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EFFECT OF FIRING TEMPERATURE ON COMPRESSIVE STRENGTH OF CLAY BRICKS AT RAFIN MAKARANTA, BAUCHI

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ABSTRACT
Clay is a naturally occurring building raw material with a considerable varying physical properties, colour, hardness, water absorption etc and mineralogical content which is used in producing clay bricks. This study is aimed at examining the clay properties found at Rafin Makaranta, Bauchi state which include linear shrinkage, plasticity index, liquid limit, plastic limit, compaction and compressive strength. The laboratory tests result shows that the compressive strength of the clay increases with increase in relation to varying temperatures until a temperature peak of 1200^0c which gives a maximum compressive strength of 10.2 N/mm^2. The compressive strength gradually decreases when the firing temperature goes between 1400^0c and 1600^0c with strengths of 9.6 N/mm^2 & 8.7 N/mm^2. Based on the above findings, it then shows that for a quality bricks to be produced the chemical and physical properties are highly considered and the rate of firing temperature also have a great effect on the compressive strength of clay bricks as illustrated above which can be referenced to.

Key words: *clay, bricks, linear shrinkage, plasticity index, liquid limit, plastic limit, compaction and compressive strength*

INTRODUCTION
CLAYS
Clay are very tiny crystalline particles evolved primarily from chemical weathering of rock forming minerals, with predominantly silicate of aluminum and, or plus other metallic irons (Holtz and Kovacs) 1981).

Clay bricks masonry is one of the oldest and most durable construction material used by mankind found in the ancient civilization in parts of the Great Wall of China, Mesopotamian, Egypt and Roman buildings. Clay bricks have been used during medieval and modern times, despite several modification of clay bricks uses, shapes and manufacture along thousands of years of constant evolution, the simplicity that make it success remained.

The 3-major clay minerals are Kaolinite, Illite and montmorillonite.

Kaolinite is formed principally as an alteration product of feldspar, pelpathold, and muscovite from weathering under active condition, and has a structural consisting basically a repeated layer of one tetrahedral (silica) sheet and one octahedral (alumina or gibbsite) sheet. i.e 1:1 mineral type.

Illite is formed from weathering of feldspar. Mica's clay minerals upon diagnosis under an alkaline environment it is a 2:1 type of mineral.

Montmorillonite are formed when basic igneous rock is badly drained and are weathered in an alkaline environment. Its structure is a 2:1 and is the simplest in size, shape and specific surface (Holtz and Kovacs 1981).

The techniques and identification of clay minerals include the use of Scanning Electronic Microscope (SEM), X-ray diffraction, Differential Thermal Analysis (DTA) and from a Consisting Limit Chart, (Casagrande 1948).

Microstructure play an important role in determining the properties of any polycrystalline or amorphous material, and therefore in the performance of the products. It influences virtually all aspect of the bahaviour of the material (R.T. Dehoff 1999).

(Olgun et al, 2004) in their works "development of ceramic tiles from coal fly ash and tinical ore waste", it was observed that, in a glassy matrix and microstructures of the tile bodies were not thoroughly homogeneous. Compared to sample containing 2% fly ash, the fractured surface of the sample showed a denser well-sintered micro structure with a uniform distribution of pores. The fractured surface the sample prepared from tinical ore waste and fly ash, 5% and 2% respectively was very different from others with denser well-sintered micro-structural associated with the formation of elongated cavities. From these result it may be suggested that this dense micro-structure is responsible for better mechanical properties of the sample.

Compressive strength and water absorption and two major physical properties of brick that are good predictors of bricks ability to resist cracking of face. Compressive strength is highly affected by firing temperature, method of production, physical, chemical and mineralogical properties of the new material. Water absorption is a measure of available pores space and expressed as a percentage of the dry brick weight. It is affected by properties of clay, method of manufacturing and degree of firing.

Firing shrinkage increases with higher temperature, varying in temperature and firing time has important effect on quality of bricks. Decreasing firing temperature and shortening firing time do not only reduce the cost of production but also increase the productivity of the factory.

RAW MATERIAL AND MANUFACTURE

Clay bricks are made by shaping suitable clay and shapes to unit of standard size which are then fired to a temperature in the range 900 to 1200^0c the fired product (see figure 1.0) is a ceramic composed predominantly of silica Sio_2 (general between 55 and 65 percent by weight) and alumina Al_20_3 (10 to 25 percent) combined with as much as 25% of the other constituents.

Said facings and face textures may be applied before firing and key slots formed for plaster finishes. Many bricks are perforated and pressed bricks commonly have frogs (see figure 1.0). Both features reduce brick weight and the normal size of the building brick is 215mm x 102.5mm x 65mm. Allowing for 10mm mortar joint, this correspond to the standard format or coordinating size of 255mm x 112.5mm x 75mm as defined in BS 3921. Some brick are also available in a metric modular format 200mm x 100mm 75mm (BS6649) Beside standard rectangular bricks, a large number of so-called standard special shapes are commonly available. This ranges from simple half brick (bats or closers) to special shapes for the construction of arches, plinths and other elaboration details and are fully defined in BS4729.

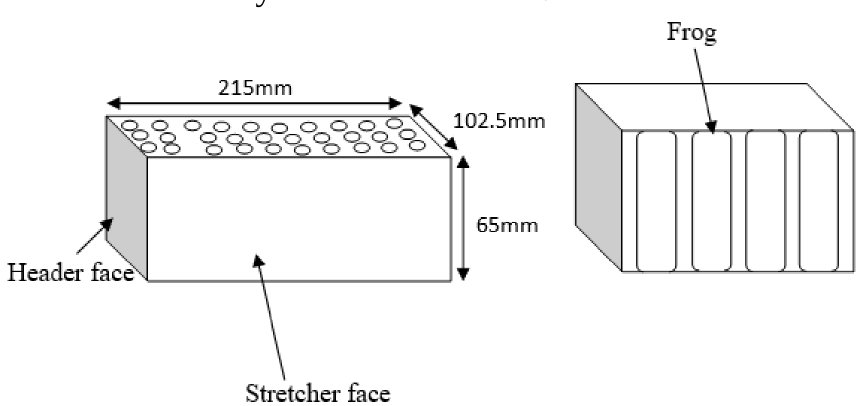

Figure 1.0 Clay bricks

Figure 1.0 is a typical bricks one perforated, the other frogged with plastering key on one stretcher and one header face. The dimensions (work size) are those of a standard format brick as defined in BS3921.

BRICK-MAKING CLAYS

The bricks industry uses a great variety of clays laid down at different geological periods and ranging from soft, easily molded glacial deposit to much older, relativity harder sheles (keeling, 1963: prentice, 1990). This geological diversity reflects itself in this varied composition and mineralogy of brick-making clays. Crystalline allumino silicate minerals, most commonly kaolinite and illite, loss commonly montmorillonite and the clorites, and present as major constituent together with associated water. There minerals are in this form of fine particles (with typical dimension of 2 micro meter and less) and are responsible for the cohesion and plasticity of the moist clay. However the clays rarely exceed 30 to 45 percent of the total composition. In addition, there are coarser particles (silt and sand compounds, predominantly quartz and micas) together with minor accessory minerals such as gypsum $CaCO_4$, $2H_2O$ pyrites, Iron oxides $FeS_2$and calcite $CaCO_3$.

COMPRESSIVE STRENGTH OF CLAY BRICKS

Compressive strength of brick is remarkably improved by firing at higher temperature with increase in firing temperature, compressive strength increased as follows: 700-500^{0}c, and 700-11000c, by 25.3% sharp increase strength at 100^{0}c and above may be attributed to the enhanced versification in clay material. Increase in compression strength is due to decrease in porosity and increase in bulk density with increasing temperature strength firing time (120 - 48min) is the time that the material was subjected to the firing temperature (700 - 1100^{0}c). The firing time had no significant effect on the compressive strength. Increasing firing time (120-48mm) resulted in small increase (7%) in compressive strength of the clay brick. Energy consumption in brick production is both time and temperature dependent. Since increasing firing time does not improve the quality of brick, prolonged firing time will result in waste of energy and time, thereby increasing the cost of production.

FIRING TEMPERATURE

Firing temperature is a key factor affecting shrinkage. In the firing process, high shrinkage consist destruction of bricks both in firing and drying stages of production. Shrinkage in brick occurs as chemically and mechanically bound water a lost. A highly significant liner relationship occurred between firing temperature and shrinkage. However increase in firing time had no significant effect on firing shrinkage at any firing temperature.

Table 1.0: Physical properties of clay soil

Property (%)	Amount
Moisture content	12.2
Specific gravity	2.75
Liquid limit	44
Plastic limit	22
Plastic index	22
Linear shrinkage	12.3

Table 1.1: Particle size distribution

Property %	Amount
Clay	20
Silt	48
Sand	30
Gravel	O

Table 1.2: Chemical analysis of clay soil (Ghata, 1999)

Constituent	Unit
S_iO_2	48.49
Al_2O_3	16.39
M_nO	0.02
P_2O_5	0.01
SO2	0.01
Fe_2O_3	4.09
N_iO_2	0.05
Cl_2O3	0.01

MATERIALS AND METHODS

LABORATORY TESTS

Preliminary test were carried out on the clay sample in order to determine the suitability to be used as a brick making clay. The tests performed include the following:

(i) Natural moisture content
(ii) Atterberg limits: liquid limit (LL), plastic limit (PL), shrinkage limit (ShL)
(iii) Compaction

(i). **Natural moisture content test:** Moisture content is the amount of water present in any sample at its natural state usually expressed in percentage.

An empty container was cleaned dried and then weight. A portion of soil sample which has just gotten from the field was placed into the container and weight. The sample together with the container is then placed into the oven for 24 hours at temperature 105^0c-110^0c. After 24 hours, the sample was removed and allowed to cool, after which it was weighted. The moisture content mathematically it is given as:

$$\text{Moisture content, } (w) = \frac{\text{Moisture loss}}{\text{Dry mass}} \times 100\%$$

$$W = \frac{m_2 - m_3}{m_3 - m_1} \times 100\%$$

Where:

W = moisture content in percentage.

M_1 = weight of container empty

M_2 = weight of wet soil + container

M_3 = weight of the dry soil + container

(ii). Atterberg Limits:

a. Liquid limit Test (L.L): The liquid limit is the moisture content at which the soil stops acting as a liquid and start acting as a plastic soil.

The soil sample for this test was air-dried, pounded and sieved through 425 micro metre sieve. The normal procedure for the cone penetrometer method test for determining the liquid limit of a given material was carried out in accordance with BS 1377 (1990) and care was taken in order to produce a acceptable result. To obtain the L.L, the graph of moisture content is plotted against penetration of the cone (mm) and straight line was obtained, the moisture content corresponding to 20mm penetration is taken as the liquid limit of the soil and is impressed to nearest whole number. Table 1.6 gives the summary of liquid limit result of clay soil.

b. **Plasticity Index (PI):** The plasticity index is the numerical difference between the liquid limit and the plastic limit, mathematically it is expressed as:

P.I = L.L - P.L

Table 1.6 also gives the summary of plasticity index result of the clay soil.

c. **Linear shrinkage:** The test gives the percentage linear shrinkage of the soil and was carried out in accordance with BS 1377, 1990. If the drying process is prolonged after the plastic limit has been reached, the soil will continue to decrease until a certain value of moisture is reached. This value is known as the shrinkage limit and the values of moisture content below this level makes soil partially saturated.

Mathematically, the linear shrinkage is expressed as:-

$$\text{Linear shrinkage (LS)} = 1 - \frac{L_D}{L_0} \times 100\%$$

Where:

L_0 = length of original sample (mould) mm

L_D = length of dry sample (mm)

Table 1.6 also gives the summary of linear shrinkage result of clay soil.

d. **Plastic limit:** The plastic limit is the limit between plastic and brittle failure. The sample for this test was also prepared in the same way for liquid, and the procedure is as specified by Bs 1377, 1990 was followed. Mathematically, the plastic limit is expressed as:

$$\text{Plastic Limit (P.L)} = \frac{\text{Mass of water}}{\text{Mass of oven dry sample}} \times 100\%$$

e. **Soil Compaction Test:** Soil compaction is a process of packing soil more closely together by mechanical means to expel air or to reduce the ratio of void there by increasing the dry density of the soil.

The aim of the compaction is to determine the maximum dry density and optimum moisture content. The procedures followed for this test were strictly in accordance with BS 1377, 1990 using one-litre proctor mould. The sample was compacted using 25kg rammer falling freely through a height of 300mm in 3 layers by given 25 blows to each successive layer. Table 1.8: Gives the summary of compaction test result.

The equation below was used in calculating the dry density of the soil.

$$P_d = \frac{100\ P_w}{100 + w}$$

Where; P_d = Dry density of the compacted sample (mg/m3)

w = Moisture content of the compacted sample (%)

P_w = Wet density of the compacted sample.

Table 1.8: Summary for compaction test result.

Maximum dry density (mg/m^3)	Optimum moisture (%)
1.65	18.3

BRICKS MANUFACTURING PROCESS

Essentially, bricks are produced by mixing clay with water, forming them into desired shapes, then drying them and firing them.

The bricks manufacturing procedure have six phases:

1. Wining and storage of raw materials
2. Preparing raw material
3. Forming unit
4. Drying unit
5. Firing and cooling
6. Drawing and storing finished products.

1. **Wining and storage**: To win originally mean to obtain. After obtaining the clay mixture are then transported to plant for storage areas.
2. **Preparation**: They clay is crushed to break up large chunks and remove stores and ground prior to mixing material, the clay is then screened passing it through serve to control the particle size.
3. **Forming**: Tempering, the first step in the forming process, produces a homogenous, plastic mass ready for molding. It is most commonly achieved by adding water to the clay in pug mill. A mixing chamber which contains one or more revolving sharp with blades or by any manual aided mixing.

   After pugging the now clay mass is ready to go to the forming step. The mixture is then placed in the standard brick mould of dimension

225x112.5x75mm and pressed mechanically between two plates at a pressure rate of Mpa from which the bricks of sizes 40mm x 40mm x 40mm were extruded.

4. **Firing and cooling**: Firing is one of the specialized step in the manufacture of brick, requires 40 to 150 of firing. The brick are then fired to temperature of 400^0c, 600^0c, 800^0c, 1000^0c, 1200^0c, 1400^0c and 1600^0c respectively at rate of 3^0c/min and allow to cool to room temperature before testing.

COMPRESSIVE STRENGTH OF BRICKS

The compressive strength test on fired bricks was carried out on universal crusting machine (ELE hydraulically operated machine, have a capacity of 150KN). Load was applied to the brick sample until failure. The brick sample was tested and the average failure load recorded results is shown in table 1.9. The compressive strength is obtain by dividing the failure load (KN) by the cross-sectional area of brick (mm^2). Mathematically, it is expressed as:

$$\text{Compressive strength} = \frac{\text{failure load}}{\text{Area}} \quad (N/mm^2)$$

RESULTS AND DISCUSSION

The soil sample that was used in this research work was from Rafin-Makaranta in Bauchi State. The soil was subjected to various test in conformity with the British standard 1377 to ascertain the suitability of the research work.

Table 1.6 and 1.7: Shows the physical and chemical properties of the clay soil respectively.

Table 1.6: Physical properties of clay soil

Property	Amount (%)
Moisture content (%)	12.2
Specific gravity	2.75
Liquid limit (L.L)%	44
Plastic Limit (P.L)%	22
Linear shrinkage (L.S)%	12.3
Plastic index (P.I) %	22

Table 1.7 Chemical Analyses of clay soil (Ghata 1999).

Property	Amount (%)
S_iO_2	48.49
Al_2O_3	16.39
Fe_2O_3	4.09
SO_2\	0.01
MgO	0.68
NiO	0.05
K_2O	1.36
MnO	0.02
Cl_2O_3	0.01
CaO	0.51
TiO_2	0.81
Mo	0.061
P_2O_5	0.01

Table 1.8: Particle size distribution

Particle size distribution	Amount (%)
Clay (%)	20
Silt (%)	48
Sand (%)	30
Gravel (%)	0

1.9 Result for the compressive strength test on the brick.

Temperature	Compressive strength N/mm2
400^0c	4.6
600^0c	6.4
800^0c	7.4
1000^0c	8.9
1200^0c	10.2
1400^0c	9.6
1600^0c	8.7

CLAY SOIL

Table 1.6 and 1.7 shows the physical and chemical properties of clay minerals used for this research work. The plastic limit test of 22%. These values obtained shows that the clay soil belongs Kaolinite group of clay mineral. The 22% plasticity obtained meets the requirement of 15 to 25% P.I value specified by Indian standard (I.S:2117:1986) for bricks making clays. Table 1.6 also shows

that the clay soil contain 20% clay, 48% silt and 30% sand, this composition also meet the requirement as specified by Indian standard (1.5:2117:1987) for bricks production.
Table 1.7: Shows the chemical analysis of the clay soil used for this research work which indicated that the clay soil contain high percentage of SiO_2, Al_2O_3 in great quantity will produe a brick of high strength. Since $Si0_2$ and Al_2O_3 are responsible for gain strength. Also the presence of Fe_2O_3 will give the bricks specimen a brow, yellow or blue colour during firing. The clay soil also contain < 1% of MgO and CaO which are responsible for cracking in clay soil, presence of less quantity of sulphate the clay soil indicate that the brick to be produced will not be prone to efflorescent as the sulphates are responsible for that.

COMPRESSIVE STRENGTH
Figure 1.7 shows the effect of temperature on compressive strength of bricks. This figure reveals the compressive strength of brick increases with the increase in temperature of firing. The higher strength of the bricks was achieved at $1,200^0$c. This shows in normal firing any temperature above $1,200^0$c will lead to the decrease in strength of the clay brick as shown in figure. 1.1. It is observed that the brick strength decrease when the temperature goes beyond $1,200^0$c i.e 1400^0c and 1600^0c.

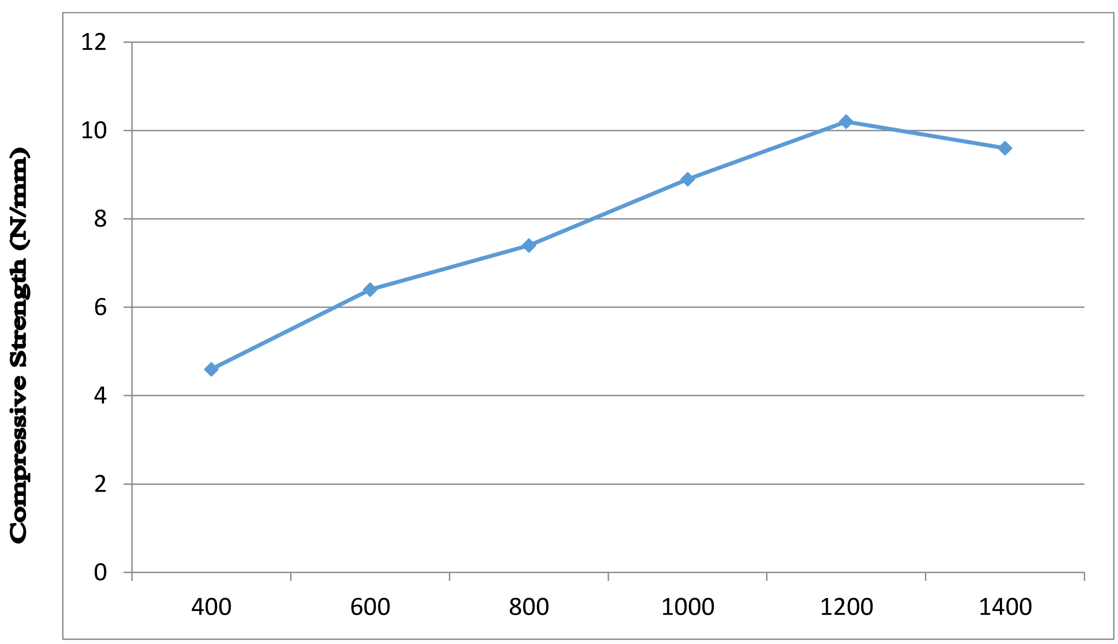

Fig. 1.1: Graph of Compressive of strength versus Temperature

Linear shrinkage

The linear shrinkage of the fired bricks where determined by measuring the difference in length between the unfired bricks using a digital Vanier caliper. The percentage shrinkage was determined using relation below.

$$\text{Linear shrinkage (\%)} = \frac{L_0 - L_1}{L_0} \times 100\%$$

Where

L_0: length of the unfired brick (mm)

L_1: length of the fired brick (mm)

3 bricks samples were used in this test and their averages were taken as is shown in table 2.0

Table2.0: Linear shrinkage result

Temperature	400	600	800	1000	1200	1400	1600
Average leaner shrinkage	6.23	6.45	705	7.65	8.28	3.31	8.34

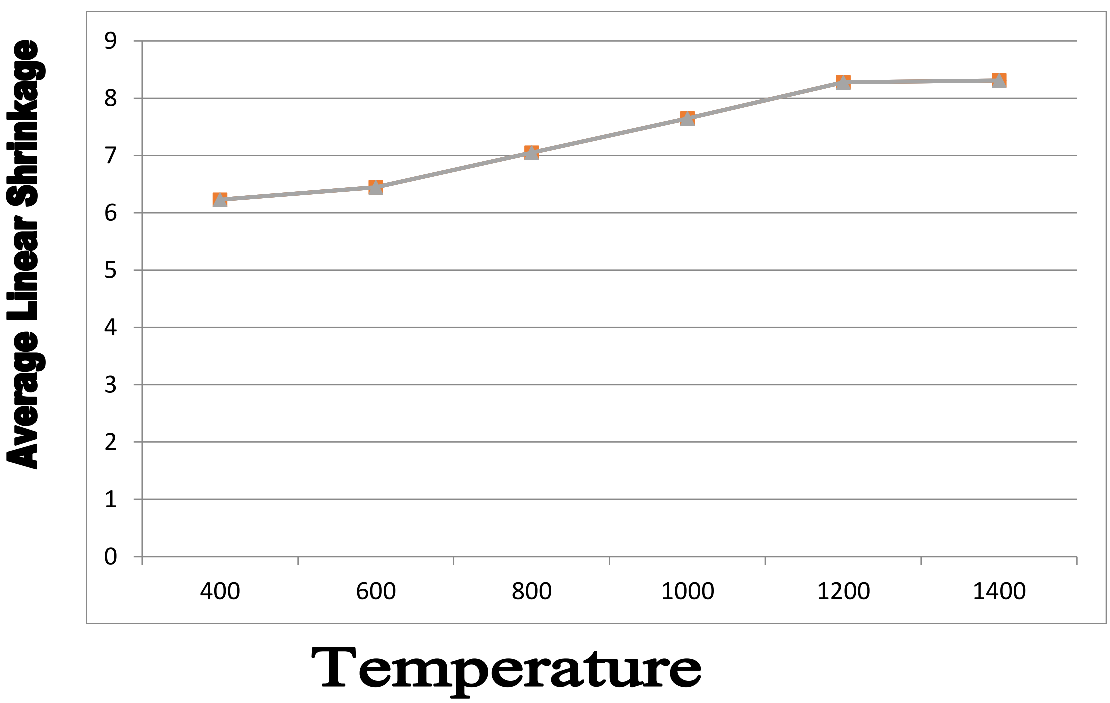

Fig. 1.2 Average Linear Shrinkage Vs Temperature

CONCLUSIONS

From the results discussed, the following conclusion can be drawn:

i. The Rafin Makaranta clay used for bricks making contained 20% clay, 48% silt and 30% sand which proves better for effective strength achievement.

ii. The compressive strength of the brick increased as the firing temperature was increased with the highest strength of 10.2 N/mm^2 obtained at 1200^0c.

iii. The use of standard bricks size should be considered as smaller dimension proves difficult in terms of fabrication of the mould,

iv. Fired clay bricks at temperature 1000^0c-1200^0c can serve as a replacement of sand creete blocks in normal bungalows which can minimize the cost.

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