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Development of Electrical Porcelain Insulators from Local Clays

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***Abstract* – In this paper, the development of electrical porcelain insulators based on local clays has been investigated. Test samples were made by varying the quantities of silica and feldspar required to form a mouldable plastic body with each clay sample. The clay samples were bisque fired to 900°C and glazed before it was fired to 1250°C after air-drying. Electrical properties such as electrical resistance were determined for each test sample that survived the high temperature. The composition for optimum properties from Ekwulobia and Iva Valley clays each is at composition 3 of 60% clay, 25% feldspar and 15% silica; while for Nawfija clay, the composition for optimum properties was 50% clay, 30% feldspar and 20% silica. Porcelain insulators containing 50-70% clay, 20-30% feldspar and 10-20% silica were found to possess requisite properties that make them suitable for domestic production of porcelains insulators from the clays studied.**

***Keywords* – Clay, Feldspar, Porcelain, Porosity, Silica, Translucence.**

I. Introduction

Clays originated as a result of the dissolution of a given mineral or group of minerals composing rocks like granites [1]. Many benefits are to be derivable from local processing of minerals [2].The recognition of these benefits motivated the Nigerian government to make a shift from the import-substitution, industrialization policy to a resource-based industrialization strategy [3]. This strategy places great emphasis on the development of indigenous technology requiring the utilization of available local raw materials.

Generally speaking, porcelains are vitrified and fine-grained ceramic white wares, used either glazed or unglazed. They refer to a wide range of ceramic products that have been baked at high temperatures to achieve vitreous, or glassy, qualities such as low porosity and translucence. In the manufacture of ceramics, the 600-1000^{0}C zone is of greatest importance in transforming the dried clay into a new, more rigid substance. The word "porcelain" has its origin in the Italian "porcella" literally "little pig", a Mediterranean sea-snail whose shell is white and translucent. Marco Polo was the first to apply the name to porcelain [4].They are used as electrical insulators in household, laboratory and industrial applications. For technical purposes, porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares [5]. Electrical insulators are generally ceramic materials and they prevent the flow of electrical current through them. Insulators are extensively used for high voltage applications [6]. They are required to be electrically inert and they isolate two conductors of different potentials [7].The primary components of electrical porcelain are clays, feldspar and silica (flint), which are all characterized by small particle size. The clay gives plasticity to ceramic mixtures, silica maintains the shape of the formed article during firing and feldspar serves as flux, which is added to decrease firing temperature in order to reduce costs by saving fuel or energy.

Electrical porcelains are widely used as insulators in electrical power transmission system due to the high stability of their electrical, mechanical and thermal properties in the presence of harsh environments. These are the reasons for their continued use over the centuries despite the emergence of new materials like plastics and composites. They form a large base of the commonly used ceramic insulators for both low and high tension insulation. They are considered to be one of the most complex ceramic materials and represent the most widely studied ceramic system [8].

By varying the proportions of the three main ingredients, it is possible to emphasize the thermal, dielectric or mechanical properties of the porcelain. In developing industrial nation like Nigeria, the porcelain need is potentially enormous, especially in improving the nation's rural electrification. Nigeria expends a lot of foreign exchange importing porcelains. Yet, a lot of clay deposits abound in the country, which can be developed to meet our local needs and also reduce cost. This state of affairs adversely affects the country's foreign exchange reverse and is inconsistent with the drive for local substitution of imported goods [9]. The effect of composition on the electrical properties of electrical porcelain insulators made from some eastern Nigerian clay is the focus of this paper.

II. Porcelain Production

There are several stages that are involved in the production of porcelain as shown in the flow chat of Fig.1

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(A) Preliminary Crushing/Drying: The as-mined clay samples which were in lumps were crushed to smaller grain sizes using hammer in order to liberate the mineral constituents and to ease drying and grinding. The feldspar and silica were obtained as already processed samples. The crushed clay samples were sun-dried before grinding. Drying was necessary, as damp clays are difficult to crush or grind.

(B) Grinding: The dried clay samples were ground into powder form using pan mill in Project Development Institute (PRODA) Ceramic department.

(C) Sieving: The samples were then sieved.

(D) Proportioning: The porcelain body was formulated by varying the composition of the plastic (clay) and the non-plastic (feldspar and silica) materials. Ten porcelain insulator bodies were formulated for each clay, in the order shown in Table 1.

(E) Mixing, Blending and Wetting of Moulding Materials: The samples were then mixed with the non-plastic materials respectively in their different composition and then kept wet for some time.

(F) Moulding: The mould was produced with the plaster of paris (POP) which is the best for quick absorption. The already mixed samples that were poured into the mould were left for two days to dry.

(G) Drying and Bisque Firing: The samples were left to air-dry slowly for a days. This was followed by Bisque firing. A Kiln was used for firing. The samples were all fired in the same heating sequence at the rate of 150^0C/hr to the temperature of 900^0C.

(H) Glazing: The samples were removed from the Kiln after cooling. Then the glaze was applied to each sample by the use of brush. The brush was dipped inside the glaze and then applied on the samples smoothly.

(I) Firing: The samples were returned to the Kiln for firing. They were fired to the temperature of 1250^0C. The Kiln was turned off and allowed to cool before removing the samples.

(J) Sorting: The samples were sorted and labeled according to their compositions and location before the testing commenced.

(K) Testing: The resistance test was conducted.

(L) Delivery: The samples were delivered after the necessary tests have been conducted.

Table 1: Porcelain Body Formulations

Sample	Clay (%)	Feldspar(%)	Silica (%)
1	100	0	0
2	90	5	5
3	80	15	5
4	70	20	10
5	60	25	15
6	50	30	20
7	50	25	25
8	50	20	30
9	50	15	35
10	50	35	15

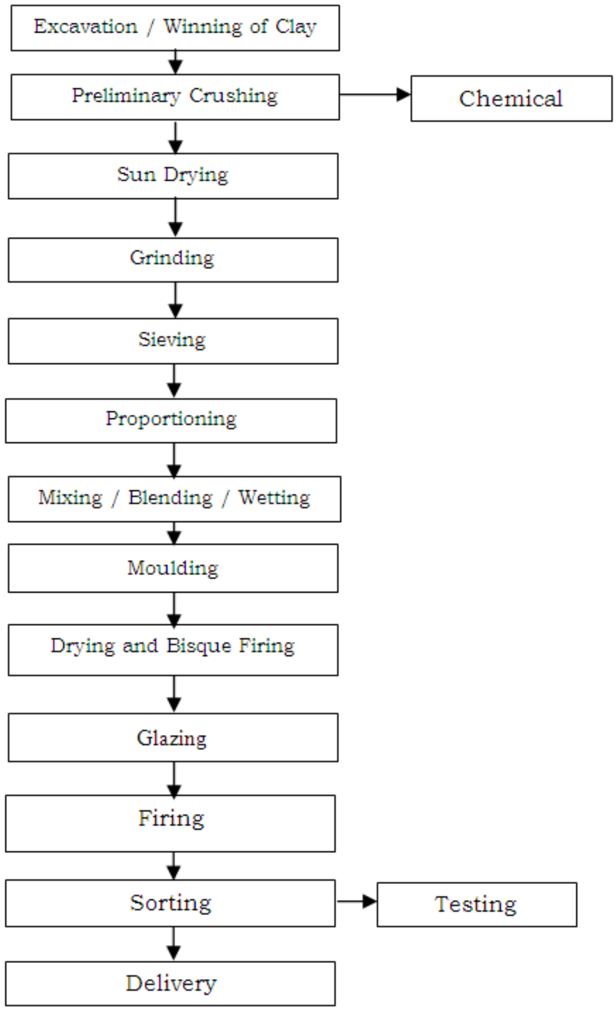

Fig 1: Flow Diagram for Porcelain Production

III. Experimentation and Testing Procedures

The samples that survived the high temperature were the only samples that were tested, tabulated and plotted in a graph tested for the two experimental tests; electrical resistance and dielectric strength that are of interest in this paper. The snail shell was grinded into a powdered form to be used as an additive. The snail shell additive was added to the sample composition 3 (clay 60**%**, feldspar 25**%** and silica 15**%**) from each location in five compositions as stated in Table 2. Some other tests that were carried out for better understanding of the work are as follows; linear shrinkage, apparent porosity, bulk density and water absorption. The samples that survived the high temperature are as follows;

Table 2: The clay samples that survived heating

Sample	Clay (%)	Feldspar (%)	Silica(%)
1	80	15	5
2	70	20	10
3	60	25	15
4	50	30	20
5	50	25	25

3.1 Determination of Electrical Resistance

The block diagram shown in Figure 2 shows the experimental setup used in determination of electrical resistance of the samples and existing insulators. The insulation resistance test was done in Enugu Electricity Distribution Company (EEDC) Achalla Layout office in Enugu, Enugu state. The 5KV insulation resistance tester which is manufactured by Megger with serial number PP-MD1-PP-5FV and model number MIT520/2 was used during the test. The 5KV insulation resistance tester shows its reading in Gigaohms (G**Ω**).

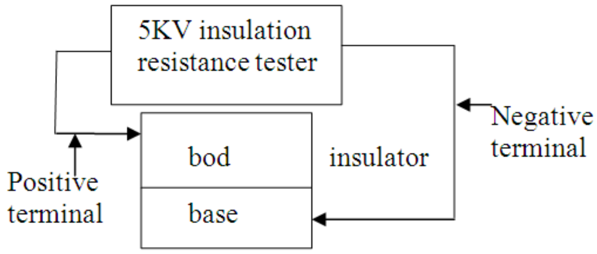

Fig 2: Block diagram of the resistance test

Before the test was conducted, the positive terminal of the 5KV Insulation resistance tester was connected to the body of the insulator while the negative terminal was connected to the base as shown in the appendix. The 5KV insulation resistance tester has digital readout. The test voltage required (5KV) was set. To start the test, the press button was long pressed until the red test indicator comes showing that the test have started. Some reading will be showing on the display until it obtains the actual value. At that point, the reading on the display will stop varying giving a final result.

The test results of electrical resistance are shown in Tables 4, 5 and 6 for Iva Valley, Nawfija and Ekwulobia clay formulations respectively.

Resistance(R) readings were taken and resistivity was therefore calculated from the resistance values using the relationship shown in equation 1

$$\ell = \frac{RA}{L} \qquad (1)$$

where R represents the resistance (Ω), ℓ represents resistivity (Ω-m),A represents the area (mm^2) and L represents the length (mm).

IV. Data Presentation and Results Analysis

The data presentation of the results for the existing insulator, Iva Valley, Nawfija and Ekwulobia clay sample formations is shown in Table 3, 4, 5 and 6.

Table 3: Electrical resistance results for existing insulator

Sample	Diameter (mm)	Area (mm^2)	Length (mm)	Resistance, R (GΩ)	Resistivity, ℓ (Ωm)
1	30.00	707.95	42.00	0.95	16.01
2	30.00	707.95	42.00	0.90	15.17
3	30.00	683.58	41.50	1.01	16.64
4	30.00	707.95	42.00	1.02	17.19
5	29.20	669.75	42.50	1.02	16.07

The resistance recorded range from 0.90 to 1.02 GΩ for existing insulators.

Table 4: Electrical resistance test for Iva Valley clay formulations

Sample	Diameter (mm)	Area (mm^2)	Length (mm)	Resistance R(GΩ)	Resistivity ℓ (Ω-m)
1	30.00	707.95	42.00	1.05	17.70
2	30.00	707.95	42.00	1.09	18.37
3	30.00	707.95	42.00	1.12	18.88
4	29.50	683.58	42.50	1.08	17.37
5	30.00	707.95	42.00	1.03	17.19

The resistance recorded range from 1.03 to 1.12 GΩ for Iva Valley clay sample.

Table 5: Results for Nawfija clay formulations

Sample	Diameter (mm)	Area (mm^2)	Length (mm)	Resistance, R (GΩ)	Resistivity, ℓ (Ω-m)
1	30.00	707.95	42.00	1.04	17.53
2	30.00	707.95	42.00	1.08	17.70
3	30.00	707.95	42.00	1.06	17.87
4	30.00	707.95	42.00	1.13	19.05
5	30.00	707.95	42.00	1.08	18.20

The resistance recorded range from 1.04 to 1.13 GΩ for Nawfija clay sample.

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Table 6: Results for Ekwulobia clay formulation

Sample	Diameter (mm)	Area (mm^2)	Length (mm)	Resistance, R (GΩ)	Resistivity, ℓ (Ωm)
1	29.50	683.58	42.50	1.02	16.41
2	29.50	683.58	42.50	1.07	17.21
3	30.00	707.95	42.00	1.10	18.54
4	30.00	707.95	42.00	1.08	18.20
5	30.00	707.95	42.00	1.04	17.53

The resistance recorded range from 1.02 to 1.10 GΩ for Ekwulobia clay sample.

Table 7: Comparison of the resistance result for existing insulator and the clay samples of Iva Valley, Nawfija and Ekwulobia

Length (mm)	Existing insulator (GΩ)	Iva (GΩ)	Nawfija (GΩ)	Ekwulobia (GΩ)
10mm	0.24	0.27	0.25	0.26
20mm	0.49	0.53	0.50	0.52
30mm	0.73	0.80	0.76	0.79
40mm	0.97	1.07	1.01	1.05
42mm	1.02	1.12	1.06	1.10

4.2 Graphical Presentation of Results

The electrical resistance results are represented graphically in Figure 3 to Figure 7 for existing insulator, Iva Valley, Nawfija and Ekwulobia respectively.

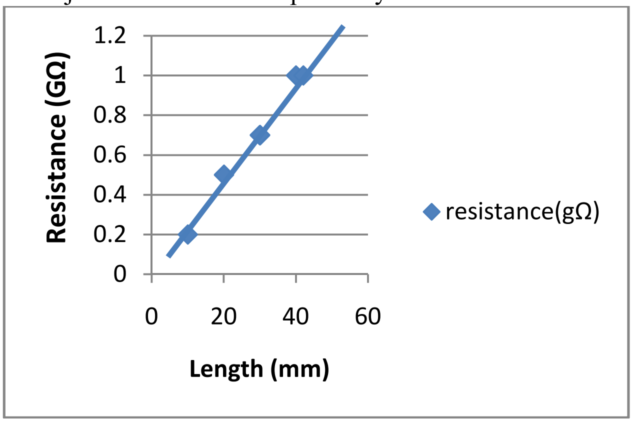

Fig 3: Electrical Resistance graph for the Existing Insulator

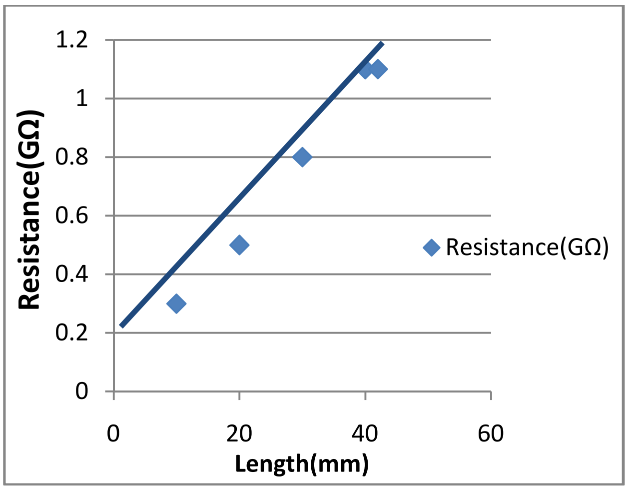

Fig 4: Electrical Resistance graph for the Iva Valley clay sample

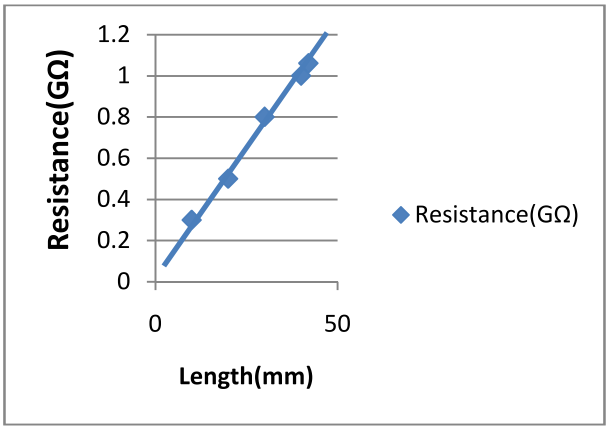

Fig 5: Electrical Resistance graph for the Nawfija clay sample

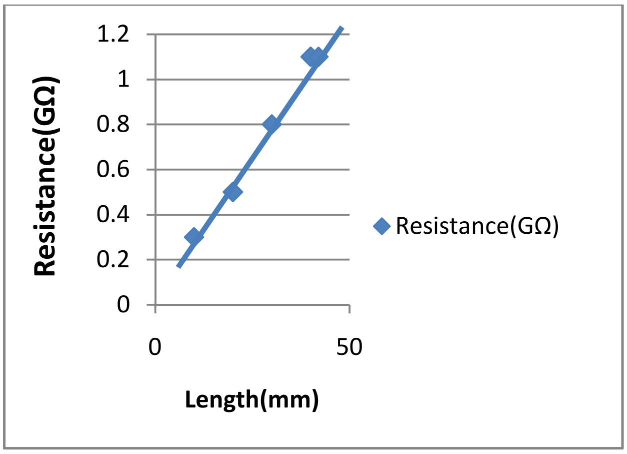

Fig 6: Electrical Resistance graph for the Ekwulobia clay sample

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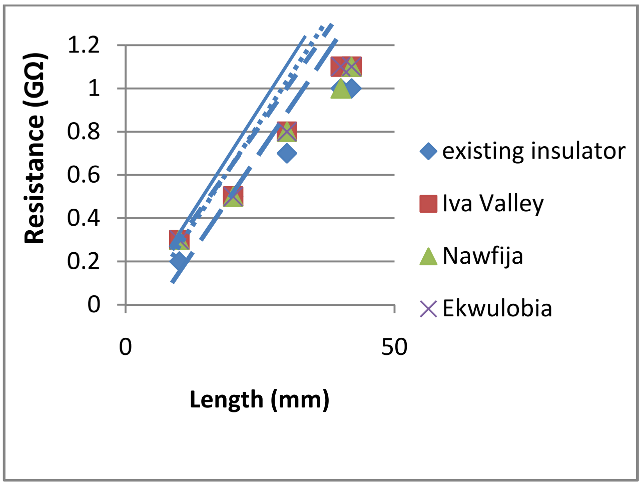

Fig.7. Electrical resistance existing insulator and clay samples

4.3 Findings

Combining the results of Figure 3, 4, 5 and 6 it is observed that at length 42mm, the existing insulator, Iva sample, Nawfija sample and Ekwulobia sample recorded a resistance of 1.02GΩ, 1.12GΩ, 1.06GΩ and 1.10GΩ respectively as shown in Figure 7.

V. Conclusion

Nigeria needs and consumes a lot of electrical porcelains for power distribution; most of which are imported, yet there is abundant raw materials in the country that could be utilized for porcelain production to serve both the local needs and for export. The proportions of clay, feldspar and silica were varied in the production of porcelain test samples and properties such as dielectric strength and electrical resistance were investigated. Clays from Iva Valley, Nawfija and Ekwulobia were researched for electrical porcelain applications. The suitable amount of feldspar required by the clays for optimal properties ranges from 20% to 30%, while that of silica is 10% to 20%.The low content of silica required is attributable to the high silica content of the clays. Too high quantity of the non-plastic materials resulted to poor vitrification leading to cracking and disintegration of the porcelain product after firing while very low content resulted to distortion and high firing shrinkage. Based on the results obtained, the best formulation for Iva Valley and Ekwulobia clays is 60% clay, 25% feldspar and 15% silica while that for Nawfija is 50% clay, 30% feldspar and 20% silica. It is therefore concluded that the three clays are suitable for the production of electrical porcelain provided the above compositional specifications are followed.

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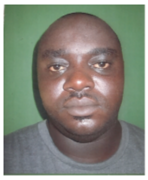
Author’s Profile



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