Evaluation of Mixed Local Materials for Low Voltage Insulators

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***Abstract*– Varying compositions of stoneware clay, fire clay, feldspar and quartz were used to produce different specimens of porcelain insulators to investigate their resulting properties and suitability for mass production and commercial viability, comparing the specimens with Budnikov's recommendation for electrical porcelain. The basic raw materials were separately prepared using a sieve to remove the iron content and other impurities before casting. The mixtures were formulated to produce porcelain samples by using sodium silicate to keep it in a slurry state, while the slip casting process was used in the production of the electrical porcelain insulator. Produced insulator samples were fired by means of bisque and glaze firing techniques respectively. The specimen with composition of 50% stoneware clay, 20% feldspar and 30% quartz (silica) was found to possess a high quality properties, corresponding to water of absorption (14.44%), porosity (25.23%), bulk density (1.75 g/cm^3) at a very high temperature of 1200°C,with appreciable insulation breakdown voltage of 45V. The investigation had shown that high quality electrical porcelain insulators could be achieved from locally available sourced materials for distribution line insulators.**

***Keywords*– Clay, Electrical Porcelain and Low Voltage Insulators**

I. INTRODUCTION

Insulators are used in electrical equipment to support and separate electrical conductors without allowing current through themselves. An insulating material used to wrap electrical cables or other equipment is called insulation. The term insulator is also used more specifically to refer to insulating supports used to attach electric power distribution or transmission lines to utility poles and transmission towers. They support the weight of the suspended wires without allowing the current to flow through the tower to ground [1].

Electrical insulator must be used in electrical system to prevent unwanted flow of current to the earth from its supporting points. The insulator plays a vital role in electrical systems. Electrical insulator offers very high resistive path through which practically no current can flow. In transmission and distribution system, the overhead conductors are generally supported by supporting towers or poles. The towers and poles both are properly grounded. So there must be insulator between tower or pole body and current carrying conductors to prevent the flow of current from conductor to earth through the grounded supporting towers or poles [2].

Indigenously developed technology is considered an essential index for exploring and promoting underutilized resources, technological and economical potential of a nation's industrialization processes. It has been established that abundant raw materials are available for the manufacture of electrical porcelain insulators as well as heated ceramic wares in Nigeria [3]. The need for electrical insulators is essentially to prevent the passage of electricity to some other device or area, so that the electricity does not cause harm or cause death to those who touch areas or devices which are connected to the electrical insulators [4]. Insulators are extensively used for high voltage applications [5]. In spite the availability of local raw materials, mostly used insulators are still imported to Nigeria due to manufacturing of electrical insulators in small quantities and majorly restricted to the low voltage shackle, it is hereby imperative to facilitate manufacturing of locally produced electrical insulators to meet increasing demand. Hence, the developments of techniques for the production of high quality porcelain bodies that are commercially viable and also meet required standards cannot be overemphasized. Porcelain is a ceramic material made by heating raw materials, generally including clay in the form of kaolin, in a kiln to temperatures between 1,200 °C (2,192 °F) and 1,400 °C (2,552 °F). The toughness, strength, and translucence of porcelain arise mainly from the formation of glass and the mineral mullite within the fired body at these high temperatures [6]. Porcelain had been found to be veritable stoneware due to its very high density, industrial fast firing cycles, tangible mechanical strength and wear resistance [7]. Unquestionably porcelain insulators have a wide range of applications in the safe transmission of electricity. Porcelain is primarily composed of clay, feldspar and filler material, usually quartz or alumina. The clay [$(Al_2Si_2O_5\ (OH)_4$] gives plasticity to the ceramic mixture, flint or quartz [SiO_2] maintains the shape of the formed article during firing and feldspar [$KxNai\text{-}x\ (AlSi_3)O_8$] serves as flux [8]. These three constituents place electrical porcelain in the phase system in terms of oxide constituents, hence the term triaxial porcelain [9].

Most existing literature on body compositions and processing conditions for porcelains of all kinds such as Norton [10] and Olupot [11] apply mainly to foreign raw materials, which can be quite different from the local ones in terms of chemical, mineralogical and physical characteristics. Therefore more efforts should be channeled to establish data and procedures on the development of electrical porcelain with local raw materials. Attempts were made by Onaji and Usman [5] to develop a slip casting technique for the electrical porcelain body using ball clay materials. The clay used was grossly inadequate resulting in poor characterization of the porcelain body produced. Thus, the process developed was not suitable for mass production of electrical porcelain.

The major objective of this study is to investigate the composite potential of locally available materials for porcelain insulators as an alternative to the imported porcelain. It is also intended to make a comparison between the local manufactured porcelain with the imported v ariety.

II. MATERIALS AND METHODS

A) Source of the Raw Materials

The characterization of electrical porcelain insulators depends to a marked degree on the percentage composition of the mixture and method of manufacture [12]. The raw materials used in the preparation of electrical porcelain were clay, feldspar and quartz (in the form of silica sand) and these raw materials are all collected in Nigeria and specimen A to D was used for the study. The sources of the raw materials and their chemical composition are shown in Table 1.

B) Percentage Composition of the Materials

The percentage composition of the mixture chosen as the standard to compare with the locally available materials in the study – kaolin, 30; ball clay, 10; feldspar, 22; and quartz, 38 was in accordance with Budnikov's recommendation for electrical porcelain [13]. Various alternative mixtures of the insulation materials are shown in Table 2.

C) Physical and Chemical analysis of clay

The physical properties of the clay was determined by the method described by Abuh et al [14], while the chemical analysis was determined by the Atomic Absorption Spectrophotometer (AAS) (Buck scientific model 210VGP) after digestion of the sample with nitric and hydrofluoric acid.

D) Production Process

Raw Material Processing

Porcelain insulators are made of wet–process, confected mainly by Feldspar, Quartz, and Clay, each material is strictly selected. The clay which is the major constituents is processed first by crushing the clay to reduce the particle sizes; soaking the clay, sieving the clay and decanting the water after it might have settled. The clay is poured in a POP bath to absorb the remaining water; it is then put to the dryer to dry, after that crushing will take place and finally sieved.

Ball Mill

Different raw materials need equally mixed to amount to certain fineness. The Feldspar, Quartz and other additive are ball milled.

Body Formulation

The body formulation is the compounding of the porcelain body which comprises of Feldspar, Quartz (Silica), Clay and Grog if the need may arise. The clay must be 50%, the silica and feldspar may take the remaining 50% depending on the plasticity of the clay. After compounding the body, the body is kept in a plastic state then adds little sodium silicate ($NaSiO_2$) to reduce the power of suspension and to keep the body in slurry form (slip) for easy casting.

Solid Slip Casting

After preparing the slip, the slip will be poured in an already made P.O.P porcelain insulator mould as shown in figure 2.1 and 3.1. It will be topped continuously for about 2 to 3 hours for the body to settles completely.

Fettling

The body (the casted electrical porcelain) will be fettled. Fettling is the process of cutting the edge of the body and cleaning with form and water to smoothen the body and to remove the particles of the POP that may be seen in the body.

Drying

Drying is the process of removing the mechanical combined moisture in the electrical porcelain insulator body (i.e. semi–product) the semi–product is dried with an oven between $100^{o}C$ to $120^{o}C$.

Water Cleaning

Cleaning the dust on the surface of the insulator before the proper firing. (Bisque firing).

Bisque Firing

The first firing in the Kiln is called Bisque firing. The temperature for the bisque firing is between $800^{o}C$ to $900^{o}C$.

Glazing

The semi-product electrical porcelain insulator that has been bisque fired was glazed either by dipping or spraying the glaze on the body and the transparent glaze materials used for the work.

Gloss Firing

The final firing (Gloss firing) will be done after the body has been glazed. The Gloss firing temperature is between $1200^{o}C$ to $1300^{o}C$ for low temperature porcelain insulator (low voltage).

Electrical Breakdown Voltage Test

Flashover tests were carried out on industrial-size specimens. The tests were carried out concurrently on the fabricated specimen and on those procured from the utility supplier so as to compare these properties. The procedures of this test are highlighted and the test circuit diagram is shown in Fig.1. High voltage a.c. tests at 50 Hz are carried out as

Routine tests on low voltage (415V to 11KV) porcelain insulators. Each one of these insulators is subjected to a high voltage in order to determine the breakdown voltage, these tests are generally carried out after manufacture before installation. The test was performed in the high voltage laboratory as shown in Plate 2. The specimen was placed between transformer T_2 and earth, an high voltage was gradually applied to the specimen from control desk. The corona occurred at 25V and flashover voltage at 45V as the voltage was gradually increased from the control desk. The recorded flashover voltage value was the arithmetic mean of five individual flashovers taken consecutively. Therefore comparing the breakdown voltage of the specimen with 11KV distribution line glass insulator and 11KV pin porcelain insulator, the same test procedures were carried out to be able to compare them with the specimens used in the study.

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

Mineralogical Name	Chemical Composition	Source
Stoneware clay	$A1_2O_3. 2SiO_2.2H_2O$	Nando (Anambra State)
Fire clay	$Al_2O_3.2SiO_2.2H_2O$	Iva valley (Enugu state)
Feldspar	$(Na/K)_2O.Al_2O_3.6SiO_2$	Lokoja (Kogi State)
Quartz (Silica Sand)	SiO_2	Nsugbe (Anambra State)

Table 2: Constituent Percentage Composition of Porcelain Insulators used for the study

Specimen	Specimen A (%)	Specimen B (%)	Specimen C (%)	Specimen D (%)
Stoneware clay	50	40	30	-
Feldspar	20	20	20	22
Quartz (Silica)	30	30	30	38
Fire Clay	-	10	20	-
Kaolin	-	-	-	30
Ball clay	-	-	-	10
Total	100	100	100	100

Plate 1: POP Mould for shackle insulators used for the study

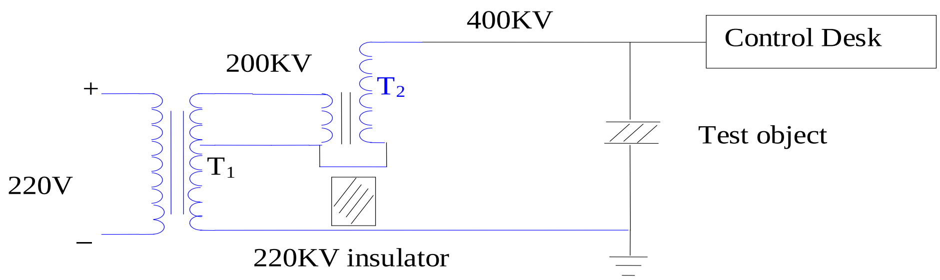

Fig. 1: Test circuit diagram

Plate 2. Experimental set-up for breakdown voltage test

Plate 3 Green stage electrical porcelain body

Plate 4: Glazed and glost fired electrical porcelain insulator

Table 3: Chemical analysis of Nando clay

Metal Oxides	(%) Composition
SiO_2	20.10
Al_3O_2	18.75
Fe_2O_3	0.92
TiO_2	0.07
MgO	0.05
Na_2O	2.59
MnO	0.09
K_2O	0.30
CaO	0.13
Loss on ignition(LOI)	14

III. RESULTS AND DISCUSSION

The electrical porcelain insulators produced using different body formulations are shown in Plate 3 and plate 4. Plate 3 shows the green stage of the electrical porcelain insulators that is when the porcelain insulator body is not yet fired, while Plate 4 shows the glazed and gloss fired porcelain produced. The chemical composition of the clay is shown in Table 3, it is observed that silica and alumina form the major composition of the clay while other oxide minerals are present in minute amount as impurities.

A) Physical Characterization

The physical analysis of the samples is shown in Fig. 2 to Fig. 15.

Dry to fired shrinkage

The graph in the Fig. 2 below shows the effect of temperature on the dry to fired shrinkage of the porcelain bodies. However the Specimen D which is the standard proves to have the highest shrinkage than the other samples.

B) Total Shrinkage

The effect temperature has on the shrinkage changes with temperature; the total shrinkage of the porcelain body desired a material that has low shrinkage for accurate dimension, However even if the body records very high shrinkage it can still be utilized simply by predicting the shrinkage dimension accurately. These make the shrinkage a property that should not be solely relies on for predicting a body suitable or not suitable for a dimension. As for the effect of temperature on the total shrinkage, it is observed that an increase in total shrinkage with the firing temperature was recorded for all the body and Specimen A has the highest total shrinkage than the other Specimens. It is seen that as the temperature increases the most volatile component and impurities are removed from the clay leading to the compression of the clay after drying, it is also as a result of coming together of the particles to form aggregate with an increase in temperature. It was observed that average total shrinkage for each of the samples was within the recommended value for porcelain production [15]. Higher shrinkage values result in warping and cracking of the porcelain wares resulting in loss or reduction in its strength. Fig. 3 shows the effect of firing temperature on the total shrinkage of the porcelain bodies.

C) Apparent porosity

Porosity is required for electrical insulation because it helps the insulating properties of the materials and Specimen A has the highest porosity as shown in the figure below. After the glazing, zero porosity will be observed, the decrease in porosity of the entire Specimen with increase in temperature is as a result of increase in shrinkage with the temperature to close the porosity. This shows that as the temperature increases, the percentage apparent porosity decreases, indicating more closure of the pores. Fig. 4 shows the effect of firing temperature on the apparent porosity of the porcelain bodies.

D) Bulk Density

The Bulk Density is an important property in porcelain wares. Bulk densities of the mixed samples lie within the range of 1.7 to 2.1 g/cm^3 which fall within the standard requirements for porcelain body [16] and it tells how high or low the density of materials can be. The strength of the Bulk density is very low and Specimen A has the highest Bulk density. As the temperature increases the Bulk density increases as shown in Fig. 5.

E) Apparent Density

Apparent Density is the inverse of the Bulk Density. The apparent density of the sample was found to fall within the internationally accepted standard range of 2.3 – 3.5g/cm^3 [16], [17]. Therefore increase in temperature decreases the apparent density as shown in Fig. 6.

F) Water of Absorption

The porous the material the more water it absorb which is related to the Apparent porosity. The graph follows the same pattern of the apparent porosity. The temperature of the water of absorption increases as the water of absorption decreases and Specimen A has the highest water of absorption while Specimen C has the least as shown in Fig. 7.

G) Modulus of Rupture

Specimen A shows the best strength than the standard which is Specimen D. An increase in the Modulus of rupture with the increase in the temperature was also observed due to the fact that shrinkage was experienced making the materials to compact together and therefore increase in strength. The effect of firing temperature on the modulus of rupture of the porcelain bodies is shown in Fig. 8.

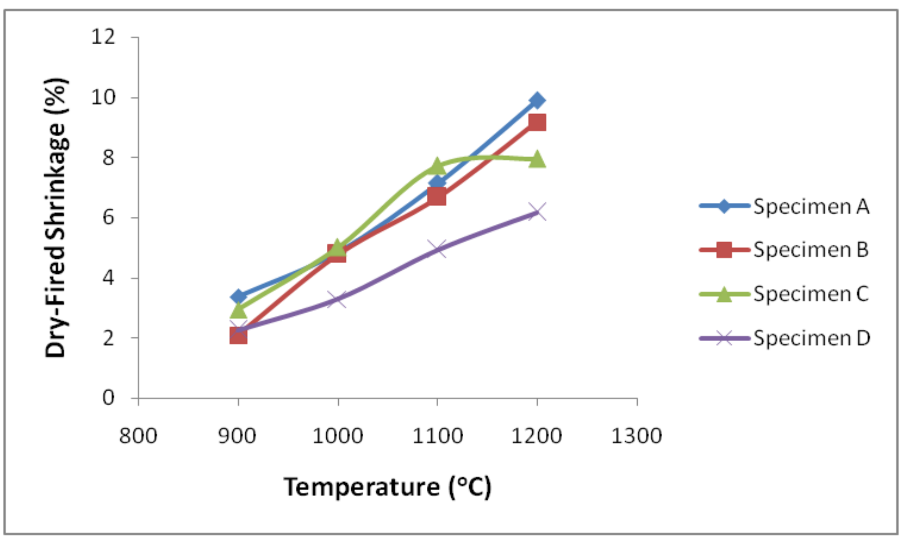

Fig. 2: Effect of firing temperature on the dry to fired shrinkage of the porcelain bodies.

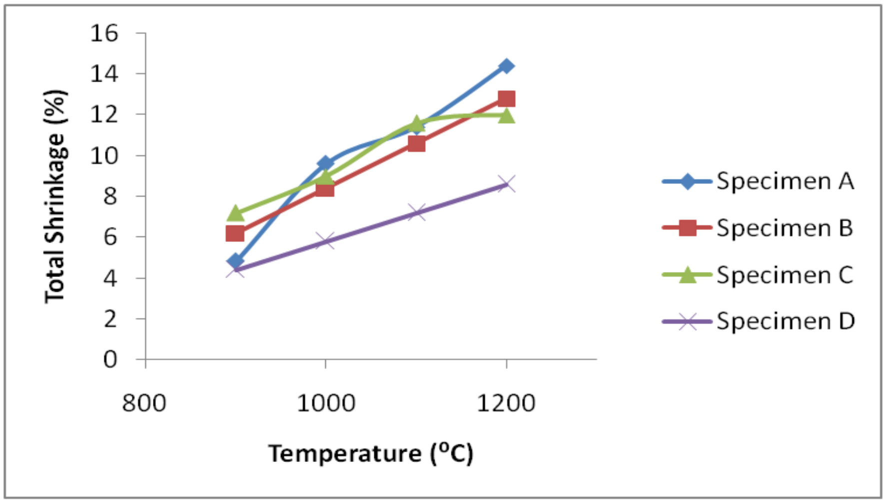

Fig. 3: Effect of firing temperature on the total shrinkage of the porcelain bodies.

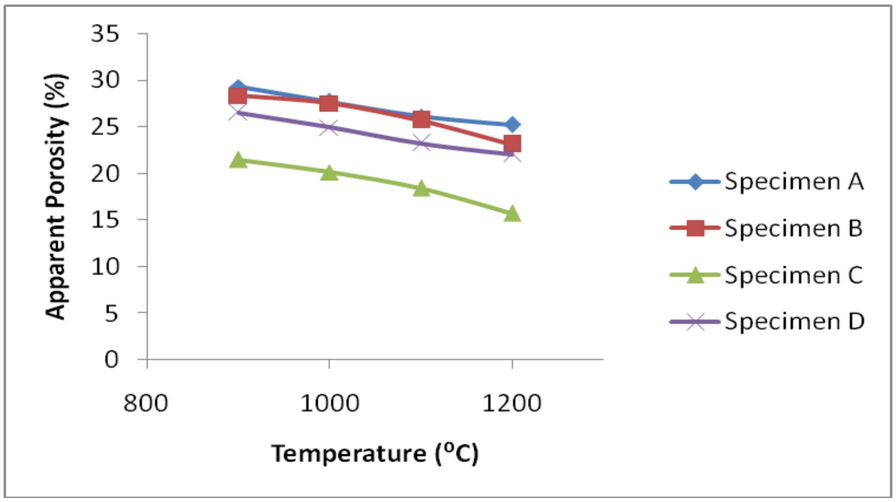

Fig. 4: Effect of firing temperature on the apparent porosity of the porcelain bodies.

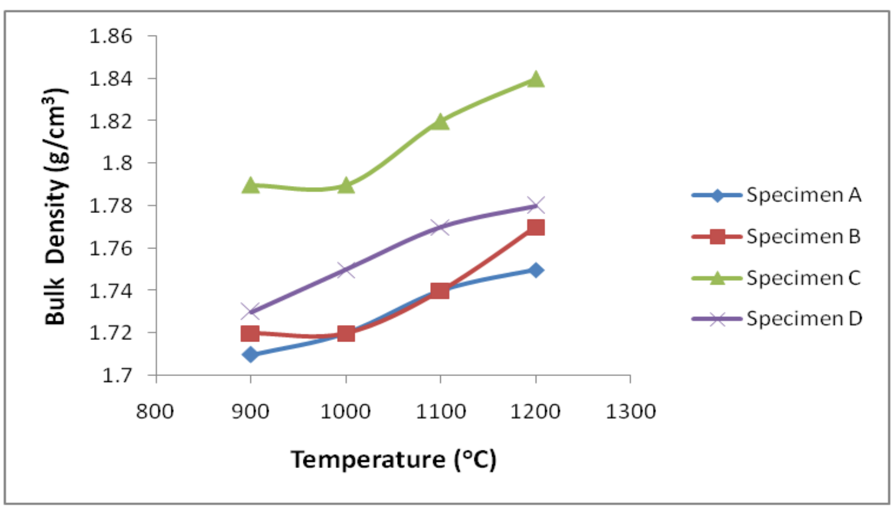

Fig. 5: Effect of firing temperature on the Bulk Density of the porcelain bodies.

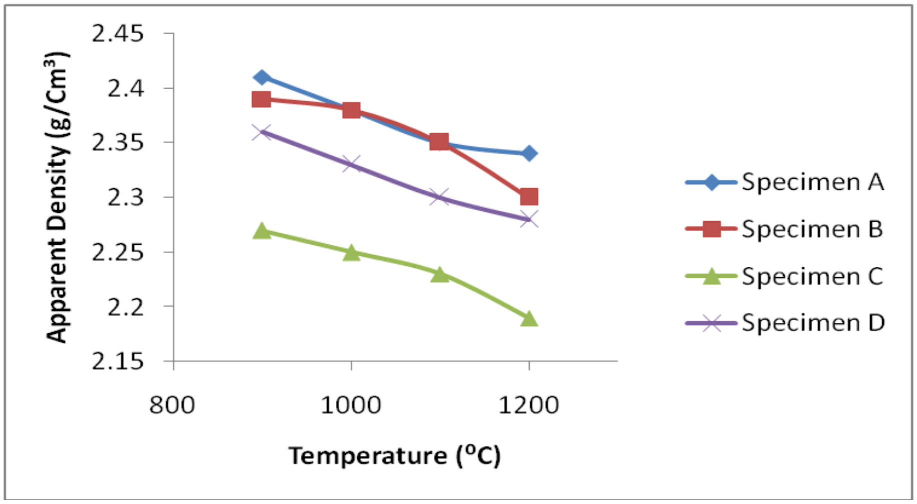

Fig. 6: Effect of firing temperature on the Apparent Density of the porcelain bodies.

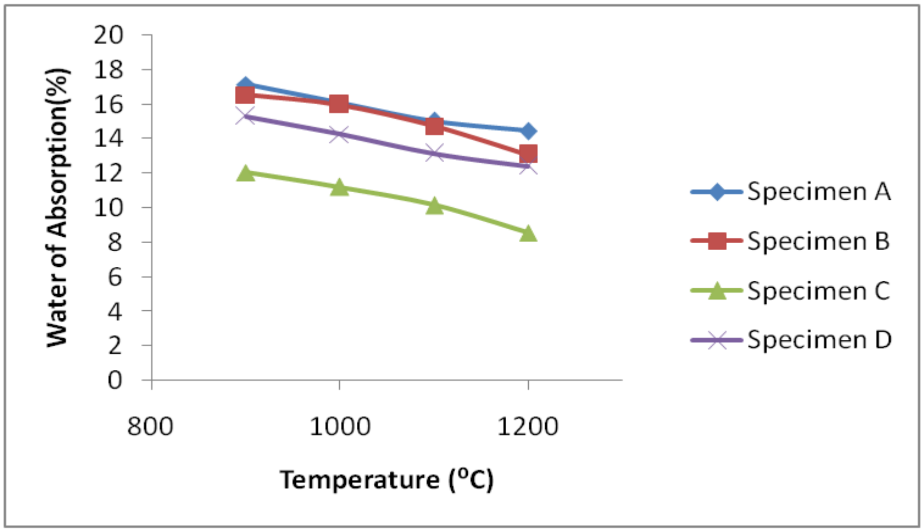

Fig. 7: Effect of firing temperature on the Water of Absorption of the porcelain bodies.

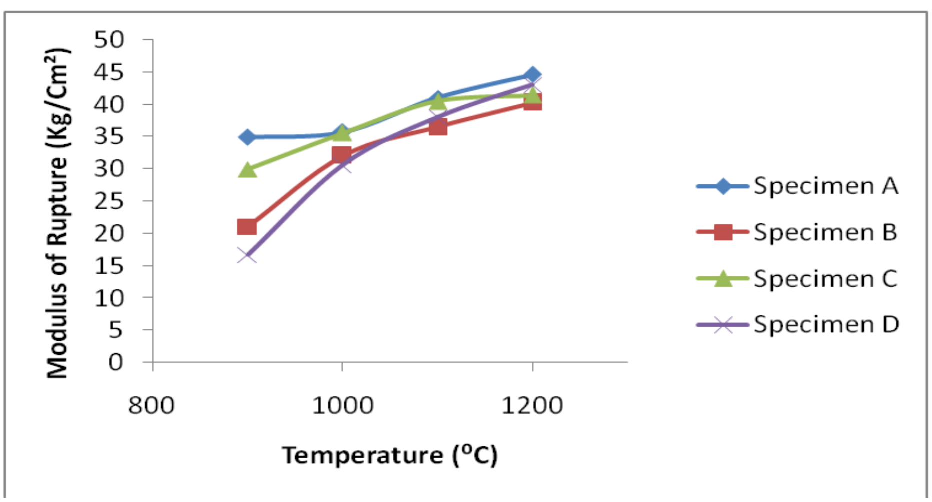

Fig. 8: Effect of firing temperature on the Modulus of Rupture of the porcelain bodies.

H) Physical analysis of Nando clay

Fig. 9 to Fig. 15 shows the physical analysis result of Nando clay, Fig. 9 shows the effect of firing temperature on the dry-fired shrinkage of the clay. The result presented showed that the increase in temperature increases the dry fired shrinkage. The shrinkage experienced was due to drying and firing of the clay sample. The effect of firing temperature on the total shrinkage of the clay is shown in Figure 10. The figure showed that as the temperature increases the shrinkage occurs mostly from 1000 to 1100^{o} C up to 1200^{o}C. The shrinkage is high at very high temperature and it withstands very high temperature (stoneware clay). The effect of temperature on the apparent porosity of nando clay is shown in Fig. 11. The results showed that as the temperature increases the apparent porosity decrease which indicates that the porosity is not that much. The porosity decreases with increase in temperature which is due to the closure of the pores as a result of the coming together of the particles to form aggregates with temperature increase. The results indicate that as temperature increases the apparent density decreases which determines the weight of the clay sample to be less as shown in Fig 12**.** Bulk density results showed the opposite of apparent density, as the temperature increases the bulk density decreases but the graph is inverse of the apparent density as shown in fig. 13. The effect of firing temperature on the water of absorption of the clay is shown in Fig. 14, The results indicate that as the temperature increases the water of absorption decreases therefore indicating that the clay sample has low water of absorption due to decease in porosity with temperature. The effect of firing temperature on the modulus of rupture of the clay is shown in Fig. 15. Modulus of rupture also known as the bending strength of the clay tend to increase with increase in firing temperature due to compression of the particles which tend to make the clay more rigid, thus having higher strength.

I) Calculation of the Actual Breakdown Voltage

For 11KV glass insulator the corona occurred at 30V, flash over occurred at 90V while for 11KV pin porcelain insulator we have corona to be 40V and flashover 85V. The standard 11KV porcelain insulator gave a test reading of 85V. The porcelain specimen tested gave a flashover voltage reading of 45V.

Hence rating of the porcelain specimen is:

$$\frac{45V}{85V} X\ 11kv$$

= 5.8KV

The impulse breakdown voltage of an 11KV porcelain insulator is 110KV [18].

Hence the porcelain specimen insulator rated 5.8KV = 5.8KV X 10 = 58KV

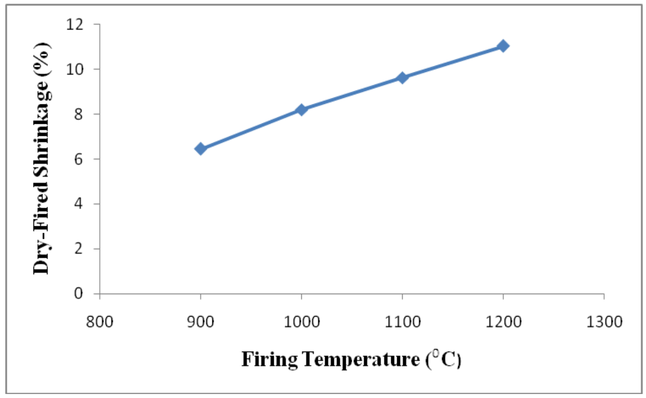

Fig. 9: Effect of firing temperature on the Dry – Fired shrinkage of the clay

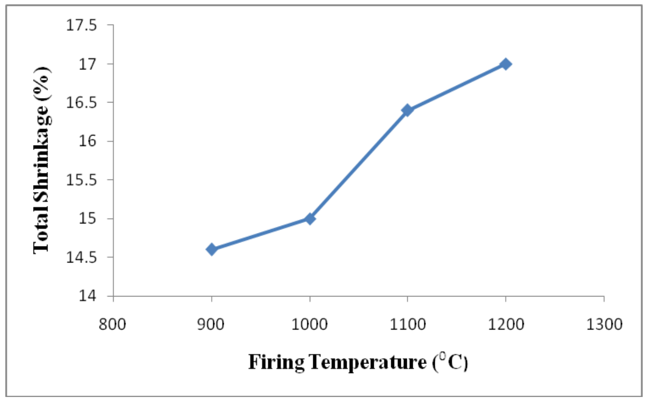

Fig 10: Effect of firing temperature on the Total shrinkage of the clay

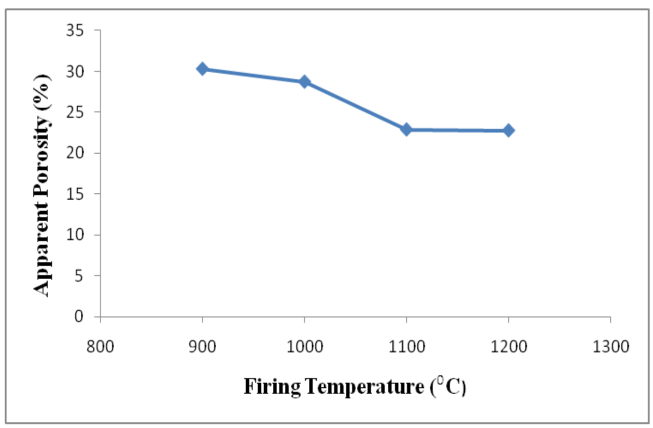

Fig. 11: Effect of firing temperature on the Apparent Porosity of the clay

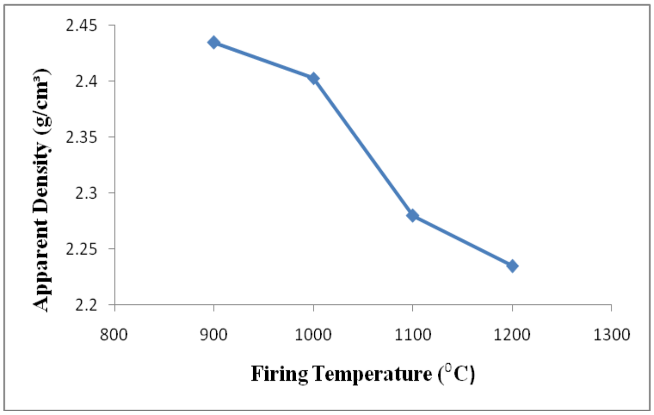

Fig. 12: Effect of firing temperature on the Apparent Density of the clay

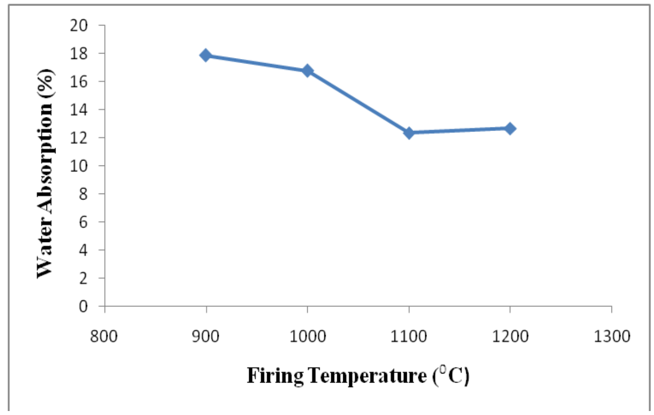

Fig. 14: Effect of firing temperature on the water absorption of the clay

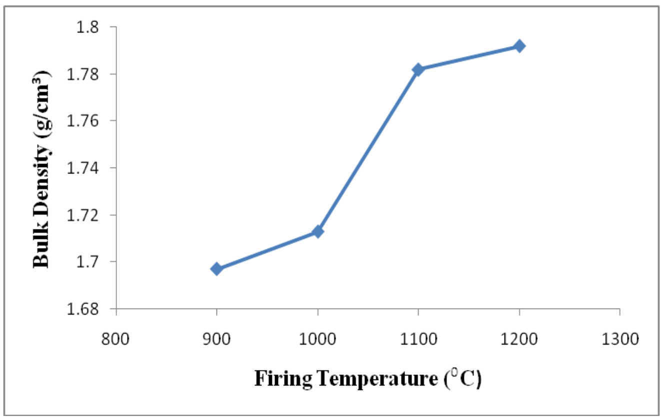

Fig. 13: Effect of firing temperature on the Bulk Density of the clay

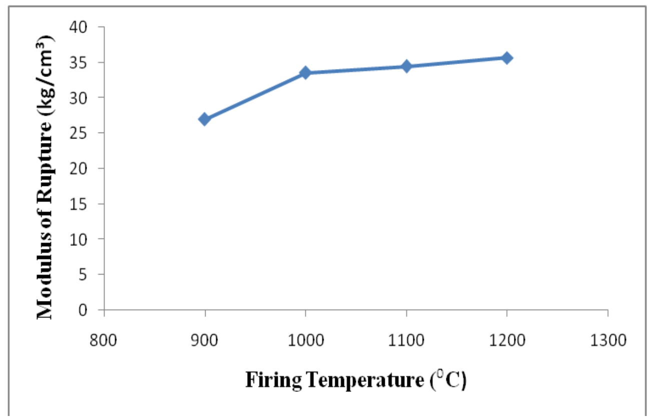

Fig. 15: Effect of firing temperature on the modulus of rupture of the clay

IV. CONCLUSION

Good quality low voltage (distribution line insulators) porcelain bodies were produced from local materials which are stoneware clay, feldspar and quartz. The sample A with composition of 50% stoneware clay, 20% feldspar and 30% quartz with appreciable insulation breakdown voltage of 45V was found to possess a quality result required for electrical porcelain insulator compare to the standard product and the results obtained from all the tests showed that sample A is better in insulation. The improvement of insulation performance is important in order to increase its lifetime, cost-saving capability and durability. A good insulator will keep the people safe as well as maintain the perfect operation of the power industry. The new insulator material needs to be developed from time to time in order to overcome its limitation and to enhance its performance as well as to increase the lifetime. Some constraints were encountered during firing which led to abnormality in the properties of some specimens produced and tested.

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