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Physical and Mechanical Property Evaluation of Some Clay Deposits in Mubi for Production of Glazed Roofing Tiles

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Abstract: Five different clay samples were collected from different locations within Mubi Local Government Area of Adamawa State, Nigeria were mixed with 5% to 35% silica sand, which were later subjected to a compressive force to bind the mixture to produce ceramic tiles. The tiles were dried and heat treated using an electric furnace at a temperature of 1100°C for four (4) hours to produce unglazed ceramic tiles. The produced tiles are later glazed using water glass and further heated to a temperature of 1200°C for another four (4) hours to produce glazed ceramic tiles. The tiles produced were subjected to stress-strain analysis to determine their mechanical properties (compressive strength, and breaking load) and physical properties (water absorption, % shrinkage and % warpage). The results of the analysis for samples (A, B, C, and D) gave compressive strength (59.06%, 75.20%, 69.80%, and 52%) breaking load (420KN, 400KN, 410KN, and 320KN) % water absorption (8.10%, 12.10%, 10.20%, and 14.20%), % total shrinkage (6.27%, 4.64%, 4.21%, and 3.51%), % warpage (0.48%, 0.21%, 0.43% and 0.02%) respectively. The results of the analysis produced were found to be within the allowable limit recommended by the American Society of Testing and Material (ASTM).

I. Introduction

Tiles are thin slabs used for roofing, flooring, paving and making drains. They may be made of clays burnt in kilns (ceramic tiles) or concrete (cement tiles). Tiles can be classified according to usage into three kinds namely; roofing tiles, flooring or paving tiles (Singh, 1979). The manufacture of ceramic tiles involves careful preparation of clay (Peter, 1984), compressing moulding or extrusion process to be followed by drying and heating and finally the glazing operation (Adeyemi, 1987). The allowable recommended ceramic tile properties such as least compressive strength, maximum percentage water absorption water absorption and maximum percentage total shrinkage, etc are examined for floor, roof and wall ceramic tiles (Gillot, 1968).

A mixture of clay and water has unique plastic properties which can be shaped and fired in the kiln (Samuel, 1995). At the sintering temperatures, the alkali flux gives rise to molten glass which partly dissolves the other oxide constituents and binds them together on cooling. Ceramic materials are relatively cheap and easily located across the country (Adeyemi, 1989). Nigeria fortunately is blessed abundantly with materials necessary for the production of tiles. As a nation that is determined to grow industrially, we need to encourage the dependence on our locally produced tiles.

The aim of this work was to produce glazed ceramic tiles using clays from Mubi and investigate the effects of additives on the quality and mechanical properties of some selected clay soils. Also to examine the effects of varying compositions of clay/silica on the compressive strength, breaking load, % shrinkage, % water absorption and % warpage, on the tiles produced and compare them with the properties recommended by the American Society of Testing and Materials (ASTM).

II. Materials and Method -

A. Sample Collection

Base clay A, which is the Digil clay, was collected from Digil area of Mubi North. Base clay B, which is Vimtim clay, is collected from Vimtim area of Mubi North. Base clay C, which is Lokuwa clay is collected from Mubi I Primary School area of Lokuwa in Mubi North. Base clay E which is the works clay is collected from the works area in Mubi North. All the soil samples were collected from Mubi North Local Government Area of Adamawa State. The silica sand was collected from the River Yedzaram, Mubi, Adamawa State.

B. Sample Preparation

The clay samples A, B, C, D and E used for the production of tiles were collected as lumps and crushed into small sizes, dried and grounded into fine clay particle. The clays were sieved through a 500mm mesh and the silica sand was sieved through a 250mm mesh. In the production of tiles of varying silica contents for a typical base clay A, as the percentage silica additions were increased, the same corresponding percentage of base clay A were reduced by weight. For example, to produce tiles with sample A, the percentage composition mixes of silica, the silica was varied over range of 5% to 35% increment with corresponding decrease in the base clay A contents (Figure 1, x-axis of graph A). The percentage composition mixes by weight of the various clays investigated (Table 1) were thoroughly mixed in a dry condition before adding 15% to 20% water by weight to

the mixes. The quantity of water added is dependent on the types of clay compositions. The clay mixtures were then kneaded for about ten minutes until the mixed clays become plastic and workable. The clay mixtures were rolled into ball shapes and stored in a warm dark place for between 4 to 7 days. The physical properties of the five clay samples and the silica sand were determined and presented in Table 1.

C. Tiles Production

The tempered clay samples were then moulded by pressing to produce tiles of 210mm square dimension to produce good tiles, drying process (Adeyemi, 1989), should be carefully undertaken to reduce excessive warping or even crack of the tiles. To achieve this, the freshly moulded tiles were covered with polythene for one day so as to allow initial uniform moisture drying followed by stiffening process, involving removal of the polythene for three days and finally open air drying for at least seven days. The dried tiles, arranged in piles, were fired to various temperatures soaking for specified hours and heating rates as given in Table 3. Using an electric heating furnace of maximum range of 1250°C. To produce biscuit ceramic tiles (unglazed). The unglazed ceramic tiles were arranged singly to avoid gluing during melting state and fired using the kiln furnace to a temperature of 110°C to obtain unglazed tiles. The tiles produced were later glazed and reheated to a temperature of 1200°C to produce glazed ceramic roof tiles.

III. Determination of Some Physical Properties of the Clay

The experimental procedure was conducted in accordance with the American Society of Testing and Materials (ASTM) standards (Priemon, 1985). The physical properties tested include the following: percentage water absorption, percentage shrinkage, percentage warpage, and grain fineness ratio.

Table 1: Composition and Locations of Clays Investigated (% by weight) Constant Additive of 15%, 20%, 25%, 30% and 35% silica sand.

Base Clays	Locations in Mubi North L.G.A.	Varying % Main Composition	Constant % Additives Composition
Clay A	Digil	Silica + Clay A (55)	20% clay B
Clay B	Vimtim	Silica + Clay B (40)	22.5 clay C, 12.5% flux
Clay C	Lokuwa	Silica + Clay (50)	20% clay A, 15% clay D
Clay D	Lamorde	Silica + Clay D (55)	10% clay B, 15% clay A
Clay E	Works	Silica + Clay (70)	10% clay C

Constant % additives compositions are based on the clays composition mixtures for the manufacture of hard porcelain products (Grimehaw, 1971).

Table 2: Step Firing Stages used to Produce the Biscuits Tiles

S/N	Firing Stages	Temperature (°C)	Heating rate (°c/min)	Soaking Period (Hours)
1.	Water smoking	0 - 200	0.95	4
2	Dehydration	550	2.65	4
3.	Oxidation	880	4.19	4
4.	Verification	1100 - 12.1200	5.24	4
5.	Cooling	To room temperature	1.11	16

A. Percentage Water Absorption

This parameter is measured to determine the durability of the products when exposed to environmental conditions. Each tile was initially weighed on a weighing scale and later submerged in a clean water at room temperature for twenty four hours (24 hrs). After this period, the tile specimen were removed, wiped off with a clean dry cotton rag and reweighed. The percentage water absorption, on dry basis was calculated using.

$$W = \frac{Mg - Mf}{Mf} \text{-----(1) (Chindapi, 2011)}$$

Where Ms = mass of saturated tiles specimen (kg) after cold water submersion, Mf = fired mass of tile specimen (kg). The recorded percentage water absorption was based on the average of percentage water absorption obtained for five tiles of the same composition.

B. Percentage Shrinkage

The percentage shrinkage properties were determine by measuring the original length of the given tile along the centre and re-measuring the lengths after drying and firing of the tiles using a vernier calliper. The percentage shrinkage were determined using the following relationships. The percentage total shrinkage was determined from percentage dry shrinkage and percentage fired shrinkage.

$$\begin{aligned} \% \text{ dry shrinkage} &= \frac{L_0 - L_1}{L_0} \times 100 \text{----- (2a)} \\ \% \text{ fired shrinkage} &= \frac{L_0 - L_2}{L_0} \times 100 \text{----- (2b)} \\ \% \text{ total shrinkage} &= \frac{L_0 - L_3}{L_0} \times 100 \text{----- (2c)} \end{aligned} \quad \left. \vphantom{\begin{aligned} \% \text{ dry shrinkage} \\ \% \text{ fired shrinkage} \\ \% \text{ total shrinkage} \end{aligned}} \right\} \text{ (Chindapi, 2011)}$$

Where: L_0 = original length (mm) of the green tile
 L_1 = fired length (mm) of the dried tile
 L_2 = fired length (mm) of the fired tile

C. Percentage Warpage

Warping is the measurement of curvature (convex or concave) of deviation of the tiles surface from a true plane along the edges or the diagonals. The deviations were measured at the mid-length of an edge or a diagonal and expressed as percentage of the length of the edge or diagonal. The method was used by initially setting a dial indicator to zero at the mid-centre of the tiles and later moving the dial indicator lines on the tiles. The percentage warpage were calculated from

$$\% \text{ warpage} = \frac{W_i}{D_i} \times 100 \text{----- (3) (Gillot, 1968)}$$

Where: W_i (mm) Amount of warpage
 D_i (mm) = the gauge length

D. Grain Fineness Ratio

The clay samples collected as lumps and crushed into small sizes, dried and grounded into fine clay particle and weighed on a weighing balance. The clay was then sieved through a 500 μ m mesh to obtain the fine grain particle size. The grain fineness ratio was found to be the ratio of the sieved fine clay particle to the mass of the grounded clay particles before sieving.

$$GFR = \frac{Ms}{Mc}$$

Where GFR = grain fineness ratio, MS is the mass of sieved clay particles in M and Mc is the mass of the grounded clay before sieving in M.

The recorded percentage warpage was based on average percentage warpage of at least five tiles of the same composition.

IV. Mechanical Property Tests

The mechanical properties, compressive strength, breaking load of the tiles produced were tested as follows.

i. Compressive Strength

The tile specimen was placed on a hardened steel plate, load was gradually applied by a manually operated hydraulic press through an indicator or load applicator until there was a sign of crack. The compressive strength was calculated from

$$\sigma_c = \frac{W}{A} \text{----- (4) (Priemon, 1985)}$$

Where w = maximum load attained (Mpa) and A = area of load applicator (m²). The recorded compressive strength was an average value of at least five test specimens of a given tiles composition mixes.

ii. Breaking Load

The test method consists of supporting the tile specimens on the ends of the three cylindrical rods, arranged in an equilateral triangle form and applying a load until the tile specimen failed. The tiles strength was the load necessary to cause such tile failure. The tiles strength recorded was based on average values of at least five tiles of the same composition mixes.

V. Results and Discussion

Physical Properties

Table 3 shows the physical properties for the various clay samples and silica sand used for the production of ceramic tiles.

Shrinkage of the Glazed Ceramic Tiles

Figure 1 shows the effect of increase in percentage of silica sand on the percentage shrinkage of glazed ceramic tiles.

It was observed that products made from clay sample A have a slight decrease in the percentage shrinkage from 6.25, 5.9, 5.0, 4.9, and 4.1 with increase of the silica sand of 15%, 20%, 25%, 30%, and 35% respectively.

While for tiles produced with clay sample B, the percentage shrinkage shows an initial increase in the value of 4.6, 4.7, 4.9 at 5%, 10% and 15% silica sand addition, then maintains a constant value of 4.9 with increase of silica sand from 15%, 20% and 25%.

Sample C tiles indicate slight increase in percentage shrinkage of 4.2, 4.4, 4.7, 4.8, 4.9 with increase of silica sand addition from 5% to 35%.

Clay sample D showed initial constant shrinkage value at 3.6% at 5%, 10%, and 15% silica sand addition before decreasing in value to 3.3% and 3.2% at 20% and 25% silica sand addition.

Figure 1 shows that clay tiles A has the highest shrinkage value of 6.27%, while clay sample D indicate the lowest shrinkage value over the percentage silica sand addition. The shrinkage value of all the tiles produced were found to be within the shrinkage value recommended by the American Society of Testing and Materials (ASTM) values (15% max).

Water Absorption of the Glazed Ceramic Tiles

Figure 2 shows the percentage water absorption with percentage silica sand addition for all the samples investigated.

Clay A indicates slight increase in percentage water absorption of 9.1%, 9.2%, 9.3%, 9.4% and 10% at 15%, 20%, 25%, 30% and 35% silica sand addition and gave the least percentage water absorption of 9.1% at 15% silica sand addition.

Clay sample B shows decrease in water absorption with percentage silica sand addition of 12%, 11.8%, 11.7%, 11.6%, 11.5% at 5%, 10%, 15%, 20% and 25% silica sand addition respectively.

Clay C tiles shows initial constant water absorption of 10.20%, at 5%, 10% and 15% silica sand addition then decrease to 10.10, and 10.50 at 20% and 25% silica sand addition respectively.

Clay D tiles shows decrease in percentage water absorption from 14.20%, 13.9%, 13.2%, 13%, 12.9%, at 5%, 10%, 15%, 20% and 25% respectively.

Clay sample D gave the highest percentage water absorption of 14.20% at 5% silica sand addition, followed by clay sample B, 12.10% at 5% silica sand addition and least percentage water absorption by clay sample A, 9.1% at 5% silica sand addition. Clay sample A, with least percentage water absorption will withstand exposure to water than tiles D with highest percentage water absorption. The values of the water absorption of all the tiles were found to be within the allowable limit recommended by ASTM which is 16.0% max.

Percentage Warpage of the Glazed Ceramic Tiles

From Table 3, the percentage warpage for samples A, B, C, and D are 0.48, 0.21, 0.43 and 0.42 respectively. The percentage warpage obtained for all the samples investigated were found to be within the percentage warpage range (Gillot, 1970) of 2.1% as specified by ASTM standard. The variation in percentage warpage obtained may be due to the drying/firing methods applied.

VI. Mechanical Properties

Compressive Strength of the Glazed Ceramic Tiles

Figure 3 shows compressive strength values with increase of silica percentage sand addition for ceramic tiles produced.

Sample A tiles shows an initial constant of compressive strength of 59.06Mpa at 15%, 20%, and 25% silica sand addition then decrease to 48Mpa and 44Mpa at 30% and 35% respectively.

Sample B tiles shows an increase of compressive strength of 40Mpa, 45Mpa, 59Mpa, 65Mpa and 75Mpa at 5%, 10%, 15%, 20% and 25% sand addition respectively.

Clay sample C tiles shows a gradual decrease in compressive strength as the percentage of silica sand increases from 70Mpa, 65Mpa, 49Mpa, 41Mpa and 36Mpa at 5%, 10%, 15%, 20% and 25% respectively.

Clay D tiles shows increase in compressive strength of 30Mpa, 35Mpa, 42Mpa, 45Mpa and 52Mpa 5%, 10%, 15%, 20% and 25% silica sand addition respectively.

Clay sample B gave the highest compressive strength of 75.20Mpa followed by clay sample C 69.80Mpa and least with clay sample D. All the clay samples have compressive strength value within the allowable value (48Mpa), recommended by the American Society of Testing and Materials.

Breaking Load (KN) for the Glazed Ceramic Tiles

Figure 4 shows a plot of breaking load with percentage silica sand addition. This figure indicates that there is increase in breaking load, as the percentage silica sand addition increase for all the tiles produced from all the four clay samples investigated.

Clay sample A shows an increase in breaking load of value 280KN, 300KN, 320KN, 350KN, and 420KN at 15%, 20%, 25%, 30% and 35% respectively, with an increase of percentage silica sand addition.

Clay sample B shows an initial constant value of breaking load 280KN, at 5% and 10% silica sand addition then increase to 320KN, 340KN, 400KN at 15%, 20%, 25% silica sand addition.

Clay sample C shows an increase of breaking load of 260KN, 320KN, 340KN, 370KN, 410KN, at 5%, 10%, 15%, 20% and 25% silica sand addition respectively.

Clay sample D shows an increase of breaking load from 240KN, 250KN, 260KN, 300KN, 320KN at 5%, 10%, 15%, 20% and 25% silica sand addition respectively.

Clay sample A gave the highest breaking load of 420KN followed closely by tiles produced from clay sample C and B, 410KN and 400KN respectively. Clay sample D gave the lowest breaking load of 320KN over the percentage silica sand addition. The breaking load for all the tiles produced were found to be within the allowable limit recommended by ASTM (260KN minimum).

Optimum Tile Properties

The best percentage composition mixed clay samples investigated to produce the tiles (glazed) with the optimum properties were determined based on the following properties maximum values of compressive strength, and breaking loads, minimum value of percentage total shrinkage and percentage warpage of the tiles produced.

Table 4 showed the best percentage composition mixture for optimum properties of glazed ceramic tiles produced using the clay samples investigated were found to give values recommended by the American Society of Testing and Materials (ASTM).

Table 3: Physical Properties of Clays

S/N	Physical Properties	Clay A	Clay B	Clay C	Clay D	Clay E	Silica
	Colour	Reddish Brown	Creamy Grey	White	White	Creamy White	Creamy
1.	Specific gravity	2.31	2.03	2.00	2.01	2.62	2.73
2.	Clay content (%)	77.50	77.50	41.25	40.10	46.10	3.00
3.	Initial moisture content (%)	2.56	1.28	1.29	19.70	18.50	6.67
4.	Grain fineness ratio	86.50	69.86	83.83	89.73	64.92	65.4

Table 4: Percentage composition for optimum properties of unglazed tiles

Base Clay	Composition of Mixture	Compressive Strength (Mpa)	Breaking Load (1N)	% Water Absorption	% Total Shrinkage	% Warpage
A	55%, 20%, 25% Clay A, Clay B Silica	51.39	380.00	10.23	8.23	0.56
B	40% 22.5% 12.5% 25% Clay B Clay A Flux Silica	69.07	330.00	12.00	5.61	0.36
C	50% 20% 15% 15% Clay C Clay A Clay D Silica	56.50	357.00	11.14	6.20	0.63
D	55% 10% 15% 20% Clay D Clay B Clay A Silica	41.0	234.64	15.41	5.20	0.63
E	70% 20% 10% Clay E Clay D Silica	It cracked all over, it was therefore ruled out of the experiment				

Table 5: Percentage (%) composition for optimum properties of glazed tiles

Base Clay	Composition of Mixture	Compressive Strength (mpa)	Breaking Load (KN)	% Water Absorption	% Total Shrinkage	% Warpage
A	55% 20% 25% Clay A Clay B Silica	59.06	420.00	9.10	6.27	0.48
B	40% 22.5% 12.5% 25% Clay B Clay C Flux Silica	75.20	400.00	12.10	4.64	0.21
C	50% 20% 15% 15% Clay C Clay A Clay D Silica	69.80	410.00	10.20	4.21	0.43
D	55% 10% 15% 20% Clay D Clay B Clay A Silica	52.00	320.00	14.20	3.0	0.42
	ASTM allowable values	48Mpa (Min)	260KN (Min)	16.0 (Max)	15% (Max)	2.1% (Max)

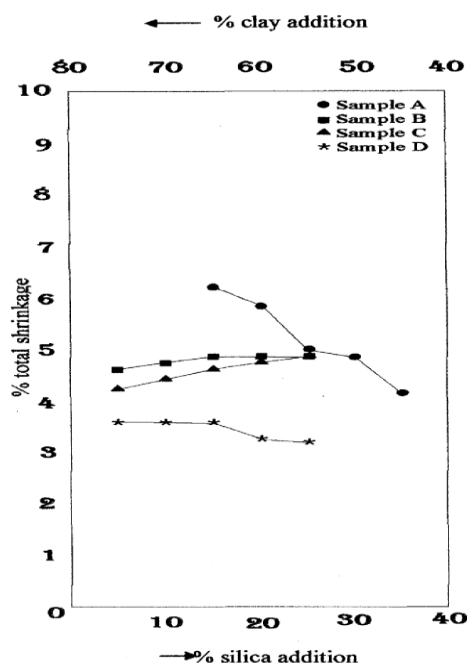


Fig. 1: Effect of percentage increase of silica sand on the percentage total shrinkage of glaze tiles

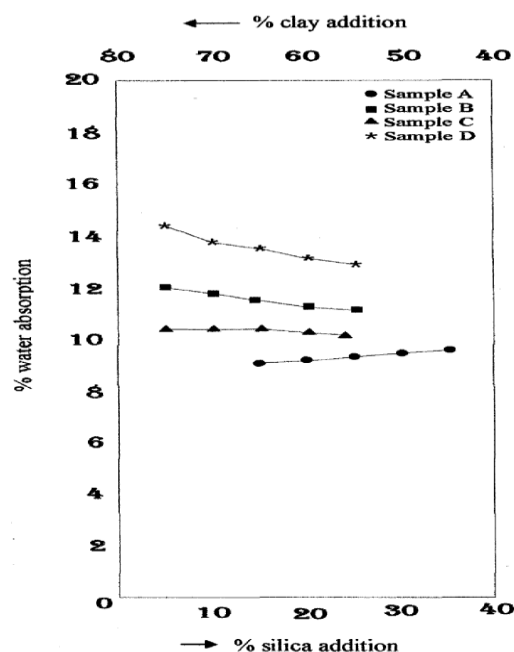


Fig. 2: Percentage water absorption with percentage silica sand addition for glazed tiles

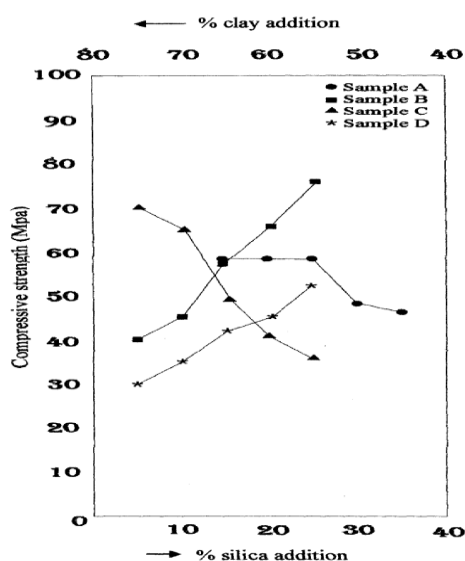


Fig. 3: Compressive strength versus percentage silica sand addition for glaze tiles

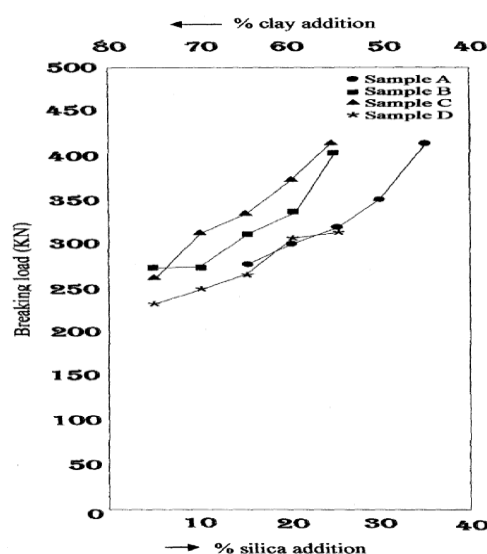


Fig. 4: Breaking load versus percentage silica sand addition for glazed tiles

VII. Conclusion

Increase of percentage silica sand addition within the percentage range investigated had the following effects on tiles properties.

- Decrease in percentage water absorption of all the tiles produced with percentage silica sand addition, except for slight increase of percentage absorption produced from clay sample A.

- ii. The breaking load of tiles produced increase for all four clay samples investigated, showing a positive effect of increase in silica sand addition.
- iii. The compressive strength increase (a positive effect) for tiles produced from base clays B and D, showing the effects of silica addition to these base clay samples.

The percentage shrinkage decrease (a positive effect) for tiles produced from base clay A and D plus a slight increase (a negative effect) on tiles produced with clay samples B and C.

Ceramic roof tiles produced by using best composition mixture for all the four clay samples were found to give properties (physical and mechanical) that are within the allowable limit recommended by the American Society of testing and Materials (see Table 5)

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