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Development of Terracotta Wall Tiles from Local Clay Blends in South Eastern Nigeria

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ABSTRACT: Prototypes of terracotta wall tiles were produced from samples of Ishiagu clay, Edda clay and Unwana clay. The clay samples were analyzed using x-ray diffraction, to determine their mineral composition. The analyses revealed that Ishiagu clay sample contained 47% quarts, 14% albite, 5%orthoclase, 2% chlorite and 32% muscovite. Edda clay contained, 35%kaolinite, 26% quartz, 18% orthoclase, 3.7% albite, 14% illite, 2.7% muscovite. Unwana clay contained, 56% apatite, 3% quartz, 7% orthoclase, 28% calcite, 1% lime and 5% muscovite. Five batches were made from each clay sample. Batches A_1, B_1 and C_1 100% of the as received Ishiagu, Edda and Unwana clays, respectively. Batches A_2, B_2 and C_2, contained 10% of washed silica sand. Batches A_3, B_3 and C_3 contained 20% of the washed silica sand. Batches A_4, B_4, and C_4, contained 10% of granite quarry dust instead of silica sand. Batches A_5, B_5 and C_5 contained 20% of granite quarry dust instead of silica sand. The test pieces were dried and later fired to a temperature of 950^{o}C, in a gas kiln. Visual examination of the fired test pieces revealed that the gray coloured granite quarry dust did not influence the fired colour of the test pieces. It was also observed that samples made from Edda clay did not attain any reasonable maturity at 950^{o}C and were all friable. Results of mechanical tests on the test pieces revealed that Batch A_1 had a modulus of rupture of 811.2 KN/m^2 and a modulus of elasticity value of 19040 N.mm2. Batch C_1 had a modulus of rupture value of 854KN/m^2 and a modulus of elasticity value of 21200N/mm^2. Addition of silica in the form of silica sand or granite quarry dust steadily increased the modulus of rupture and the modulus of elasticity of the as received clays. The commercial grade sample had a modulus of rupture value of 3690 KN/m^2 and a modulus of elasticity of 32864 N/mm^2. The shrinkage and water absorption values of the test pieces, when compared to those of the commercial grade sample, indicate that the samples would attain a better maturity at a higher firing temperature, possibly up to about 1050^{o}C. Batches made from Edda clay could not attain reasonable maturity at 950oc because of high content of kaolin (35%) in the clay. Ishiagu clay and Unwana clay contained higher levels of more fusible minerals, such as orthoclase and muscovite that are rich in potassium. It is recommended to combine the three clays in various proportions in order to create various shades of colours in the finished products. Addition of colouring oxides to Edda clay can also be further explored, since it fires white.

KEYWORDS: *clay, modulus of elasticity, modulus of rupture, shrinkage, Terracotta, wall tiles, water absorption.*

I. INTRODUCTION

Terracotta is a fired ceramic material used since ancient times as architectural ornament. Terra cotta products are made from terra cotta bodies, a type of red earthenware usually unglazed with a typical firing temperature of around 1000^{0}C.

The high iron content gives the fired body a brownish color, which varies considerably to give yellow, orange, red terra cotta, pink, grey or brown, depending on the degree of oxidation.

Terracotta provides a natural look with an attractive clay finish and is widely used for surface decoration in both commercial and private buildings. Apart from providing superior aesthetics, terra cotta claddings perform the functional role of screening out rain from the main walls of a building. This improves a structure's life expectancy by protecting primary walls as well as increase energy efficiency of the building by providing additional insulation, (Kidder 1905).

Terracotta wall claddings weigh approximately 1060–1390 kg/m^2. Water absorption values typically range from 6 to 14 per cent by weight. Compressive strength typically ranges from 345 to 1380 N/cm^2 depending on web orientation

(Kidder et al 1956). These cladding systems also have the advantage of greater ventilation, resistance to grout & mildew, with high-energy savings, which makes them ideal for several constructions & building applications.
Compared to stone, the lighter weight of terra-cotta units allowed architects to introduce cornices and other projecting building elements. In addition, designers used terra-cotta for spandrels, sills, jambs, and heads. Further, advances in chemical engineering allowed designers to use textures, colors, and finishes unavailable in natural stone such as gold luster finishes or elaborate polychromatic finishes.
For manufacturing purposes, terracotta units measured usually about 45.7 cm long, but generally no longer than 61.0 cm, 15.2–30.5 cm deep; the height was determined by the character of the piece. By combining terra cotta units of various colors, installation personnel can produce an endless variety of patterns, (Gerns et al 2007).
The red earthenware color of terracotta can usually be altered by the nature and amount of additives in the body. The color of the ceramic body depends not only on the
total amount of iron in the mixture, but also on the way the iron is combined in clay minerals and additives and on what compounds, containing iron, are formed during the firing process of the ceramic body, (Valanciene et al 2010). Various pigments, waste products and natural raw materials can be deployed to improve the color of terra cotta products, (Sglavo et al 2000), (Corradi et al 1993).

Nigeria has an abundance of clay mineral raw materials. Some of these minerals include kaolin, ballclay, red clays, feldspar, quartz/silica, limestone, bentonite, laterite, sand, talc,dolomite, granite and many others. China clay and ball clay are the main clay raw materials used in the ceramic industry all over the world, (Herath 2003). According to the findings of Perera et al (2021), the undue dependence of local ceramic industries in developing countries on imported clays is detrimental to their economic viability. Increased utilization of red clay stocks could reduce the pressure on kaolin and ball clay stocks and make them more readily available for higher end products, (Hettiarachchi et al 2010).

Despite the abundance of local raw materials for ceramic production, Nigeria’s import of ceramic products for use in building and construction industry, including terra cotta wall tiles and claddings, stood at nearly 240 Million USD in 2015, (Akinbogun 2021).According to Grandview research (2016), the U.S. terracotta cladding market size alone was estimated at USD 456.1 million in 2015 and is expected to grow at a CAGR of 6.5 % from 2016 to 2022,

Growing demands for housing, especially in urban and semi urban settlements in Nigeria are expected to continue to drive the growth for the demand of ceramic construction materials such as terracotta claddings.

This research work aims at developing suitable terracotta cladding units that are technically comparable to commercial grade products, from various blends of local clays in south eastern Nigeria.

II. DESCRIPTION OF STUDY AREA

The beneficiation processing of all raw materials were done at the ceramic workshop of Akanu Ibiam Federal Polytechnic Unwana. The batching, blending, production of prototypes and test pieces, as well as firing and testing of prototypes were done using equipment at the ceramic workshop and materials testing laboratory of Akanu Ibiam Federal Polytechnic Unwana. X-ray analyses of the clays were done at The National Geological Research Center Kaduna.

III. MATERIALS AND METHODOLOGY

The clays used in this research work were sourced from Unwana, Edda and Ishiagu, all in Ebonyi state, south eastern Nigeria. Granite quarry dust sourced from a quarry site in Amasiri Ebonyi state, was used to supply additional silica to some batches.A jaw crusher was used to reduce the clay lumps to smaller particles and they were later sieved using mesh 30.

Five batches were formulated from each clay sample according to the formula shown in tables 1, 2 and 3 below:-

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Table 1. Batch A- Ishiagu clay

Sample No.	Ishiagu clay (wt%)	Unwana beach sand (wt%)	Limestone quarry dust (wt%)
A_1	100	0	0
A_2	90	10	0
A_3	80	20	0
A_4	90	0	10
A_5	80	0	20

Table 2. Batch B- Edda clay

Sample No.	Edda clay (wt%)	Unwana beach sand (wt%)	Limestone quarry dust (wt%)
B_1	100	0	0
B_2	90	10	0
B_3	80	20	0
B_4	90	0	10
B_5	80	0	20

Table 3. Batch C- Unwana clay

Sample No.	Unwana clay (wt%)	Unwana beach sand (wt%)	Limestone quarry dust (wt%)
C_1	100	0	0
C_2	90	10	0
C_3	80	20	0
C_4	90	0	10
C_5	80	0	20

Suitable amount of water was added to each batch to form a granulated mass with suitable plasticity for compaction. Prototype terracotta tile slabs were compacted from each batch, using a hydraulic compaction machine. Five samples were produced from each batch. A 10 cm mark was put on two samples from each of the batches, to be used in determining the shrinkage behavior.

The prototype tiles were air dried for several days, and later dried in an electric drying cabinet at 110Oc for 8 hours and then placed in a gas kiln and fired at 950Oc. The kiln was allowed to cool overnight and the tile slabs were unloaded the next day for inspection and other physical and mechanical tests. It was noted that samples mad from … did not mature at the firing temperature of 950Oc and were all friable when handled.

A. Determination of bulk density and apparent porosity

One sample was taken from each batch and weighed using a spring balance and the weight recorded as W1. The sample was then soaked in ample amount of distilled water, fully immersed in the water and left to stand for 24 hours, as described by Gadzama et al (2016). After 24 hours, the sample was brought out and wiped dry gently with a dry absorbent cloth and then weighed immediately and the weight recorded as W2.

The sample was then attached with a thread and immersed fully in water and weighed again and the weight was recorded as W3. Apparent porosity was then calculated as

$$Apparent\ porosity = \frac{W_2 - W_1}{W_2 - W_3}\ X\ 100\% \quad \text{..............................equation 1.}$$

Water absorption was calculated as

$Water\ absorbtion = \frac{W_2 - W_1}{W_1}\ X\ 100\%$ ……………………………equation 2.

Bulk density was calculated as

$Bulk\ density = \frac{W_1}{W_2 - W_3}$ …………………………………… equation 3. (Gadzama et al 2016).

B. Determination of modulus of rupture and modulus of elasticity

The test pieces were loaded in three point bend configuration and a load of 25 N was applied and the deflection of the center of the beam recorded. The distance between the supports, the width and the thickness of the test pieces were also measured as described by Temenoff et al (2008). Another set of test pieces were similarly tested in three-point loading configuration until fracture and the breaking load of the specimen were recorded.

Modulus of rupture was calculated as,

$MoR = \frac{3FL}{2BD^2} \ldots\ldots\ldots\ldots\, equation\ 4.$ $(Temenof\ et\ al\ 2008).$

Modulus of elasticity $E_f$was calculated as,

$E_f = \frac{mL^3}{4BD^3}$………………………..equation 5. (Zweben et al 1979).

C. Determination of linear shrinkage

The 10 cm mark L_0, that were originally marked on the green test pieces immediately after forming was measured after drying and the length recorded as L_d. The length of the marks were also measured again after firing and the length recorded as L_f.

Drying shrinkage was calculated as,$\frac{L_0 - L_d}{L_0}$…………..equation 6.

Firing shrinkage was calculated as,$\frac{L_d - L_f}{L_d}$…………………………equation 7.

Total shrinkage was calculated as,$\frac{L_0 - L_f}{L_0}$……………………..equation 8. ASTM C 326-09 (2009)

IV. RESULTS AND DISCUSSION

Figures 1, 2 and 3 respectively, show the x-ray qualitative analyses of Ishiagu, Edda and Unwana clays used to formulate the batch compositions. Table 4 shows the linear shrinkage results of the test pieces, while table 5 shows the bulk density, apparent porosity and water absorption of the test pieces. Similarly, table 6 shows the mechanical behavior of the test pieces as indicated by modulus of elasticity and modulus of rupture.

From the physical inspection of the samples after firing, it was observed that the addition of gray coloured granite dust in place of silica sand did not influence the colour of the fired samples. Also the test pieces made from Edda clay were quite friable and could not be subjected to further mechanical testing. This is possibly because of the high content of kaolinite (35%) in the clay, thus the test pieces did not mature at the relatively low firing temperature of 950^{o}C. The shrinkage results of the test pieces produced from Edda clay (batch B), also lend credence to this poor maturity.

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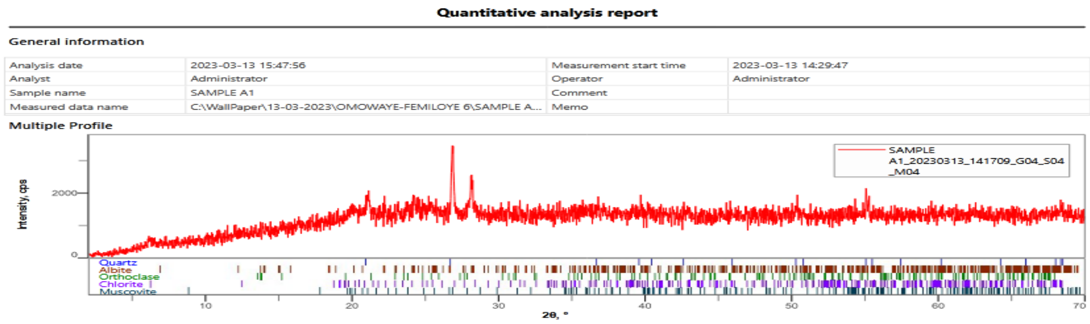
Samples made from Ishiagu clay and Unwana clay attained higher degrees of densification at 950°C because they contained more fusible minerals, such as orthoclase and muscovite that are rich in potassium, however it is obvious from comparison with the commercial grade sample, that higher temperature of firing, perharps up to 1050 °C, is required to turn these batches into suitable marketable products.

From the results of the mechanical tests on the samples, it can be observed that the addition of up to 20% silica improved the mechanical strength of the test pieces. Increasing the firing temperature of the test pieces up to about 1050°c could result in further densification and improved mechanical strength comparable with the commercial grade sample and in agreement with the recommendations of Felixberger (2006).



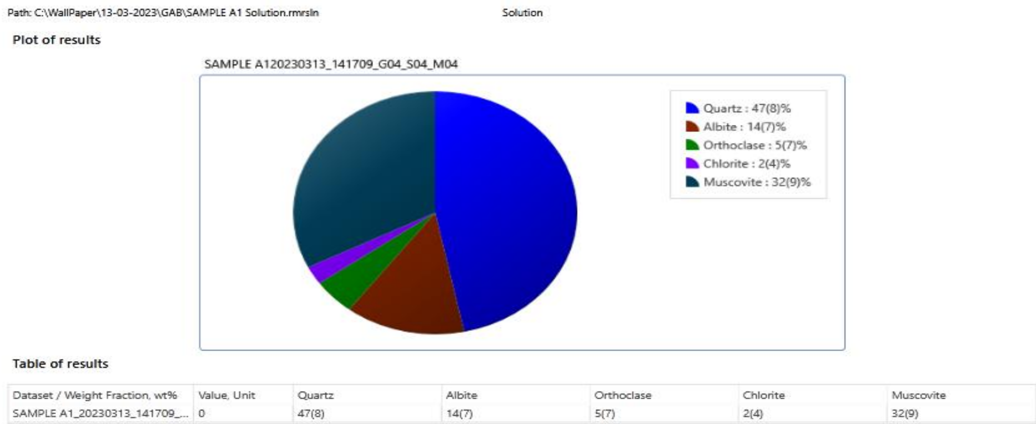


Figure 1. X-ray qualitative analyses results of Sample A- Ishiagu clay.

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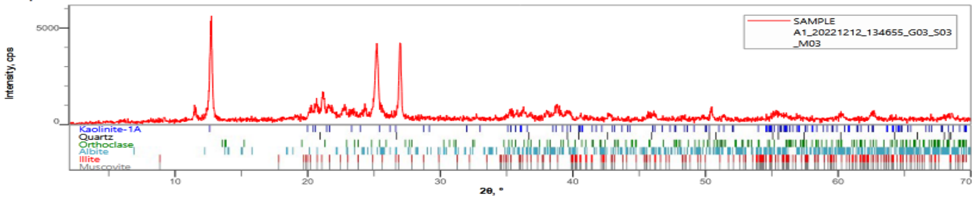
Quantitative analysis report

General information

Analysis date	2022-12-12 14:37:34	Measurement start time	2022-12-12 13:55:32
Analyst	Administrator	Operator	Administrator
Sample name	SAMPLE A1	Comment	
Measured data name	C:\WallPaper\12-12-2022B\SAMPLE A1_20221212_134655_G...	Memo	

Multiple Profile



Path: C:\WallPaper\12-12-2022B\SAMPLE A1 Solution.rmrsln Solution

Plot of results

SAMPLE A120221212_134655_G03_S03_M03

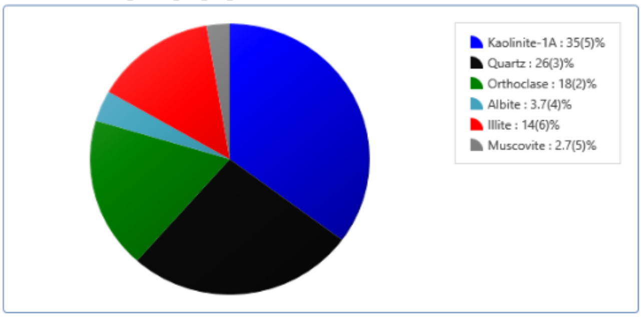


Table of results

Dataset / Weight Fraction,...	Value, Unit	Kaolinite-1A	Quartz	Orthoclase	Albite	Illite	Muscovite
SAMPLE A1_20221212_134...	0	35(5)	26(3)	18(2)	3.7(4)	14(6)	2.7(5)

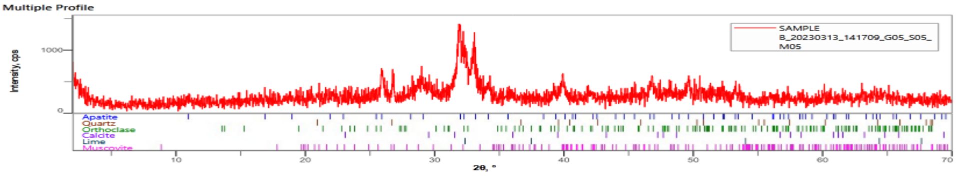
Figure 2. X-ray qualitative results of sample B- Edda clay

Quantitative analysis report

General information

Analysis date	2023-03-13 15:51:21	Measurement start time	2023-03-13 14:33:35
Analyst	Administrator	Operator	Administrator
Sample name	SAMPLE B	Comment	
Measured data name	C:\WallPaper\13-03-2023\OMOWAYE-FEMILOYE 6\SAMPLE B...	Memo	

Multiple Profile



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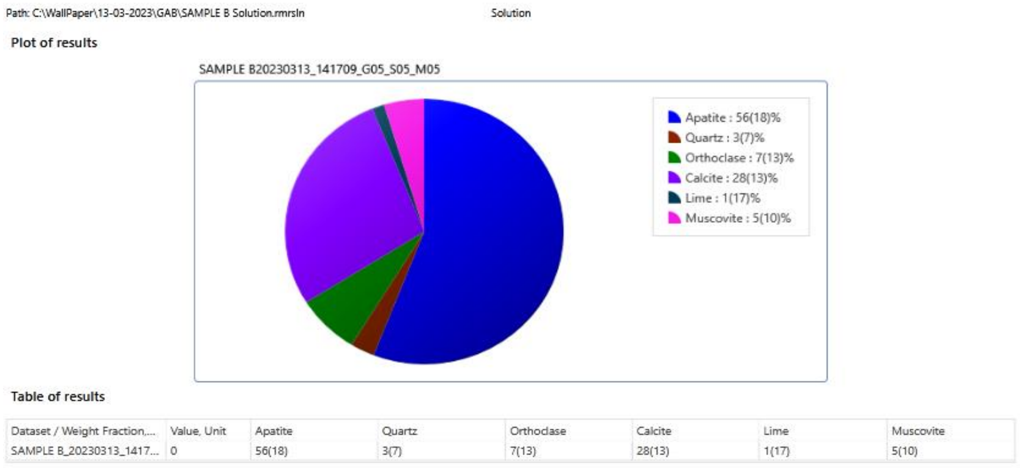

Figure 3. X-ray qualitative results of sample C-Unwana clay

Table 4. Results of physical and mechanical tests on Sample A- Ishiagu clay

Sample No.	Drying shrinkage %	Firing shrinkage %	Total shrinkage %	Water absorption %	Modulus of rupture (KN/m^2)	Modulus of elasticity (N/mm^2)
A1	2	2.04	4.0	20.78	811.2	19040
A2	2.5	0.51	3.0	15.95	876.9	21302
A3	2.6	1.43	4.0	15.15	964.6	26816
A4	2.8	0.2	3.0	15.46	964.6	24903
A5	1.0	1.0	2.0	15.89	876.9	23701
Commercial grade	n.a	n.a	n.a	10.59	3690	32864

Table 5. Results of physical and mechanical tests on Sample B-Edda clay

Sample No.	Drying shrinkage %	Firing shrinkage %	Total shrinkage %	Water absorption %	Modulus of rupture (KN/m^2)	Modulus of elasticity (N/mm^2)
B1	1.0	1.01	2.0	52.84	n.a	n.a
B2	1.0	1.01	2.0	67.97	n.a	n.a
B3	1.0	2.02	3.0	60.28	n.a	n.a
B4	1.0	2.02	3.0	59.81	n.a	n.a
B5	1.0	1.01	2.0	53.72	n.a	n.a
Commercial grade	n.a	n.a	n.a	10.59	3690	32864

Table 6. Results of physical and mechanical tests on Sample C- Unwana clay

Sample No.	Drying shrinkage %	Firing shrinkage %	Total shrinkage %	Water absorption %	Modulus of rupture (KN/m^2)	Modulus of elasticity (N/mm^2)
C1	3.0	2.06	5.0	21.75	854	21200
C2	3.2	0.82	4.0	11.30	939.2	23133
C3	3.5	1.55	5.0	19.12	1152.7	28627
C4	4.0	2.08	6.0	15.84	896.5	26401
C5	4.0	3.12	7.0	19.37	939.2	24950
Commercial grade				10.59	3690	32864

V. CONCLUSION AND RECOMMENDATION

From the results stated and discussed above, it can be concluded that Ishiagu clay, Edda clay and Unwana clay can be successfully utilized for the commercial production of terracotta wall tiles. All three clays would require to be fired at about 1050 ^{o}C for proper maturity and good strength development.

The technical characteristics of terracotta wall tiles made from these clay samples will be comparable to those of commercial grade in Nigerian market. Addition of up to 20% silica will increase the strength development of products made from these clay samples. Silica in the form of granite quarry dust will not affect the colour of the fired body from these clays, although it also contributes to strength development.

It is recommended to combine the three clays in various proportions in order to create various shades of colours in the finished products.Addition of colouring oxides to Edda clay can also be further explored, since it fires white.

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