



Development of Electrical Porcelain Insulators using Locally Sourced Raw Material in Bauchi State

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ABSTRACT

This paper outlines the characteristics of three different compositions of electrical porcelain insulators using locally available raw materials found in Bauchi state. Physical analysis was carried out to test the plasticity, compressive strength, shrinkage rate of the samples, with both drying shrinkage rate of the samples. Three set of samples were prepared as; Sample A (contains ball clay 15%, kaolin 33% feldspar 32% quartz 20%), Sample B (contains ball clay 15%, kaolin 30%, feldspar 30%, and quartz 25%) and Sample C (contains ball clay 10%, kaolin 40%, feldspar 35%, and quartz 15%). The results revealed that the firing shrinkage ranges between 1.6% and 4%, and the water absorption ranges between 10% and 11%. The compressive strength has a value ranging between 11.1% and 30.3%. Based on the simulation results obtained, all the three samples exhibited excellent insulation properties. The results indicated that the samples used can be used as alternative raw material for the production of porcelain insulators for electricity transmission and distribution.

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INTRODUCTION

Insulator is one of the electrical safety components designed to curtail the flow of electrical charges in electric motor, appliances and devices that provide lights in the homes. The need to prevent dangerous effect of electricity flowing through a conductor requires a non-conductor such as insulators. An insulator contains no movable electric charges and when a voltage is passed through it, does not conduct electricity. It is extensively used in grid extension. The International Energy Agency (IEA) reported that more than 1 billion individuals stayed without access to power in 2014, of which the greater part were in India, Nigeria, Ethiopia, Democratic Republic of Congo and, Bangladesh. Without insulator, it is difficult for household, industries and all other power consumption outlets to connect to the national grid.

Insulator produced from ceramic materials is referred to as porcelain insulator. It is a vitrified fine grained ceramic white ware body which can either be glazed or unglazed. It is composed basically of clay which gives plasticity to the mixture in order to make it workable; feldspar acts as fluxing agent at lowering the melting point of the mixture during heating, Kaolin gives the body a refractory capacity to withstand the excess heat and quartz helps to maintain the shape of the formed article during firing. These four constituents that is clay, feldspar, kaolin and quartz, place electrical porcelain insulator in a phase system in term of oxide constituent when bisque - fired at 1200 °C.

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According to Hubert and Bruno, (2003), ceramic products produced depend not only on the over-all chemical composition but also on the individual compositions, its crystalline structures and particles sizes of the raw materials. It is also often influenced considerably by minor impurities which make it very difficult to make quantitative predictions about the optimum composition firing schedule for a desired product.

The raw materials used to prepare porcelain bodies play a vital role in the ultimate product quality. It is an understatement to say that ceramic materials are not abundantly available in Nigeria. Studies reviewed show that there are abundant sources of materials for the production of electrical porcelain insulators in Nigeria. Some existing studies among others have exploited porcelain raw materials from various locations within Nigeria for the production of porcelain products. These studies have given insight to best materials locations and proved the abundance of such materials in Nigeria. Without evidence of doubt, this study agrees with other studies on mineral exploration in Nigeria that porcelain raw materials are readily available. Thus, locally available materials were optimally utilized in the course of this study with a view of providing source of information on available materials and its viability for prospecting porcelain insulator production industries with regard to local content maximization using locally available materials from Bauchi state, Nigeria.

In spite of the enormous wide range of application and availability of locally available ceramics raw materials in Bauchi state, mostly used insulators are still imported into the country due to lack of inadequate industries that are manufacturing the porcelain insulators in Bauchi state and its neighboring states. Standardization is difficult if not impossible since the raw materials and the manufacturing technology are non-resident in Bauchi. In addition, dependence on foreign products is susceptible to sabotage and more often than not the manufactured products may not be the most ideal product for the importing country's climate which invariably affects efficiency.

The main objectives of this study ranges from highlighting the local availability of the ceramic's raw materials for the production of porcelain insulators to the actual manufacture of sample porcelain insulators from the locally available ceramics raw materials and their characterization.

The availability of natural deposit of ceramics raw materials in Bauchi state will enhance economy in the state and Nigeria. Porcelain Insulators are most useful Ceramic wares across the globe and none of any industries in Nigeria have the adequate insight of the ceramics raw materials in Bauchi state and, it may serve as deposit to produce electrical insulators in Nigeria which will be a way to improve Nigeria Economy and boast the exportation of Electrical Insulator produced in Nigeria using Bauchi raw materials.

LITERATURE REVIEW

An insulator is a material that resists the flow of electric current. The consumption of electric energy has been significantly increasing in developing countries due to the rapid evolution of industries and change in human life style. For instance, in Ethiopia the energy sector has been growing in the past two decades and reached currently electric power of 2360 MW, this would be expected to reach 10,000 MW in the next 10 years (Mondal et al., 2018 in Andualem et al, 2019). Hence, the power industries work all the way to develop high voltage and long-distance transmission. For safe transmission and distribution of the electric power, application of insulator is very much essential to prevent the flow of current from the wire to the earth through ground supporting tower or poles (Ezenwabude and Madueme, 2015).

Among the insulator materials utilized in electric power transmission and distribution system porcelain insulator is the most commonly used material for overhead insulators (Ovri and Onuoha, 2015 in Andualem et al, 2019). Moreover, the raw materials used for its production are also naturally available compared to other type of insulators which needs industrially

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processed materials. Ceramic industries in Nigeria are producing porcelain insulators from ball clay material, which is not locally available. Therefore, the development of porcelain insulators from locally available raw materials will have a significant contribution to the economy of the country by import substitution and exploring and promoting underutilized resources.

A) Theoretical Background

Electrical porcelain insulators are the most complex multiphase ceramic materials used as overhead insulator for both low- and high-tension insulation (Yaya et al., 2017 in Anduaem et al., 2019). It basically produced from natural ceramic raw materials such as clays (ball clay, China clay or kaolin), feldspar and quartz (Akwilapo and Wiik, 2004).

These ingredients go through different physical changes and react together under thermal condition to produce the final product (Yaya et al., (2017); Anduaem et al., (2019)). The quality and quantity of the raw materials plays a significant role on the properties of blended green body and the fired body/microstructure of porcelain body that ultimately affect the performance of electrical porcelain insulators. The clay $[Al_2Si_2O_5(OH)_4]$ content when wet, acts as a binder for the other body ingredients in the green state which confirm plasticity of the body for easy molding and shaping, while feldspar $[K_x Na_{1-x}(AlSi_3)O_8]$ serve as flux and alternative source of alumina and silica, whereas quartz (SiO_2) used as a filler material helps to maintain the shape of porcelain body at green state and during firing (Ngayakamo and Park, 2018 in Anduaem et al 2019). Various scholars designed efficient high quality porcelain insulator using ball clay as a plastic material (Anih et al., (2015); Oladiji et al., (2010)). But high-quality ball clay that makes up a large proportion of a porcelain insulators are very scarce and found in very few places around the world. As a result, the sustainable development of porcelain insulator requires searching for alternative clay materials that partially or fully supplement the current need of scarce ball clay.

According to (Liebermann (2003); Islam et al., (2004); Meng et al., (2014)). The most desirable properties of a porcelain insulator for applications in electric power distribution and transmission system includes, high electrical resistivity, high dielectric strength, good mechanical properties, and excellent heat radiating and insulating capacity even in humid and corrosive environments. Among those properties, dielectric strength and mechanical strength are the two most important determinant properties which must be taken in to consideration to produce quality porcelain insulator. These two properties of porcelain insulator are mainly affected by major phases of porcelain materials namely mullite and glassy phases which are developed at high firing temperature (Moyo and Park, (2014); Anduaem (2019)).

A crystalline alumino-silicate mullite ($Al_6Si_2O_{13}$) compound primary originated from clay relict called primary mullite and has a cuboidal structure under SEM analysis (Iqbal and Lee, 2000; Lee and Iqbal, 2001; Lee et al., 2008; Anduaem, 2019). Whereas, the glassy phase or liquid phase originated during sintering of feldspar, causes densification of the ceramic bodies (Anduaem, 2019). But an excess amount of glassy phase promotes free movement of ions in the porcelain bodies that result in poor electrical insulation. Hence, by varying the raw material composition (clay to feldspar ratio) and the firing temperature, it is possible to influence the properties of the fired porcelain body.

Therefore, the present study was aimed to develop good quality electrical porcelain insulator by using locally available clay materials, characterize the properties of locally available ceramic raw materials (Rafin Makaranta clay, Sabon Kaura feldspar, Alkaleri kaolin and Tambari quartz) and Optimize batch composition to influence important properties such as continuity test and mechanical strength by producing sample porcelain insulators.

Shackle insulator is used in the following applications.

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- i. It is used in a distribution system by arranging in between tower & conductors to support & insulate.
- ii. These insulators are used in overhead lines with low & medium voltage.
- iii. This insulator is used with a bolt by placing on the pole otherwise telegraph to avoid outflow current from conductors
- iv. It can be used in both horizontal & vertical positions (Tesla Edison, 2021).



Figure 1: Samples of Shackle Insulators

The tapered hole of the spool-type porcelain insulator distributes the load more evenly and minimizes the possibility of breakage when heavily loaded. The conductor in the groove of shackle-type porcelain insulator is fixed with the help of soft binding wire. Such insulators can be used either in a horizontal position or in a vertical position. They can be directly fixed to the pole with a bolt or to the cross arm.

The advantages of porcelain insulators include superior electrical properties, good mechanical properties (especially tensile strength), good creep resistance at room temperature and high corrosion resistance. High voltage porcelain insulators are also able to resist heat, chemicals, weather and bacteria without allowing them to affect their properties or alter their structure, and also offer dimensional stability and rigidity.

The properties of any electrical porcelain insulators are a direct result of its crystalline structure and chemical composition. There are different types of electrical porcelain

insulators which can have very different properties. But the general properties such as high melting temperature, high hardness, and poor conductivity, high moduli of elasticity, chemical resistance and low ductility are the norm.

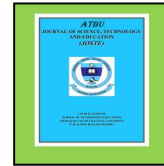
In general, electrical porcelain insulators are corrosion-resistant, they are very hard strong in compression (have been hardened by heating at high temperatures), less brittle, chemically inert, refractory (can withstand very high heat without deformation), poor conductors of heat and electricity (they are dielectrics), weak in shearing tension and also have low densities. In addition to the above properties; the properties of porcelain insulator associated with low permeability, elasticity; considerable strength, whiteness, translucency, resonance; and a high resistance to chemical attack and thermal shock. These insulating materials also offer lower thermal expansion than metals or plastics, and longer part life at original design dimensions and tolerances.

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LITERATURE REVIEW

Ball clay is an earth material of very fine particle size which forms as an end result of the residue due to weathering or by hydrothermal action which is a result of sedimentary deposit. Clay is cohesive and usually plastic when wet. It serves as a primary binder and fires in different colors depending on the types and compositions. It shrinks when dry and expands when wet. It is a poor conductor and that is why clay materials are used as thermal insulators. Clay materials are usually stable at high temperatures and this makes them have good thermal shock, i.e. ability to retain their original forms without cracking, spalling or flaking under sudden thermal changes and to have good resistance to environmental attack. It has appreciable amounts of organic matter. Various grades of ball clay occur in Nigeria (FMST, 2010).

Kaolin is a white, soft, plastic clay composed mainly of kaolinite, $Al_4(OH)_8[Si_4O_{10}]$, and other related clay minerals such as nacrite and dickite (Eney, 2024). Kaolin deposits are classified as primary or secondary according to their genesis; primary deposits originate *in situ* by alteration, whereas secondary deposits are of sedimentary origin (Eney, 2024). The formation and localization of sedimentary clay is controlled by the location of the sedimentary basin and the presence of weathered feldspar-rich rocks such as granite, syenite or gneiss adjacent to the basin, particularly rapidly eroding paleo topographic highs. Ideal conditions to produce kaolinitic by chemical weathering are high rainfall, warm temperatures, lush vegetation, low relief and high groundwater table (Eney, 2024).

The kaolin is eroded and transported by streams to a quiet, fresh or brackish water environment. Post-depositional leaching, oxidation, and diagenesis can significantly modify the original clay mineralogy with improvement of kaolin quality (Anduaem, 2019). Kaolin has wide range of application among which is the ceramic industry. Each

specific use of kaolin requires the kaolin to possess some specific properties. The chemical composition of Kaolin is $Al_2O_3 \cdot SiO_2 \cdot 2H_2O$. Kaolin has also been used topically as an emollient and drying agent, it has a low shrink-swell capacity and a low cation-exchange capacity. It is a soft, earthy, usually white, mineral (di-octahedral phyllosilicate clay), produced by the chemical weathering of aluminum silicate minerals like feldspar. It is a white or yellow-white powder that has a slightly oily feel. Kaolin is formed in two ways, namely, by the action of weathering and hydrothermal alteration, and both varieties are common in Bauchi, although the latter is preferred to abundance and quality.

Feldspar is a group of closely related, rock forming aluminosilicate minerals, which contain varying proportions of potassium, sodium and calcium. Feldspar is the most abundant of all minerals, comprising over 50% of the earth's crust. It forms the major constituent of most igneous and metamorphic rocks, as well as arkosic sediments (Anih, 1988). They are characterized by low iron oxide content; little variation in composition and a white colour. They are used mainly in the production of tableware, electrical and sanitary porcelain, glazes, porcelain enamels and frits (Anih et al, 2015). Parsons (2021) state that felspar are the most important group of rock forming materials.

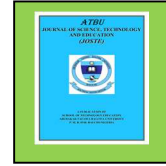
There are wide occurrences of feldspar in the granite and pegmatite rocks of Nigeria. Feldspar occurs in the feldspar rich pegmatite of the older granites around Egbe, Udiarehyu, Okene and Lokoja in Kogi State; Osogbo in Osun State; Ijero-Ekiti in Ondo State; Abeokuta in Ogu state; Gwoza in Borno State and parts of Taraba/Adamawa and Bauchi States (Ibrahim, 2000). The quality of feldspar is established by the amount composition of orthoclase and albite, respectively in the potassium and sodium feldspar and the most commonly used fluxes in porcelain. Generally high sodium feldspar will give lower Vitrification temperatures in a body than the potassium feldspar.

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Quartz constitutes one of the most readily available geological materials used in industries and factories such as glass manufacturing companies. Silica (Sand/Quartz) are said to consist of high optimal percentage of silicon dioxide (SiO₂) which is a very good chemically stable element and it remains almost the same no matter the series of cycles it may have gone through, either in transportation or re-deposition.

Quartz is silica occurring alone in pure state. Silica/glass sand on the other hand are products of weathering, erosion and transportation by rivers or/and the sea. Nigeria has extensive deposits of good quartz silica sands in almost all the states of federation. Locally Available Raw Materials and Geological Site of the Materials in Bauchi state (Munai 2017).

All the essential raw materials, which are used to produce electrical porcelain insulators, are available in the different parts of Bauchi state. The primary components of electrical porcelain insulators are clay, kaolin, feldspar, and quartz. All characterized by small particle size. The locally available raw materials are mixed together then the mixture is heated at a very high temperature (900°C, to 1200°C). To create different types of porcelain, people combine these raw materials in varying proportions until they obtain the desired and fired properties.

METHODOLOGY

The study used a quantitative research approach to evaluate the insulating properties of the materials used in the production of the insulators. The sample design and collection involved selecting the four locally available materials, namely ball clay, feldspar, kaolin, and quartz, which were sourced from local suppliers. The materials were then processed, mixed and molded to produce the porcelain insulators using a specific procedure

The methodology of the study includes the sample design, sample collection, laboratory

tested materials used, and procedure for production. The study was conducted in the ceramic studio of the Industrial Design, building laboratory, electrical engineering laboratory, and civil engineering, all in Abubakar Tafawa Balewa University Bauchi, in the following step procedures;

Samples were collected from Bauchi state, Nigeria from four districts within Bauchi metropolis; (Bauchi, Galambi, Miri and Zungur). The state is in the northeastern part of Nigeria. Bauchi Local Government Area lies between longitude 10.100 N-10.330N and latitude 9.400E-10.130E. Its altitude is 690.2m above sea level; and occupies an estimated land area of 3,687km² and has a population of 493,810 at the time of the 2006 census. Samples were collected manually into polythene bags at the site.

A) Porcelain Processing

Almost all the materials have to undergo some processing before production. Good porcelain insulators materials are known for its fineness and smoothness in order to give a qualitative, durability and strength worthy of acceptance. A rough porcelain insulators material has some disadvantages to the body which may render its texture rough. The processing of porcelain insulator materials is best pass between 100 µm to 750 µm sieved size of mesh (Khaled et al., (2018); Oladiji et al. (2010)). Calcination of feldspar and Quartz was done using electric kiln and were crushed to powder using a jaw crusher machine.

The materials that have undergone the milling and procurement process must be sized to separate desirable powders from non-usable. Ingredients are passed through a series of screens to remove any under or over-sized powders. This was accomplished using Fine Mesh Vibratory Sieving Equipment. By controlling the particle size, the result will give you proper bonding and a smooth surface on the finished product.

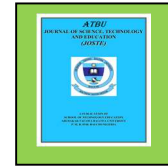


Table 1: Raw Material Processing

Kaolin	Feldspar	Ball Clay	Quartz
Soak	Excavate	Soak	Excavate
Plunge	Calcine	Sieve	Calcine
Sieve	Jaw crush	Decant	Jaw crush
Dry	Mill	Dry	Mill
Pounds	Sieve	Pound	Sieve

B) Sample Formation and Preparation

The term “Composite material” implies a combination of two or more materials differing in form or composition to achieve a particular porcelain body. And it is very important to characterize the properties of electrical porcelain insulators depend to a marked degree on the percentage composition of the mixture and method of manufacture. Several samples of porcelain bodies were produced by varying percentage compositions of clay, kaolin, feldspar, quartz.

The powder of the raw materials must be fixed (or weighted) in accordance with the intended use of the mixture, referred to as the scale of scrutiny. Budnikov’s recommendation for electrical porcelain was used as the standard to compare with the locally available materials, in the study – kaolin, 40; ball clay, 10; feldspar, 35; and quartz, 15.

The percentage compositions of the mixture are shown in Table 2.

Table 2: Percentage Compositions of Samples Using Three Raw Materials (Temitope, 2020)

Sample	% Clay	% Kaolin	% Feldspar	% Quartz
A	15	33	32	20
B	15	30	30	25
C	10	40	35	15

C) Tests to be Conducted

Amongst the various testes to be conducted on the insulator to ensure conformity with the standards include the following;

i) Shrinkage Test

ASTM standard method was used to determine the shrinkage value of dried and fired clay. Test bar of mixed samples will be marked for easy identification. They will be allowed to dried up, measured again and be then fired to a maximum temperature of 1000°C. They will then be measured again to know the shrinkage of the clay.

The shrinkage limit can then be determined through Eqns. (1) and (2):

For dry shrinkage

$$dry\ shrinkage = \frac{plastic\ length - dry\ length}{plastic\ length} \times \frac{100}{1} \dots\dots (1)$$

For firing shrinkage

$$firing\ shrinkage = \frac{plastic\ length - firing\ length}{plastic\ length} \times \frac{100}{1} \dots (2)$$

ii) Water Absorption Test

The absorption test will be carried out in order to determine the porosity of the clay at fired level. Six cubes of clay will be prepared and allow to be dried. The samples will be soaked for 48 hours and weight them again. Eqn. (3) gives the formula that can be used for determine the absorption rate:

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$$\text{Absorption rate} = \frac{\text{saturation weight} - \text{fir weight}}{\text{fired weight}} \times \frac{100}{1} \dots(3)$$

iii) Compressive Strength Test

Conducting a compressive strength test typically involves testing the strength of a material, such as concrete or rock, by applying a compressive load until the material fails or fractures. The procedure may vary slightly depending on the specific material and the testing equipment available. Here in, the insulator will be placed on the cylinder, and the machine was turned on, the reading continues until the insulator shatter. The steps to achieve that is as follows:

- i. Measure the dimensions (diameter and height) of the test specimens using a vernier caliper or other measuring tools.
- ii. Take multiple measurements and calculate the average dimensions for accuracy.
- iii. Adjust the testing machine to apply a slow, continuous, and uniform compressive load at a specified rate (typically 0.5 to 2.0 MPa per second).
- iv. Continue applying the load until the specimen fractures or reaches its maximum compressive capacity.

In recording of the data, the force is measured in Newtons (N) or kilo-Newtons (kN) using Eqn. (4):

$$\text{Compressive Strength} = \frac{\text{Maximum Load (N)}}{\text{Cross Sectional Area (mm}^2)} = \frac{\text{Maximum Load (kN)}}{\text{Cross Sectional Area (cm}^2)} \dots\dots\dots (4)$$

iv) Continuity test

Conducting a continuity test is simple but also an important used to check if an electrical circuit is complete or open circuited. This test ensures that current can flow from one point to another without any interruption. To perform a continuity test, we need a multi meter, being a

versatile electrical testing device that can measure voltage, current, and resistance. Before conducting any electrical test, always ensure that the circuit or device is disconnected from the power source to avoid accidents and injuries.

The steps taken conducted the test are as follows:

Step 1: Set up the multi meter

The multi meter was turn on and set to the continuity testing mode. This mode is usually indicated by a symbol that looks like a sound wave or a diode with an arrow pointing towards it. It may also be labeled with the word "Continuity" or "Beep" mode.

Step 2: Identifying the test points

The points in the circuit that you want to test for continuity was identified. For example, if you want to check if a wire is intact, place one test probe at one end of the wire and the other test probe at the opposite end.

Step 3: Touched the test probes

With the multi meter in continuity mode, I touched the metal tips of the test probes together. When this was done, it should make a continuous beep or show a reading close to zero ohms on the multi meter's display. This confirms that the test probes and the multi meter are working correctly.

Step 4: Test the circuit

With the test probes still touching each other, move one probe to the first test point (e.g., one end of the wire) and the other probe to the second test point (e.g., the opposite end of the wire).

Step 5: Observing the result.

If there is continuity in the material, meaning the path is continuous and unbroken, it will make a continuous beep or display a reading close to zero ohms on the multimeter. This indicates that the material is not an insulator. If there is no continuity, meaning it is an insulated material, it won't make a beep, and the multi meter



will display an infinite resistance (usually represented as "OL" or "1"). This suggests that the material is insulator.

RESULTS

After producing the clay samples, series of tests were conducted in accordance with the standards to ascertain the quality and durability of the material produced. The results of tests carried out are presented in the following sub-sections.

A) Laboratory Tests

Laboratory tests were carried out on the powdered clay samples. The analyses done

were to determine the chemical properties of the clay. Percentage occurrence of the element was determined through the use of x-ray fluorescence spectrometer techniques. The samples were grounded to a finer particle in such a way that it passes through 200mm size sieve mesh.

i) Chemical Analyses

Raw materials collected from the three locations in Bauchi state were adopted in this paper. Chemical analyses of all the kaolin, quartz and clay samples collected from Alkaleri, Tambari and Rafin Makaranta were characterized and shown in Table 3.

Table 3: Chemical Analysis of Alkaleri Kaolin, Tamabari Quartz and Rafin Makaranta Clay (Eze, 2015; Munai, 2017)

S/N	Compound	Kaolin Oxides	Quartz Oxides	Clay Oxides
1.	SiO ₂	55.4	93.9	60.80
2.	K ₂ O	0.04	0.13	2.62
3.	CaO	0.91	0.11	06.22
4.	TiO ₂	1.69	0.04	22.09
5.	Al ₂ O ₃	27.56	2.13	01.92
6.	Mn ₂ O	0.5	0.03	05.82
7.	Fe ₂ O ₃	1.33	0.39	00.00
8.	Na ₂ O	0.02	0.02	00.35
9.	ZrO ₂	0.18	0.009	00.17
10.	LOI*	10.7	1.07	60.80

From table 3, it can be observed that the silica contents of above compounds and also alumina of the Kaolin are high and was suitable for adoption as the best for Industrial Ceramics production, having values above the minimum standard of - ASTM 22, 34-71.

ii) Insulators Production

According to NPCS, pin, shackles etc. insulators were made by pressing (throwing process), followed by turning on leather hardening, as can be seen in Plates I to III.



Plate I: Throwing of porcelain insulator



Plate II: Kerosine firing being regulated



Plate III: Some of the sample insulators produced

The samples were fired using a Kerosine kiln twice (bisque and Glaze firings). Then the glaze was applied to each sample by the

use of dipping as suggested by Okolo (2004), as shown in Plates IV to IX.



Plate IV: Sample insulator



Plate V: Sample Insulator



Plate VI: Sample Insulator



Plate VII: Sample Insulator



Plate VIII: Sample Insulator



Plate IX: Sample Insulator

iii) Shrinkage Test

ASTM standard method was used to determine the shrinkage value of dried and fired

clay using Eqns. (1) and (2). The results obtained were tabulated as shown in Table 4.

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Table 4: The Result of the Shrinkage test

Materials	Plastic to Dry (%)	Plastic Firing (%)	Total Linear Shrinkage (%)
Sample A	0.8	2.5	2.5
Sample B	1.2	1.6	1.6
Sample C	2.4	0.4	0.4

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 Sample A has the highest total shrinkage than the other Samples. 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 sample was within the recommended value for porcelain production.

From Table 4 also, low water absorption is a good quality of electrical porcelain insulator since high water absorption reduces the insulating abilities. The temperature of the water of absorption increases as the water of absorption decreases and samples A and B has the highest water of absorption while sample C has the least.

iv) Compressive Strength Test

The results of the tests carried out for the compressive strength of the samples are presented in Table 5.

Table 5: Results for the Compressive Strength Tests

Sample	Compressive Strength (kN)
Sample A	17.1
Sample B	39.2
Sample C	50.5

The minimum failing load or combined electro mechanical strength according to technical specification for porcelain insulator (specification number D-24) as revised in 2001 for LT shackle insulator is 15-16 kN. The result in Table 5 revealed that the entire sample met the required specification.

v) Continuity Test result

The result of the continuity test shows that the material is an insulator, because it did not conduct electricity. High resistance means that the circuit is open and continuity is lacking. Plate IV showed the process of carrying out the continuity tests on the produced insulators.



(a)



(b)

Plate IV: Continuity Test Conducted on the Produced Insulators

CONCLUSION

Porcelain insulators were produced using locally sourced raw materials from Bauchi state. From the results obtained for different electrical porcelain insulator, the sample formulated exhibited reasonable degree of plasticity. Chemical analysis and physical property tests were carried out. The results revealed that the firing shrinkage ranges between 1.6% and 4%, and the water absorption ranges between 10% and 11%. The compressive strength has a value ranging between 11.1% and 30.3%. All the three samples exhibited excellent insulation properties. The results indicated that the samples used can be used as alternative raw material for the production of porcelain insulators for electricity transmission and distribution.

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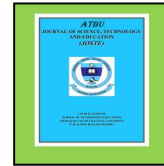
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