



## Original Research Article

### EVALUATION OF THE PHYSICAL, CHEMICAL, MINERALOGY AND THERMAL CHARACTERISTICS OF CLAY FOR THE PRODUCTION OF LOW VOLTAGE ELECTRICAL PORCELAIN INSULATOR

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#### ABSTRACT

*This study evaluated a clay sample from Umuezeagu, Obowo in Imo state, Nigeria. The study evaluated the physical and chemical properties, mineralogy and technique fitness of the clay for the production of low voltage electrical insulator. X-Ray Fluorescence (XRF) and the X-Ray Diffraction (XRD) were used to determine the chemical composition and the bulk analysis (mineralogy) of the clay respectively. Also, other established processes were used to determine the physical properties of the clay such as shrinkages, apparent porosity, water absorption, bulk density, apparent density, modulus of rupture, making moisture and refractoriness. The values of bulk density, apparent density, apparent porosity, water absorption, linear shrinkage, total shrinkage, modulus of rupture and making moisture obtained at 1200°C were 1.613g/cm<sup>3</sup>, 2.633g/cm<sup>3</sup>, 38.749%, 24.039%, 4.918%, 13.0%, 41.278kgf/cm<sup>3</sup> and 30.529% respectively. The refractoriness was > 1200°C. These showed its suitability for the production of electrical porcelain insulator.*

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## 1. INTRODUCTION

It has been recognized that plentiful raw materials are available for the manufacture of electrical porcelain insulators as well as heated ceramic wares in Nigeria (FMST, 2004). Insulators are comprehensively used for high and low voltage applications in generation, transmission and distribution of electrical power.

Clay is found underneath the topsoil, practically at most deposit sites in the world. There is a wide variety of different clays, but they all have to a greater or lesser extent, two fundamental properties that make them useful to us. The fundamental properties are insulation and thermal characteristics. Datiri and Yusuph (2004) reported

that clay is formed because of the decomposition of igneous rock of some geologic hypogenic actions that result from the mixture of gases and vapour in the interior of the earth's crust over a very long period. It must be about some million years ago. Sullayman (2006) reported that there are two views about the origin of clays, one preferred by a geologist, the other by chemists. The Ceramist classified clay into two categories, i.e. primary clay and secondary clay. Because of the natural sedimentation, secondary clays are contaminated with organic substances; these impurities include iron oxide and limestone (Cochrane, 1969).

Porcelains are among the primary materials used for insulation on power lines. They are polycrystalline ceramic bodies containing typically more than about 10 volume percent of a vitreous second phase (Buchanan, 1991; Cho and Yoon, 2001). Electrical porcelains are widely used as insulators because of the high stability of their electrical, mechanical and thermal properties in the presence of harsh environments. These are some of the reasons for their continued use over the decades despite the emergence of new materials like plastics and composites. They are considered to be one of the most complex ceramic materials and represent the most widely studied ceramic system (Dana and Das, 2004). Although the production of porcelain insulators has been ongoing for over 50 years, there remain significant challenges in understanding porcelains about raw materials, processing science, phase and microstructure evolution (Carty and Senapati, 1998).

This study aims to explore the suitability of Umuezeagu clay for ceramic production of low voltage pin electrical porcelain insulator that met acceptable standard criteria using local raw materials. The study evaluated the physical, chemical and the mineralogy of the clay. Also, the study determined the thermal characteristic of the clay.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Table 1 shows a list of primary materials used in the formulation of porcelain insulator. A 100 mesh sieve, magnetic sieve, containers, plaster-of-paris (POP) moulds, kiln, electronic weighing balance, vernier calliper, electric drying oven, mortar and pestle, pyrometer and volumetric flask were used in the apparatus set up for the formulation process.

Table 1: Materials for porcelain insulator formulation

S/No	Description
1	Kaolin (Umuezeagu clay)
2	Feldspar
3	Silica

### 2.2. Methods

#### 2.2.1. Chemical analysis of Umuezeagu clay

Samples of Umuezeagu clay was collected and taken to National Geosciences Research Laboratories Centers, Kaduna, for chemical analysis (XRF and XRD). In the XRF analysis, the finely ground raw clay mineral was pressed into a compact form and then fused with lithium tetra-borate flux in a glass bead. An X-ray beam from a tungsten X-ray gun was focused on the specimen. The focused X-rays cause the elements present in the specimen to excite leading to the emission of secondary X-rays that are characteristic of the elements. The amount of emission is also directly proportional to the concentration of the element present in the sample. The

X-ray spectrum of the sample was computer processed to determine the elements present and their concentrations.

### 2.2.2. Moulding of the test pieces

The plastic clay was then moulded into three types of shapes using metal moulds and the application of lubricants to the surface of the moulds to prevent the test pieces from sticking to the surface. The first shape was cylindrical with a width of 3.5 cm and height 3.82 cm. The second was a rectangular piece with length 8 cm, width 4 cm and height 1.5 cm. Finally, the third was rectangular shape with length 9.5 cm, width 2 cm and height 1.5 cm (Lynne et al., 1980).

### 2.2.3. Relative plasticity

The dependent plasticity was determined using the cylindrical test pieces. The original height,  $H_o$  of the test pieces were obtained by the use of the vernier calliper by taking the average of three sides. Afterwards, a manual plastometer machine was used to deform the test pieces. The deformation height  $H_i$  was recorded taking the average of three sides. The relative plasticity was then calculated (Lynne et al., 1980).

$$\text{Relative Plasticity} = H_o/H_i \quad (1)$$

### 2.2.4. Making moisture

The making moisture was determined by weighing the cylindrical test pieces immediately after moulding and the wet weight recorded as  $W_o$ . The test pieces were air-dried for 7 days and then dried in an oven at 105 °C until a constant weight was recorded. After drying the test pieces were weighed and the dry weight recorded as  $W_i$ . The making moisture (Moisture Content) was then calculated using the Equation (2).

$$\text{Making Moisture}(\%) = \frac{W_o - W_i}{W_o} \quad (2)$$

### 2.2.5. Test for shrinkage

Immediately after moulding of the rectangular test pieces, a vernier calliper was used to insert a 5 cm mark on each of them; this was recorded as the original length  $L_w$  (cm). The test pieces were then air dried for 7 days and then dried in an oven at 110 °C until an even weight was obtained. The shrinkage from the 5 cm mark was then determined. Also, the shrinkage was recorded as the dried length,  $L_d$ (cm). Subsequently, four of the dried samples were fired to their respective temperatures of 800, 900, 1000 and 1100 °C each temperature corresponding to a particular test piece. The shrinkage of the test pieces from the 5cm mark was then determined and recorded as the fired length,  $L_f$  (cm). The shrinkage was then calculated using Equations (3), (4) and (5) (Lynne et al., 1980).

$$\text{Wet - Dry (Drying) Shrinkage} = \frac{L_w - L_d}{L_d} \times 100\% \quad (3)$$

$$\text{Linear (Fired) Shrinkage} = \frac{L_d - L_f}{L_d} \times 100\% \quad (4)$$

$$\text{Total Shrinkage} = \frac{L_w - L_f}{L_w} \times 100\% \quad (5)$$

Where:

$L_d$  = Dry length

$L_w$  = Wet length

$L_f$  = Fired length

### 2.2.6. Water absorption/porosity rate and density

To enhance glaze application on wares made from the clay, its porosity and absorption rate was tested.

#### 2.2.6.1. Water absorption

The fired test pieces obtained from Equation 5 were then weighed, and the weight recorded as dry weight,  $W_d$  (g). After that, the test pieces were soaked in water for 24hrs, then removed, cleaned and weighed immediately and recorded as soaked weight,  $W_s$  (g). The water of adsorption was then calculated (Lynne *et al.*, 1980).

Water absorption was calculated as a function of the specimen's weight difference before and after water submersion. The water absorption was computed using Equation (6).

$$\text{Water Absorption \%} = \frac{W_s - W_d}{W_d} \times 100 \quad (6)$$

Where:  $W_s$  = Soaked Weight for 24 hours;  $W_d$  = Dry Weight

#### 2.2.6.2. Porosity and density

After the procedure described in section 2.2.7.1 was completed. The suspended weight of the test pieces was then determined by the use of a lever balance and recorded as  $W_{sp}$  (g). The apparent porosity was then calculated as a function of the specimen's weight difference between soaked weight and dry weight to specimen's weight difference between soaked weight and suspended immersed weight. The results were obtained by Equation (7). Apparent density and bulk density were then obtained using Equations 9 and 10 (Akwilapo and Wiik, 2003).

$$\text{Apparent Porosity} = \frac{W_s - W_d}{W_s - W_{sp}} \times 100\% \quad (7)$$

$$\text{Apparent Density} = \frac{W_d}{W_d - W_{sp}} \times 100\% \quad (8)$$

$$\text{Bulk Density} = \frac{W_d}{W_s - W_{sp}} \times 100\% \quad (9)$$

Where:  $W_s$  = Soaked Weight;  $W_d$  = Dry Weight;  $W_{sp}$  = Suspended Immersed Weight

### 2.2.7. Modulus of rupture (Strength)

Five long rectangular test pieces were made and air dried for 7 days after which they were oven dried at 110°C until an even weight was obtained. Four of the pieces were fired to their respective temperatures of 900, 1000, 1100 and 1200°C in a laboratory kiln (Fulham Pottery). The electrical transversal strength machine was used to determine the breaking load, P (Kg). A vernier calliper was used to determine the distance between supports L (cm) of the transversal machine, which is 7cm. The height, H (cm) and the width, B (cm) of the broken pieces were determined. The average value obtained from the two broken parts was recorded. The modulus of rupture was obtained using Equation 11 (Akwilapo and Wiik, 2003).

$$\text{Modulus of Rupture (kg/cm}^2\text{)} = \frac{3PL}{2BH^2} \quad (10)$$

### 2.2.8. Production of low voltage electrical porcelain insulator using slip casting

Electrical porcelain test samples were prepared, formulated and produced following the steps are shown in Figure 1. The plates of the produced porcelain insulators are shown in the appendix.

### 2.2.9. Bisque firing, glazing and gloss firing process

The dried samples were placed in the Kiln, fired between the temperatures of 800°C to 900°C which is called Bisque firing. The samples were removed from the kiln and allowed to cool for 24 hours then glazed, and gloss fired at the temperatures of 1250°C and subsequently cooled to ambient temperature.

The porcelain bodies were formulated by varying the compositions of the plastic materials (Obowo clay), fluxing agents (Feldspar) and inert materials (Silica) as shown in Table . Different batches were mixed with water to keep it in a plastic state, then little sodium silicate (NaSiO<sub>2</sub>) (deflocculant) was added to reduce the power of suspension and to keep the body in slurry form (slip) for smooth casting. The mixing ratio of the formulated body, water and sodium silicate were in the ratio of 1: 0.5: 0.06 respectively. The mixed samples were sieved with 120 mesh and allowed to age for 24 hours in a plastic container.

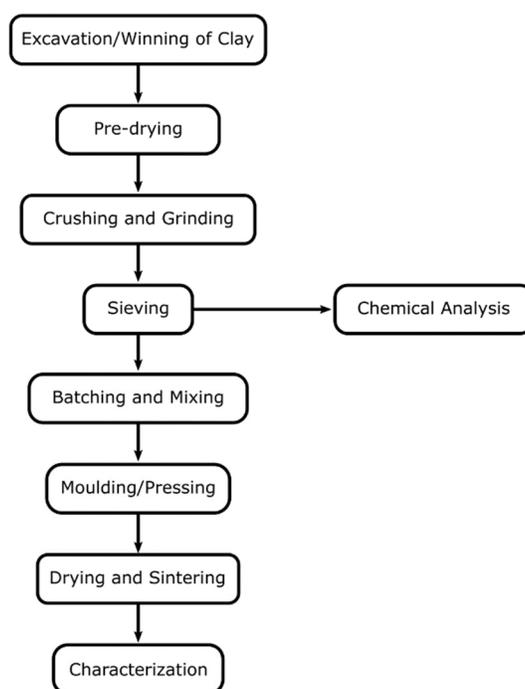


Figure 1: Flowchart of electrical porcelain production

Table 2: The porcelain bodies formulation compositions

Samples	Kaolin	Feldspar	Silica
A	40.00	40.00	20.00
B	46.66	20.42	32.92
C	54.16	20.42	25.42
D	60.00	15.00	25.00
E	42.50	40.00	17.50
F	44.16	32.92	22.92
G	60.00	25.00	15.00
H	48.33	25.83	25.84
I	40.00	30.00	30.00
J	52.50	15.00	32.50
K	42.50	17.50	40.00
L	45.00	15.00	40.00
M	45.00	40.00	15.00
N	54.16	25.42	20.42
O	40.00	20.00	40.00
P	52.50	32.50	15.00
Q	46.66	32.92	20.42
R	44.16	22.92	32.92
S	60.00	20.00	20.00

### 2.2.10. Solid slip casting and dry process

After preparing the slip, the slip poured into an already made P.O.P porcelain insulator mould. It was topped continuously for about 2 to 3 hours for the body to cast to solid settles and allowed for 24 hours or 48 hours to leather hard stage. The casted electrical porcelain samples were fettled and dry to the bone-dry stage.

### 2.2.11. Electrical breakdown voltage test

Flashover test was carried out concurrently on the fabricated specimen. The procedure of this test is highlighted, and the test circuit diagram is shown in Figure 2. High voltage A.C. tests at 50 Hz are carried out routine tests on low voltage (415V to 11KV) porcelain insulators. Each one of these insulators was subjected to a high voltage to determine the breakdown voltage; these tests are carried out after manufacture before installation. The recorded flashover voltage value was the arithmetic mean of five individual flashovers taken consecutively.

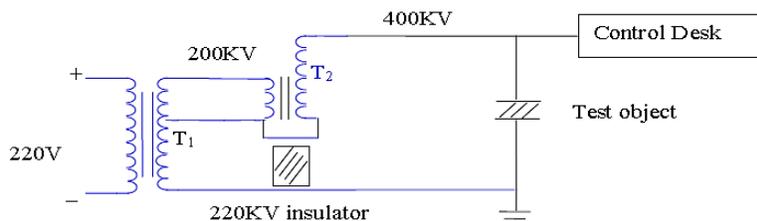


Figure 2: Test circuit diagram for the breakdown voltage

## 3. RESULTS AND DISCUSSION

### 3.1. Physical Content of the Clay

The clay under study is white. It is coarse in texture and smoothes when sieved. In a laboratory where the clay was studied under a microscope, the shapes of the particles are plate-like, and the size of each particle is about one micron. The collected clay was dispersed in excess distilled-deionised water in a pre-treated plastic container and stirred vigorously to ensure proper dissolution. The dissolved clay was then filtered to get rid of unwanted particles and plant materials. The remains obtained was allowed to settle for 48 hrs after which excess water was decanted. The settled clay at the bed of the container was sundried for several days to get rid of excess water molecules. After drying the clay, it was crushed into powder and sieved through a 100um mesh sieve; the sieved clay was then mixed with appropriate amount of water to make it plastic for the moulding process. The volume of water used was recorded.

### 3.2. Sample Description

Umuezeagu clay varies in physical characteristics such as cream with some brown stain though not conspicuous. The lumps are hard with a coarse texture. When crushed to powdery form it disintegrates into more fine particles. After pounding and sieving, it was observed that when mixed with water the substance became plastic, which suggests that the clay is kaolin as compared with other Kaolin from other locations in Nigeria

### 3.3. Chemical Composition

The X-Ray Fluorescence (XRF) Analysis of Obowo Clay samples as shown in Table 3 indicates that the clay has high contents of silica (59.70%) and alumina (33.00 %) and other elements appear in smaller quantities. Therefore, the clay can be classified as an alumina-silicate type of clay. The clay compositions mainly SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> are in qualitative agreement with the refractory clay results; 46 – 62 % SiO<sub>2</sub>, 25 – 39 % Al<sub>2</sub>O<sub>3</sub> and 40 – 60 % SiO<sub>2</sub>, 25 – 45 % Al<sub>2</sub>O<sub>3</sub>, respectively reported by (Chester, 1973) and (Grimshaw, 1971). These average values for alumina and silica make the Obowo clay to appear suitable for porcelain and other ceramic products production. The slight volume of silica in the clay shows that the sample obtained at the site was from the surface if the mining could go more in-depth purer content with lesser silica content can be obtained. The slightly high content of iron Fe<sub>2</sub>O<sub>3</sub> (2.544wt %) was responsible for the brown stain on the mineral at raw stage (Yakubu, 2009).

Table 3: Chemical analysis of Umuezeagu clay

Sample	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	K <sub>2</sub> O	CaO	Sc <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	V <sub>2</sub> O <sub>3</sub>	Cr <sub>2</sub> O <sub>3</sub>	MnO	Fe <sub>2</sub> O <sub>3</sub>	NiO
Kaolin (%)	33	59.7	0.498	0.067	0.0009	2.15	0.10	0.018	0.0074	2.544	0.0042
	CuO	ZnO	Ga <sub>2</sub> O <sub>3</sub>	SeO <sub>2</sub>	Ag <sub>2</sub> O	WO <sub>3</sub>	Re <sub>2</sub> O <sub>7</sub>	Au	HgO	PbO	Bi <sub>2</sub> O <sub>5</sub>
	0.0092	0.003	0.015	0.066	0.593	0.018	0.061	0.07	0.02	0.47	0.78

### 3.4. X-ray Diffraction (XRD) Analysis

The crystallographic and microstructural/mineralogical details of the clay can be seen in Figure 3 to 5. The significant minerals contents are kaolinite and quartz. Table 2 shows the result of shrinkage, apparent porosity, apparent density, bulk density, the water absorption, modulus of rupture for fire, modulus of plasticity, making moisture and refractoriness.

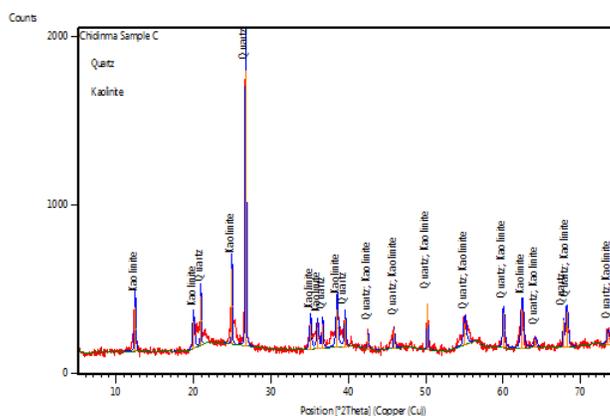


Figure 3: XRD result measuring bulk analysis of the clay combined

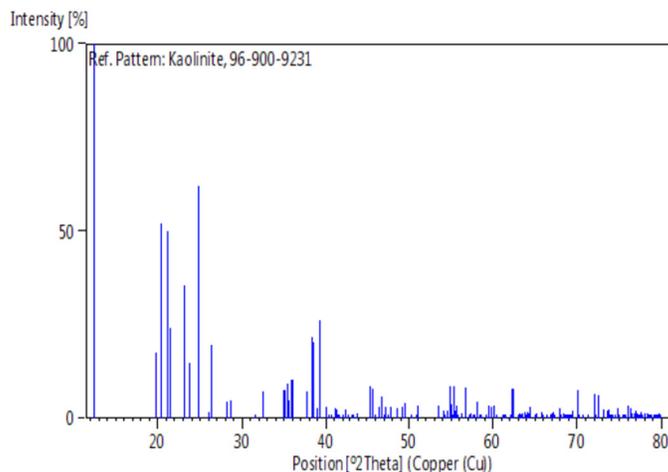


Figure 4: XRD result measuring bulk analysis of the clay Kaolinite

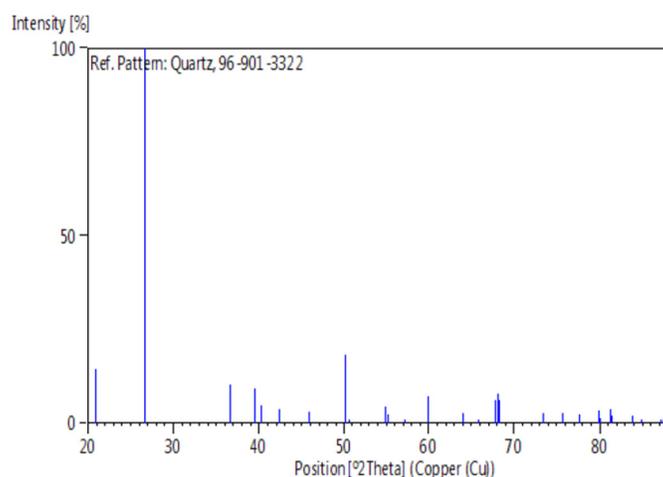


Figure 5: XRD result measuring bulk analysis of the clay Quartz

Table 2: The result of physical properties of Umuezeagu clay

Parameter/Temperature	900 °C	1000 °C	1100 °C	1200 °C
Wet-Dry Shrinkage (%) at 110 °C	8.2	8.8	8.7	8.5
Linear Shrinkage (%)	2.506	3.179	3.724	4.918
Total Shrinkage (%)	10.5	11.7	12.1	13.0
Apparent Porosity (%)	43.789	42.235	41.245	38.749
Apparent Density (g/cm <sup>3</sup> )	2.782	2.731	2.703	2.633
Bulk Density (g/cm <sup>3</sup> )	1.562	1.578	1.588	1.613
Water Absorption (%)	28.055	26.772	25.986	24.039
Modulus of Rupture (kg/cm <sup>3</sup> )	18.446	23.288	38.889	41.278
Green Modulus of Rupture (kg/cm <sup>3</sup> )	11.776			
Modulus of Plasticity	2.395			
Making Moisture (%)	30.529			

### 3.5. Linear Shrinkage

Table 2 shows the linear (dry-fired) shrinkage and the total (fired) shrinkage of the sample from the green stage (110°C to 1200°C). The linear shrinkage values vary from 2.51% at 900°C to 4.92% at 1200° which is slightly lower values for this sample when compared with the kaolinites and fired clays suggest a high content of non-fluxing impurities. The total (wet – fired) shrinkage was in the range of 10.5% – 13.0%. The total shrinkage is of little importance since their values changes with moisture content during casting.

### 3.6. Apparent Porosity

Table 2 also shows the apparent porosity value of this clay. The values for the temperature range of 900°C – 1200°C were in the range of 43.8%-38.7% which is within the internationally permissible value of 20 – 80% for fired bricks. This shows that as the temperature increases, the percentage apparent porosity decreases, indicating more closure of the pores.

### 3.7. Modulus of Rupture

At the green stage (110° C), the sample had the strength of 8.524kgF/cm<sup>3</sup>. The values for the temperature range of 900°C – 1200°C were in the range of 18.446kgF/cm<sup>3</sup> – 41.278kgF/cm<sup>3</sup>. The strength increased with increase in temperature.

### 3.8. Bulk Density and Apparent Density

For the values of bulk density, at 900°C – 1200°C, the bulk density of the clay was found to be in the range of 1.5 – 1.613g/cm<sup>3</sup>. As the temperature increase, the bulk density increase further due to the clay has not reached its melting point (fusing stage) while the apparent density (solid density) range from 2.78g/cm<sup>3</sup>-2.63g/cm<sup>3</sup> which fell within the internationally accepted range of 2.3—3.5g/cm<sup>3</sup>. The apparent density increased with a decrease in temperature.

### 3.9. Water Absorption

For the values of water absorption, the range of water absorption for the experimental temperatures of 900°C – 1200°C commonly used for production was within 28.1% – 24.0 % when glazed and the water absorption further drop down

### 3.10. The Modulus of Plasticity and Making Moisture

The modulus of the plasticity of the clay is 2.4. The making moisture of the clay is 30.5%. This showed that it had a suitable plastic.

### 3.10. Refractoriness

For the fact that all the samples did not show any sign of failure at temperatures of 1200°C and above, it means that their sintering level is very high and falls within the internationally accepted range of 1580°C – 1750°C. This eventually showed that the clay has high and good refractoriness qualities and can withstand the high temperatures.

### 3.11. Physical Characterization of Porcelain Body

Table 5 shows the physical characteristics of the clay under study. The results show that the clay is suitable for the production of both table wares and porcelain materials.

Table 3: The test result of physical properties of porcelain body

Samples	Kaloin (g)	Feldspar (g)	Silica (g)	Total shrinkage (%)	Wet-dry shrinkage (%)	Linear shrinkage	Apparent porosity (%)	Bulk density (g/cm <sup>3</sup> )	Water absorption (%)	Modulus of rupture (kgf/cm <sup>3</sup> )
A	40	40	20	13.9	7.10	7.319	3.375	1.966	1.717	49.076
B	46.67	20.42	32.92	13	7.30	6.149	6.554	1.934	3.391	41.154
C	54.16	20.42	25.42	15.2	7.90	7.926	4.419	1.956	2.259	45.424
D	60.00	15.00	25.00	15	7.70	7.909	3.853	1.961	1.964	48.682
E	42.50	40.00	17.50	15.1	8.00	7.717	2.229	1.978	1.128	49.887
F	44.16	32.92	22.92	16	9.30	7.387	2.732	1.973	1.385	49.467
G	60.00	25.00	15.00	16.4	7.60	9.524	1.049	1.989	0.527	53.346
H	48.33	25.83	25.84	13.9	6.80	7.618	4.365	1.956	2.231	46.391
I	40.00	30.00	30.00	13.1	7.00	6.559	4.268	1.957	2.181	42.267
J	52.50	15.00	32.50	13.4	7.50	6.379	6.885	1.931	3.565	40.267
K	42.50	17.50	40.00	11.4	7.00	4.731	9.167	1.908	4.805	37.344
L	45.00	15.00	40.00	11.5	7.00	4.839	9.881	1.901	5.198	28.182
M	45.00	40.00	15.00	15.9	8.30	8.288	0.656	1.993	0.329	54.581
N	54.16	25.42	20.42	15.9	8.00	8.587	2.783	1.972	1.412	49.160
O	40.00	20.00	40.00	12.5	7.70	5.200	8.402	1.916	4.387	39.977
P	52.50	32.50	15.00	16	8.50	8.197	0.549	2.007	0.275	29.877
Q	46.66	32.92	20.42	15.7	8.90	7.464	2.171	1.978	1.098	51.574
R	44.16	22.92	32.92	14.3	8.70	6.134	7.577	1.924	3.944	40.649
S	60.00	20.00	20.00	18	9.40	9.492	2.322	1.977	1.174	50.645

## 4. CONCLUSION

Umuezeagu clay was found suitable for porcelain production. Values of standard refractory tests fell within standard values for porcelain production. The higher the percentage of impurities present in kaolin clay, the higher the tendency for the sample to crack while firing at high temperatures. Based on the properties of the porcelain samples tested and analysis in the study, it can be concluded that; the local raw material Umuezeagu clay when combined with the non-plastic material in an optimal ratio is suitable for the production of electrical porcelain insulation.

## 5. ACKNOWLEDGEMENT

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## 6. CONFLICT OF INTEREST

There is no conflict interest associated with this work.

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