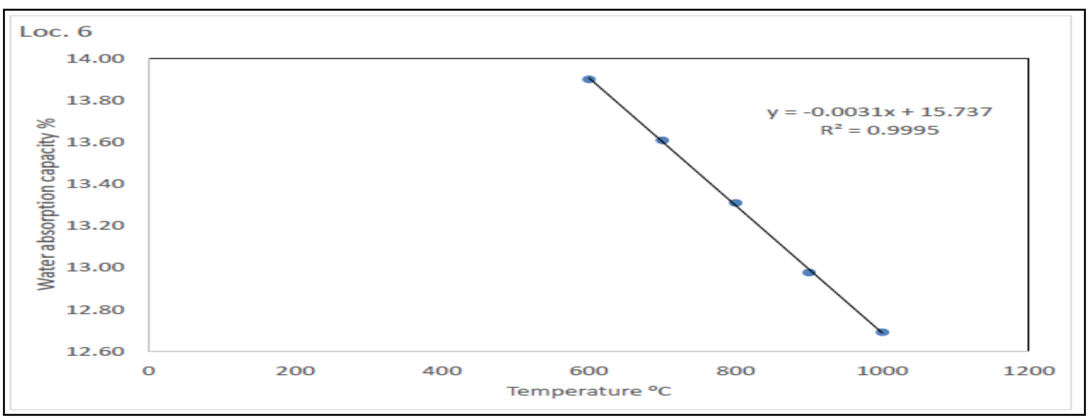

Fig. 16: Water absorption capacity against Fired Temp. (Loc.6)

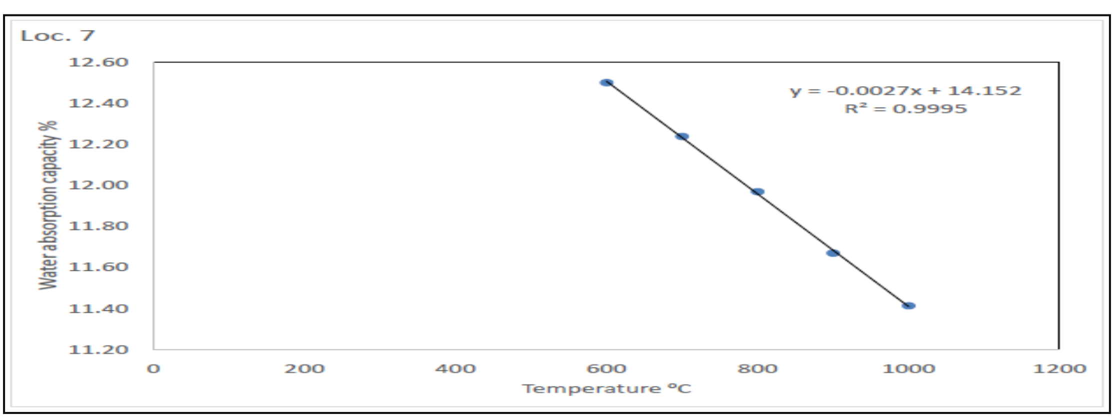

Fig. 17: Water absorption capacity against Fired Temp. (Loc.7)

The results of the water absorption capacity of the laterite soils when fired at different temperature were shown in Table 6. It can be deduced from the Table that the water absorption capacity of the laterites decrease with increase in fired temperature; hence the laterites are good materials for bricks production. Nigeria Building and Road Research Institute (NBRRI) proposed a specification of maximum water absorption of 12.5% for a soil to be use for bricks production (Menasseh and Agbede, 2002). In this study, some of the laterites met the NBRRI specification even at 600^{o}C fired temperature (samples Loc.2 and Loc.7) while laterite sample Loc.1 met the criteria at 900^{o}C, the rest of the laterites shown a tendency of meeting the criteria at temperature higher than 1000^{o}C because Figures 11 to 17 revealed a significant linear relationship between water absorption capacity and the fired temperature, hence this suggested that with further increases in the fired temperature of these laterites; the criteria of NBRRI will be met.

4 Conclusion

A compressive investigation into geotechnical properties of the laterites at different firing temperature has been performed and base on this, the following conclusions can be drawn:

(a) Base on the grain size distribution of the soils: Loc.1, Loc.2, and Loc.3 soils can be used for making solid bricks while Loc.6 and Loc.7 soils can be used for making perforated bricks while others (Loc.4 and Loc.5) can be used for either of the two if properly stabilized (fired above 1000 ^{o}C).
(b) The unconfined strength of the soils increased with increased firing temperature.
(c) The linear shrinkage of the soils decreases with firing.
(d) The water absorption capacity of the soils decreased with increased fired temperature.
(e) In conclusion, base on the results of the unconfined compressive strength and water absorption capacity; Loc.2 and Loc.7 soils can be used for making bricks if fired at 600^{o}C while Loc.1 soil will be useful for bricks if fired at 900^{o}C while the rest of the laterites will be suitable for bricks if fired at temperature higher than 1000^{o}C.

5 Recommendation

Base on the investigation of the study, the following recommendation are derived:

(a) Grain size analyses must be put into consideration when determine the type of brick suitable for any material.

(b) It is recommended that material for bricks production should be fired at various temperature and laboratory tests conducted on it to determine the firing temperature suitable for the brick production.

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