INDIGENOUS MANUFACTURE AND CHARACTERIZATION OF ELECTRICAL PORCELAIN INSULATOR

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ABSTRACT

In power systems, there is an ever-increasing demand placed on porcelain insulators especially for outdoor applications. Additionally, the huge cost of importation has resulted in a growing need for the local manufacture. To this end, an electrical porcelain insulator was manufactured from locally available raw materials and characterized. The study investigates a porcelain type percentage composition of kaolin, 30; ball clay, 10;feldspar, 22 *and quartz,* 38. *The sample was manufactured by the dry process technique. The pulverized and thoroughly mixed composition was compacted at a pressure of* 2×10^8 *N/m*^{2} *and fired at a temperature of* 1355^oC *with a soaking time of* 3 *hours for proper sintering. The results of the characterization show that the sample has a volume resistivity of* 1.97×10^9 *ohm cm, breakdown voltage of 26kV/mm, zero water absorption and dielectric constant between* 9.2 *and 10.8 within the frequency range considered. These results when compared with those of the commercial variety show that the locally manufactured sample satisfies the stringent requirements of a good insulating material.*

Index terms: kfq sample; green-ware; sintering; volume resistivity; surface resistivity

INTRODUCTION

It has been estimated that more than 20% of the total outlay for a typical transmission and/or distribution system of electric energy is spent on insulation alone and prominent among them is porcelain. Our giant electrical industry (NEPA) imports almost hundred percent of the total insulation it uses of which porcelain occupies a central position, notably from the Asian countries.

This state of affairs adversely affects the country's foreign exchange reserve and is inconsistent with the drive for local substitution of imported goods. Furthermore, tight dependence on foreign goods is highly susceptible to sabotage and more often than not, the manufactured articles may not be ideal for the importing country's climate, which invariably affects efficiency. More importantly, standardization is difficult if not impossible since the manufacturing technology is non-resident in Nigeria. Additionally, sporadic scarcity of the imported variety and the attendant exorbitant cost make the insulator highly susceptible to stealing, with the consequent vandalization of the power lines, This phenomenon has become prevalent in the recent times.

It is therefore highly anticipated that if these insulators are massively and cheaply produced from the cheap abundant local raw materials, that the prices will become very cheap and easily affordable.

This development will invariably make stealing of insulators and consequent vandalization of the power lines unattractive and unprofitable; thus ensuring a more stable power supply for the country. Indigenous manufacture of porcelain insulator will in addition to overcoming all the problems highlighted above, create employment opportunities for the teeming populace of this country. This becomes more obvious when it is considered that the establishment of one porcelain manufacturing industry per state will hardly meet the local demand for rural electrification alone. Local manufacture of porcelain insulator can be made a foreign exchange earner for the country if adequately supported by the government or some wealthy entrepreneurs.

The main objective of this paper ranges from highlighting the local availability of the raw materials for the production of porcelain insulators to the actual manufacture of porcelain insulators from the locally available raw materials and the characterization. It is also intended to make a comparison between the locally manufactured porcelain with the imported variety.

2.0 Raw materials

The principal raw materials used in the manufacture of electrical porcelain insulators are kaolin (China clay), feldspar and quartz. However, ball clay is added in small quantities. Kaolin provides the necessary plasticity to the mixture, which facilitates the shaping process. The plasticity is usually enhanced by the small addition of ball clay. Feldspar serves as a flux, which reduces the vitrification temperature of the mixture. Quartz provides the refractory crystalline phase or skeleton contributing to the mechanical strength of the body.

High demands are made on the raw materials with respect to homogeneity, stability of composition and impurities. Insufficiently pure materials are refined by elutriation, flotation and air or electromagnetic separation. All the raw materials abound in commercial quantities in Nigeria. Kaolin is produced in commercial quantity at ROP on the Jos Plataeu (Plataeu State). Large deposits of kaolin are located at Ukpor and Ozubulu in Anambra State, Katsina (Katsina State), Abuja, etc. Ball clay is found in large quantities at Nasarawa, Jos Plateau, Oji River, etc.

Feldspar, being the main constituent of igneous rock is abundantly distributed throughout the country. The chief commercial sources are found in pegmatite minerals along with quartz and various mica. Large and small feldspar variants of the porphyritic older granite rocks occur in the Igbo Ora complex in south western Nigeria, Abeokuta and Abuja. Quartz occurs as one of the major compositions of sedimentary rocks available in many parts of the country. The sedimentary beds of Nsude in Enugu State contain large deposits of quartz. Quartz in the form of silica is found practically in all locations of the earth and sufficiently pure that it can be used in ceramic industry without beneficiation. There is high quality sand deposit at Igbokoda (Ondo State) in commercial quantity, Rivers and Lagos States.

3.0 Sample preparation

The characterization of electrical porcelain insulators depends to a marked degree on the percentage composition of the mixture and method of manufacture [1]. The raw materials used in the preparation of electrical porcelain were kaolin, ball clay, feldspar and quartz (in the form of silica sand). Ball clay is added in minor amounts such that the mixture is essentially akaolin-feldspar- quartz mixture (kfq). The sources of the raw materials and their chemical composition are shown in Table 1

Table 1: The sources and chemical composition of the raw materials

Mineralogical name	**Chemical composition**	**Source**
Kaolin (china clay)/ball clay	$A1_2O_3.\ 2SiO_2.2H_2O$	Oji River (Enugu State)
Feldspar	$(Na/K)_2O.A1_2O_3.6SiO_2$	Abeokuta (Ogun State)
Quartz (silica sand)	SiO_2	Igokoda (Ondo State)

The percentage composition of the mixture chosen in the study - kaolin, 30; ball clay, 10; feldspar, 22; and quartz, 38 was in accordance with Budnikov's recommendation for electrical porcelain [2]. The raw materials were separately crushed (except silica sand), milled, sieved, carefully weighed and mixed together in a ball-mill, kneaded, de-aired in a pug mill and finally compacted at a pressure of 2 X 10^8 N/m^2 by hand press.

Two different moulds were fabricated from wear-resistant steel for the shaping process. Cylindrical mould of 25mm diameter and a square mould of 25mm X 25mm X 5mm. The green-ware was then dried and subsequently fired in an electric furnace with a steadily rising heat at a temperature of 1355^{o}C and for a soaking time of 4 hours for proper sintering. The samples were then polished.

3.1 Chemistry of the preparation

The following mineralogical changes which lead to the formation of porcelain insulator occur during the heating of the kfq mixture [3]. Between 500-550^{0}C, dehydration of the kaolin occurs

$A1_2O_3.2SiO_3.H_2O \rightarrow A1_2O_32SiO_3.H_2O$ (1)

(kaolin) (metakaolinite) (Water)

between 800 - 900°C, the metakaolinite decomposes into oxides,

$A1_2O_32SiO_{3.} \longrightarrow A1_2O_3 + 2SiO_{3.}$ (2)

Between 950 - 1000°C, crystallization of the alumina occurs

Between l150-1250°C, interaction of the oxides producing mullite and free silica in the form of cristobalite

$3A1_2O_3 + 6SiO_2 \rightarrow 3A1_2O_3.H_2O + 4SiO_2$ (3)

(Alumina) (Silica) (Mullite) (cristobalite)

Between 1250 - 1300°C; feldspar dissolves the silica present in kaolin and that present in the mixture to form feldspar glass. Feldspar + silica $\rightarrow$ feldspar glass (4)

Feldspar glass+ mullite + cristobalite $\rightarrow$ oporcelain (5)

The stages mentioned above in the formation of porcelain do not have clear-cut temperature boundaries. The dissolving of the quartz and decomposition products of the kaolinite in the feldspar glass occurs to a more or less complete extent depending on the temperature and firing period; thus the amount and composition of feldspar glass in the porcelain vary within wide limits. However, the percentage composition of feldspar glass in porcelain is about 50% [2].

4.0. Metallizing

In order to create a conduction path for electrical measurements on the sample [4], copper electrodes were deposited on the surface ends of the cylindrical sample using Edward vacuum pump at a high vacuum of 10^{-5} torr. The deposited copper electrodes of 20mm diameter in intimate contact with the porcelain sample is as shown in Fig. 1.

4.1 Measurement of the dielectric properties of the sample

For the measurement of the dielectric properties of the electrical porcelain, a 1608 impedance bridge was used. This is a high sensitivity instrument with an accuracy of ±0.05% of the reading ±0.005% of the full-scale reading. It has a provision for an external frequency supply within the range of 50-20,000Hz. The result of the dielectric measurements as an average of five measurements is as shown in Table 2.

Table 2: The results of the dielectric measurements as an average of five measurements with an accuracy of ±0.05% of the reading ±0.005% of full scale Sample's thickness = 5mm, diameter=25mm, *C_0=0.086pF

Freq (Hz)	Capacitance C(pF)	Dielectric constant	Dissipation factor
50	9.3	10.8	0.070
100	9.1	10.6	0.053
1000	8.3	9.7	0.035
10000	8.0	9.3	0.026
20000	7.9	9.2	0.024

**C_o* is the capacitance of a two-electrode system with air as the dielectric, and* C *is the capacitance with the porcelain sample as dielectric.*

The graph of the dissipation factor tanδ against frequency is shown in Fig.2 while the graph of the dielectric constant against frequency is shown in fig 3.

4.2 **Experimental determination of the surface resistivity p $_v$**

When an insulator is subjected to an electric stress, there are two possible paths for current flow, through the surface and volume respectively. The surface resistivity is associated with the ability of the insulator to resist current flow on its surface and while the volume resistivity is the ability to resist current flow through the volume. For a perfect insulator, the volume and surface resistivities are respectively infinitely large. The parallel combination of the surface resistance Rs and volume resistance R_v gives the total insulation resistance R_t of the sample.

The experimental setup for the measurement of the surface resistivity is as shown in Fig. 4.

The two platinum edged electrodes 0.4 cm apart were firmly clamped on the surface of the porcelain measuring 25mrn X 25mm X

5mm. On applying 8kV (dc) with a high voltage test equipment (80kV, Hiptronics type HP 800L No. 1710 - 1343) to the electrodes, O. 7mA was indicated in the ammeter, from which the surface resistance Rs of the sample was readily calculated as:

$$R_t = \frac{8 \times 10^3}{0.7 \times 10^{-3}} = 1.1 \times 10^7 \Omega$$

Using the calculated value of the surface resistance R_s the surface resistivity p_s was calculated as follows:

$$p_s = R_S \frac{W}{L} \Omega \qquad (6)$$

Where W is the width of the electrodes and L is the spacing between the electrodes as shown in Fig. 4. The numerical value is given by:

$$\mathrm{P_S} = 1.14 \times 10^7 \frac{2.5}{0.4} = 7.14 \times 10^7 \Omega$$

4.3 Experimental determination of the total insulation resistance Rt

The experimental setup for the determination of the total insulation resistance R_t, is shown in Fig. 5. Using the same high voltage test equipment as in section 4.2 above, 8KV (dc) was applied to the sample through the 20mm diameter deposited copper electrodes. The current that was indicated in the ammeter was 0.75mA. The total insulation resistance R_t was readily calculated as:

$$\mathrm{R_t} = \frac{8 \times 10^3}{0.7 \times 10^{-3}} = 1.1 \times 10^7 \Omega$$

4.3.1 Determination of the insulation volume resistivity p_v

The total insulation resistance R_t, is equal to the parallel combination of the surface resistance R_s, and the volume resistance R_v

$$Hence = \frac{1}{R_t} = \frac{1}{R_S} + \frac{1}{R_v} \qquad (7)$$

Using the calculated values of R_t, and R_s R_v.is easily calculated from:

$$\frac{1}{1.1 \times 10^7} = \frac{1}{1.14 \times 10^7} + \frac{1}{R_v}$$

$$\therefore R_V = 3.14 \times 10^8 \Omega$$

The volume resistivity is then readily calculated as:

$$P_v = R_v \frac{A}{L} \qquad (8)$$

Where A is the area of the deposited electrodes and L is the length of the cylindrical sample.

$$\therefore P_v = 3.14 \times 10^8 \times \frac{\pi \times 1^2}{0.5}$$
$$= 1.97 \times 10^9 \ \Omega cm$$

4.4 Determination of the breakdown voltage of the sample

The cylindrical sample of 25mm diameter and thickness of 5mm was placed between two sphere-type electrodes of 20mm diameter and an impulse voltage was gradually applied to the sample from the control desk. The insulator failed at 130kV and the breakdown voltage as an average of five measurements is 26kV/mm.

4.5 Determination of water absorption of the sample

The porcelain samples, ten in number randomly selected were completely immersed in water, coloured with dye at 20°C and left to stand for 24 hours. The samples were thereafter mechanically broken and it was discovered that there was no penetration of water in any of the samples and hence zero water absorption.

The comparison between imported porcelain and the local variety is shown in Table 3 and the flowchart for the mass production of high-grade porcelain is shown in the appendix.

5.0 Results and discussion

The maximum value of the dielectric constant of the kaolin-feldspar-quartz (kfq) sample is 10.8, suggestive of a good insulating material. Good insulating materials are materials with dielectric constant below 12 [5]. The graph of the dielectric constant shows somewhat flat response.

Table 3: Comparison between imported

porcelain and the local variety

Electrical parameter	Imported porcelain	Local porcelain
Volume resistivity p_v	≥3.7X10^{12} Ω	1.97 X10^9Ωcm
Surface resistivity p_s	≥3.7X10^9Ω	7.14X10^7Ω
Dissipation factor (20^0C)	≤0.04	0.070
Dielectric constant	6-8	9.3-10.8
Breakdown voltage	≥25KV/mm	26kv/mm
Water absorption (20^0C)	0%	0%

The significance of the low dielectric constant is that the charge storage capacity of the insulator is low and this is the main difference between dielectrics for insulator and capacitors. Thus the insulator could be used as capacitor bushings where low charge storage capacity is very desirable Dielectrics with dielectric constant above 12 are generally materials for capacitors and transducers. The kfq sample is not suitable for this application in the present form because of the low dielectric constant. The graph of the dissipation factor tanδ with frequency shows a quadratic decrease in dissipation factor with increase in frequency. This characteristic of the kfq sample shows that the insulator might be more efficient for high frequency applications such as pulse coils in radar, insulating member in induction heating etc.

The volume resistivity was fairly high and greater than 1 X 10^6 ohm cm, which is the minimum value, required of good insulating materials [4].

Insulator manufacturing business is a labour intensive one and hence employment opportunities. At optimum capacity, about 60 workers will be required to operate the plant, excluding casual workers who may be up to 100 in number.

It is highly expected that improvement in the manufacturing process will enhance the insulating properties of the local porcelain tremendously.

6.0 Conclusion

Based on the experimental results obtained in this study and in comparison with commercial porcelain, the following conclusions can be made:

(a) That using the locally available raw materials, electrical porcelain with good dielectric properties can be produced since it has dielectric constant below 12 and volume resistivity greater than 10^6 ohm cm.

(b) That the characterized composition, kaolin 30%, ball clay 10%, feldspar 22% and quartz 38% has the potentialties of good electrical insulator.

c) That the insulator might be more efficient at high frequencies where the dissipation factor is correspondingly lower.

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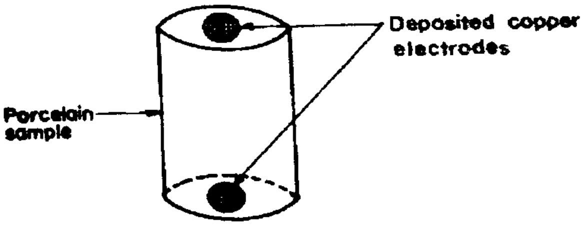

Fig. 1: Porcelain sample showing the deposited electrodes

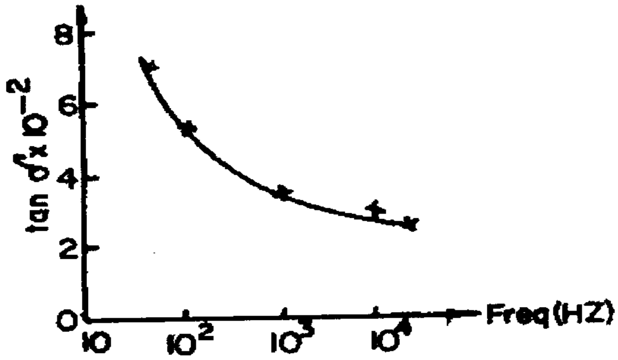

Fig. 2: A plot of the dissipation factor against frequency

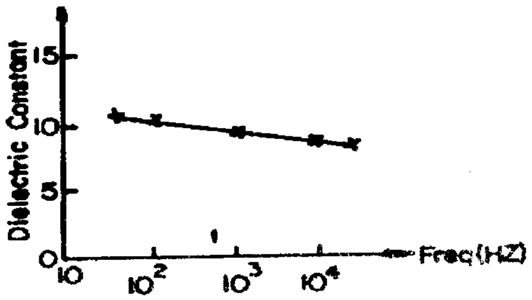

Fig. 3: A plot of the dielectric constant against frequency

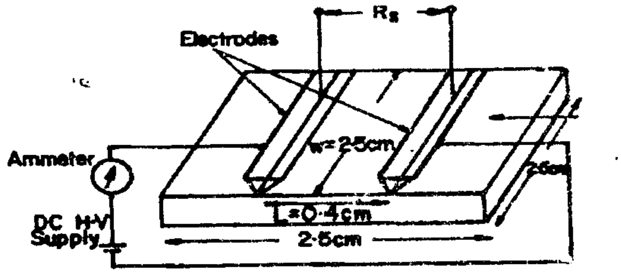

Fig.4: The experimental setup for the measurement of the surface resistivity

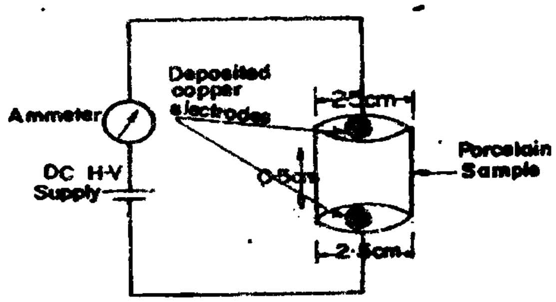

Fig. 5: Experimental setup for the measurement of the total insulation resistance

Appendix: *The flow chart for mass production of high-grade* porcelain insulator is shown in Fig.6

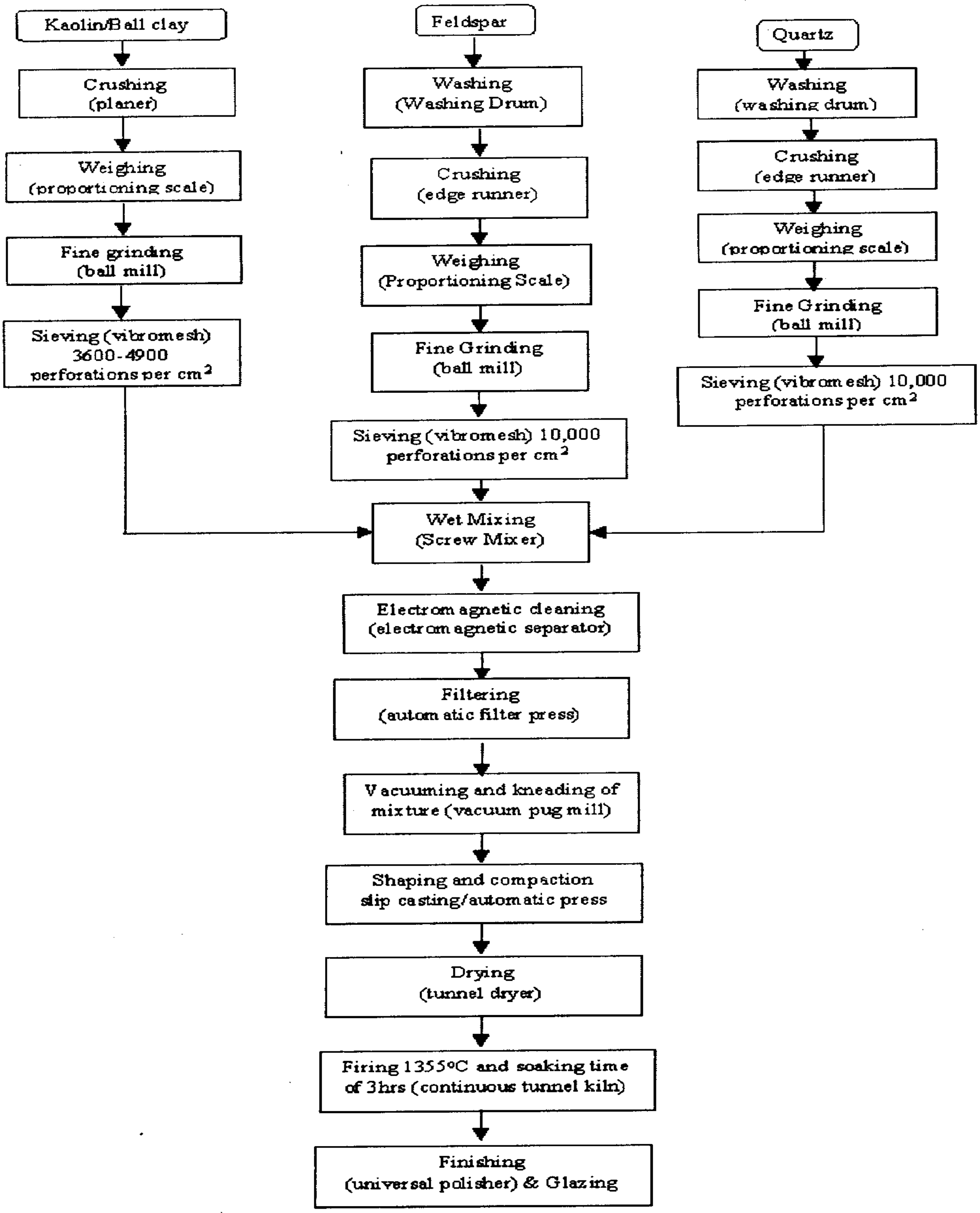

***Fig. 6:** Flow Chart for mass production of high grade porcelain*