DEVELOPMENT OF ELECTRICAL PORCELAIN INSULATOR FROM LOCALLY AVAILABLE CLAY (AKURE, EKITI AND ABEOKUTA)

BY

OLADIJI ADEDAMOLA OLUREMI

MME/90/2416

A THESIS IN THE DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF A DEGREE OF MASTER OF ENGINEERING IN METALLURGICAL AND MATERIALS ENGINEERING (MATERIALS ENGINEERING OPTION) OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE. (FUTA), NIGERIA.

DECEMBER, 2009

CERTIFICATION

This work has not been presented elsewhere for the award of a degree or any other purpose.

Candidate's Name: Oladiji Adedamola Oluremi

Signature: ..... **Date:** 16th February, 2010

I certify that this work has been carried out by Mr. Oladiji Adedamola in the Department of Metallurgical and Materials Engineering of the Federal University of Technology, Akure. Ondo State.

Supervisor's Name: Prof. J. O Borode

Signature: ..... **Date:** 19-02-2010

DEDICATION

This project is dedicated to God Almighty, my beloved wife, Oladiji Rebecca Olabimpe and my beloved Parents Elder and Elder (Mrs.) Oladiji for their unrelenting financial and moral support towards the successful accomplishment of this programme.

ACKNOWLEDGEMENT

I foremost, give thanks to Almighty God whose enabling grace has seen me through and frustrate every plan of the enemy during this work, and made his peace which passes all human understanding multiplied unto me.

I want to appreciate my project supervisor Prof. Borode J.O. for his immeasurable contribution, assistance and supervision of this work. I am also grateful and appreciate my co supervisor, HOD, Dr. Adewuyi B.O. for his tenacity to make this work enjoy speedy accomplishment.

My appreciation goes to Dr. Adewara J.O.T, Dr. Omotoyinbo J.A, Dr. Alaneme K.K., Mr Oladele, Mr Oloruntoba D.T., and Mr. Olaniran O. for their moral support and encouragement and other academic and non academic staff of the department. God bless you all.

My profound gratitude goes to my parent Elder and Elder (Mrs.) Oladiji and my dearest wife Mrs. Oladiji R.O. for their support financially and morally you are the channel God used to make this work come to reality, truly "money is a defence".

TABLE OF CONTENTS

CHAPTER THREE

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In this work investigations were carried out to determine the suitability of some locally available clay raw material for the purpose of fabricating electrical porcelain insulators. Kaolin and Ball clay were first cleaned of the deleterious material, milled and sieved through a mesh of 200μm. Pre-determined portions of various mixes were made into a slip and cast into porcelain insulators of standard dimension in a plaster of Paris. The samples were dried, fired and thereafter subjected to physical, mechanical and electrical tests to determine their properties. The obtained properties were compared with those of imported porcelain insulator. The results obtained indicated that the porcelain insulator produced possesses a very good physical, mechanical and electrical property comparable with commercially available ones. The sample with composition of 32% Kaolin, 15% ball clay, 28% feldspar and 25% quartz was found to possess the best properties due to low water absorption (1.52%), high bulk density (1.78), failing load (8.4KN) with the appreciable insulation resistance property of 8,038.1 Megaohms at injection of 5000volts.

CHAPTER ONE

1.0 INTRODUCTION

The development of indigenous science and technology is considered an essential condition for achieving certain degree of autonomy in nation industrialization processes. The need for insulators arose out of the discovery of electricity in which electrical porcelain insulator was found applicable among other types of insulators. Insulators serve in numerous and high voltage applications (Onaji and Usman, 1988) In-spite of this wide application and the commercial availability of raw materials and fuel for their manufacture, only the low voltage shackle and coach screw service insulators are produced in small quantity. In Nigeria, a substantial quantity of insulators is impure to meet the fall arising from low level of local production. Thus, there is need for home production which must be preceded by the development of suitable porcelain bodies' base on local materials.

There are vast literatures on body compositions, processing conditions for porcelains of all kinds (Norton F.H, 1980; Peter Wilberforce Olupot, 2006). These bodies in formation pertain to foreign raw materials, which can be quite different from the local one in chemical, mineralogical and physical characteristics. There are just few literatures on the development of electrical porcelain with local raw materials. It is necessary to investigate and characterize the local raw materials so as to formulate various proportions of clay compositions for manufacturing ceramic insulator from local clay

deposit; determine the properties of the insulator produced from the formulated clay composition; compare its properties with those of imported insulators and processing conditions suitable for the porcelain manufacture.

It has been established that abundant raw materials are available for the manufacture of electrical porcelain insulators as well as heated ceramic wares (FMST, 2004).

Onaji and Usman, (1988) have developed 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 could not be commercialized for mass production of electrical porcelain.

Beside the work of Onaji and Usman, (1988), there is dearth of information on the other clay bodies as to their suitability for the production of electrical porcelain .In this work, attempt was made to characterize the local clay sourced from Akure (Kaolin) clay, Ikere Ekiti (ball clay), and Abeokuta (Quartz/Alumina and Feldspar) for the production of electrical porcelain; to formulate various proportions of clay compositions for manufacturing ceramic insulator from local clay deposit; to determine the properties of the insulator produced from the formulated clay composition and to compare its properties with those of locally made and imported insulators.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 INSULATORS

The need of the insulators arose out of the discovery of electricity and as railroads began crisscrossing the countries and continents, there came the need for signal devices. Electricity has to be moved economically from one place to another to meet the increasing demands generated by these new marvelous inventions. To insulate means to separate or cover with non-conducting material in order to prevent the passage or leakage of electricity, heat or sound. Communication and electric line wires in service must be kept as dry as possible in order to function efficiently and to cut down on loss of current. The wires are kept off of the ground by being strung between poles and this leads to the need to keep the wires and (sometimes wet) poles apart by insulator.

An insulator is a material which contains no movable electrical charges. When a voltage (E.P) is passed across an insulator, no charges flow, so no electric current appears. The term electric insulator has the same meaning as the term dielectric. So electrical insulation is the absence of electrical conduction. Material that lack electric conduction must also lack other mobile charges as well. Insulators can be classified into two, pin and non-pin.

2.2 PORCELAIN

The term porcelain refers to a wide range of ceramics that have been baked at high

temperature to achieve vitreous or glassy qualities such as translucence and low porosity. Among the most familiar porcelain products are table, decorative china, chemical ware, dental crowns and electrical insulators. Usually white or off white porcelain comes in both glazed and unglazed varieties with bisque, fired at a high temperature representing the most popular unglazed variety. Although porcelain is frequently used as a synonym for "China" or soft paste porcelain, but the two are not identical. They resemble one another in that both are vitreous wares of extremely low porosity and both can be glazed or unglazed.

However, China, also known as soft paste or tender porcelain is softer. It can be cut with a file while porcelain cannot. This difference is due to the higher temperature at which the "true" or hard paste porcelain is fired at 1454^{0}C compared to 1204^{0}C for "China". Due to its greater hardness, porcelain has some medical and industrial applications while "China", which is limited to domestic and artistic use, does not. (Anonymous: Porcelain, 2004)

Moreover, whereas porcelain is always translucent, china is opaque. Hard paste or "true" porcelain originated in china during the tang dynasty (618-907A.D) however high quality porcelain compared to modern ware did not develop until the Yuan dynasty (1279-1368 A.D). Early Chinese porcelain consisted of Kaolin (china clay) and peg matite, a coarse type of granite. Effort to develop true porcelain continued, in 1707, two Germans named E.Walter Von Tschnmhaus and Johann Friedrich Bollger succeeded by

combining clay with ground feldspar instead of the ground glass previously used. Later in the eighteenth century the English further improve upon the recipe for porcelain.

2.3 PORCELAIN INSULATOR

Porcelain insulator is a fast drying non-conducting material able to hold the line wire in place and can stay in the pole. It has a wire groove to accommodate the line wire. It has a pinhole which fits onto a pin which in turn attached to the cross arm on the pole. There are two classes of porcelain insulators.

(i) ***Porcelain Pin Type Insulator:*** can be identified by U (Unipart) or M (Multipart) number

(a) Unipart is single piece of porcelain or multiple pieces that have been glazed together (Glaze-welds)

(b) Multipart insulators have two or more sections that are cemented together.

(ii) Non Pin Type Insulator.

Generally, unipart insulators are used for voltage up to 34kv. Two Piece multipart are Used in the 20 to 40 KV range, three-piece insulators are used in the 40 to 69 KV range And four-piece insulators are used for 60 to 80 KV range.

Porcelain insulators had their start when local potteries began making telegraph insulators in the 1850's and 1860's. These crude early pieces were usually threadless and were produced in much lower quantities than their glass counterparts and few have survived the years. Porcelain saw very minimal use for either Telephone or telegraph

after the development of threaded glass insulators. Glass tended to be cheaper than quality porcelain and was deemed better as it was though that clear glass would discourage insect from building nests under the insulators reducing their effectiveness. with advert of electric power distribution the 1880' s larger and more reliable insulators were need to carry the higher voltage of power line, in the ten thousands of volts. Glass at that time was not sufficient and one man in particular Fred M Locke of victor, NY was convinced that porcelain was a superior insulating medium and began experimenting with clay mixtures that would produce finer insulators even insulators that would hold up to high voltage service in all weather condition.

In 1915 on, the porcelain insulator virtually replaced glass on all electrical distribution. even at low voltages, as the superiority was demonstrated in both insulation quality and strength. In the 1940's a new type of insulator was developed called "post'' insulator. post insulator are one-piece solid or hollow core porcelain column with multiple petticoats or skirts form top to bottom. They are mounted directly on the pole or cross arm and bolted in place. Their performance was superior to pin type insulator and by the 1960's they found widespread use on power line everywhere although they have never completely replaced pin-type insulator except for medium voltage lines between 40 and 70 KV.

2.4 RAW MATERIALS FOR PORCELAIN INSULATOR

The basic raw materials for electric porcelain are quartz, feldspar, ball clay and kaolin. Porcelains are vitrified and fine grained ceramic white ware, used either glazed or unglazed. They are widely used in households, laboratories and industrial applications. For technical purposes, Porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares. The distinguishing factor in the properties of different products are brought about by variations in the proportion of these materials; the processing, and the firing schedule adopted. For electric porcelains, the quest over the production costs.(Anonymous: Porcelain insulator, 2004)

Porcelain which is primarily composed of clay, feldspar and filler materials, 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.

These three constituents place electrical porcelain in the phase system in term of oxide constituents, hence the term triaxial porcelain (Buchanan, 1991). The fired product contains mullite ($A1_6Si_2O_3$) and undissolved quartz (SiO_2) crystals embedded in a continuous glassy phase, originating from feldspar and other low melting impurities in the raw materials. By varying the proportion of the three main ingredients, it is possible to emphasize thermal, dielectric or mechanical properties as illustrated by (A.R.Von Hippel et al, 1995).

For electrical insulation applications, porcelains are expected to meet minimum specification of the two. Electrical porcelain is widely used as insulators in electrical power transmission system due to the high stability of their electrical and thermal properties in the presence of harsh environments (Kingery et al 1976, Charlotte Speight et al, 1999). These are the reasons for their continued use over the emergence of new materials plastics and composites.

2.4.1 Properties of Porcelain Constituents

2.4.1.1 Kaolin: it is a non plastic primary type of clay formed by the weathering on site of feldspar. It is difficult to shape. It is characterized by large or coarse particles, and highly refractory. Kaolin has a melting point at 1800^{0}C with a low volume shrinkage because of it's coarse particle texture. It is naturally resistant to most acids and alkalis. Naturally, Kaolin is white or grayish-white, but the presence of impurities as oxides of iron and titanium usually impact colours that range from red to light pink (Heinskanen 1993, Veglio et al, 1993).

2.4.1.2 Ball Clay: It is secondary clay found mainly in stratified layer with alternating layers of coal and other types of clay. They are hydrated aluminum silicates of sedimentary origin. It tightens into a dense structure when fired to about 1300^{0}c and burns into white, light grey or buff colour. It is plastic, fine grained clay which has an excessive shrinkage up to 20% when fired because of the fine particle size. In raw state it is usually dark gray because of the presence of carbonaceous materials, which burns

off during firing. It has high plasticity and high dry strength, so it is used as binder and to develop the workability and dry strength of non-plastic materials in forming and holding shape during and firing .In some cases as little as 10% to 15% ball clay is used to bond 85% to 90% non plastics material.

2.4.1.3 Flint/ (Quartz)/Alumina: Flint is a type of hard quartz, a compound of silicon and oxygen (SiO_2) the two most abundant elements in the earth's crust. Its resemblance to glass is visible in quartz (its crystalline form), opal (its amorphous form) and sand (its impure form). Silica is the most common filler used to facilitate forming and firing of the body as well as to improve the properties of the finished product. It maintains the shape of the formed article during firing. Porcelain may also contain alumina, a compound of aluminum and oxygen, or low – alkali containing bodies e.g. steatite known as soapstone.

2.4.1.4 Feldspar: A mineral comprising mostly Aluminum silicate serves as flux in the porcelain body or mixture. It reduces the temperature at which liquid glass forms during firing to between 1,000^{0}C and 1,300^{0}C. To create different types of porcelain, combination of these raw materials in varying proportion until they obtain the desired green (unfired) and fired properties are necessary.

2.5 CHARACTERIZATION OF RAW MATERIALS

A number of techniques are employed in characterizing the raw materials for the porcelain insulation. The methods for characterization of raw materials sample powders

for specific properties are as follows.

A. Chemical Analysis:

Chemical Composition

B. Physical Analysis:

i. Shrinkage

ii. Moisture content

iii. Plasticity

iv. Permeability test

v. Compression test

vi. Particle size

2.6 FORMULATION OF PORCELAIN BODY

Formulation of porcelain bodies are carried out using statistical method. The type adopted in this work is shown in the Table 2.1

Table 2.1: Constituent Ratio Composition of Sample Porcelain (Peter Wilberforce Olupot, 2006).

	Compositional variation of samples				
Samples	S-1	S-2	S-3	S-4	S-5
Kaolin	35	35	30	30	30
Ball Clay	15	25	20	15	15
Feldspar	25	30	20	30	25
Flint	25	20	30	25	30
% Total	100	100	100	100	100

Key: S-1, S-2, S-3, S-4 and S-5 ——►Sample 1 - 5

2.7 PORCELAIN MANUFACTURING PROCESSES

The porcelain manufacture processes can be broadly classified in o two.

i. Dry Process

ii. Wet Process.

2.7.1 Dry Process

The process entails pressing of granular powders of porcelain raw materials into solid body using steel moulds. The resulting insulators tended to be porous and are only useful for low voltage applications.

2.7.2 Wet Process

Unlike the dry process, the wet process is carried under wet conditions. The fine grained raw materials are mixed in different proportions depending on applications and conditioned with water prior to be subjected to forming process. The sequence of steps involved in wet process is represented in the Fig 2.1 below

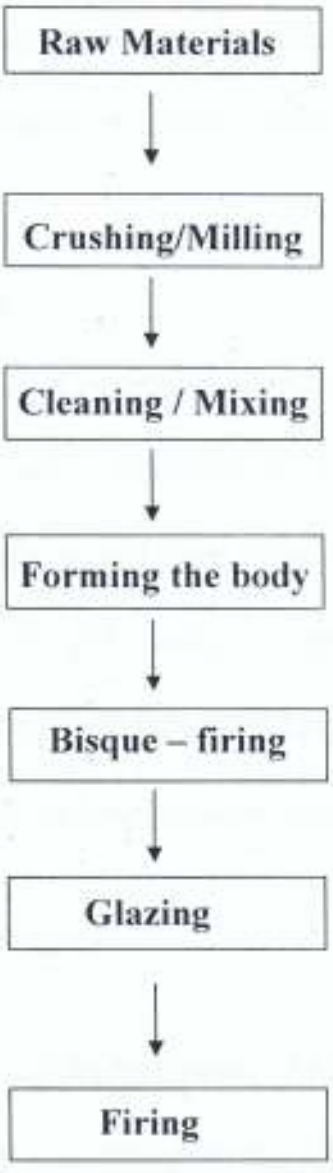

Figure 2.1: Wet Manufacturing Process

2.7.2.1 Crushing

First, the raw material particles are reduced to the desired size, which involves using a variety of equipment during several crushing and grinding steps. Primary crushing is done in jaw crushers which use swinging metals jaws. Secondary crushing reduces particle to 0.1inch (0.25cm) or less in diameter by using millers (steel-tired wheels or

hammer mills, rapidly moving steel hammers). For fine grinding craftspeople use balls that consist of large rotating cylinders partially filled with steel or ceramic grinding media of spherical shape.

2.7.2.2 Cleaning and Mixing

The ingredients are passed through a series of screens to remove any under-sized or over-sized materials. Screens, usually operated in a sloped position, are vibrated mechanically or electromechanically to improve flow. If the body is to be formed wet, the ingredients are then combined with water to produce the desired consistency. Magnetic filtration is then used to remove iron from the slurries, as these watery mixtures of insoluble material are called, because iron occurs so pervasively in most clay.

2.7.2.3 Forming the Body

At this stage, the body of the porcelain is formed. This can be done using one of four methods, depending on the type of ware being produced.

(i) **Soft plastic forming**, where the clay is shaped by manual molding, wheel throwing, jiggering, or ram pressing. In wheel throwing, a potter places the desired amount of body on a wheel and shapes it while the wheel turns. In jiggering, the clay is put on a horizontal plaster mold of the desired shapes; that mold shapes one side of the clay, while a heated die is brought down from above to shape the other side. In ram pressing, the clay is put between two plaster molds.

which shape it while forcing the water out. The mold is then separated by applying vacuum to the upper half of the mold and pressure to the lower half of the mold. Pressure is then applied to upper half to free the formed body.

(ii) **Stiff plastic forming**, this is used to shape less plastic bodies. The body is forced through a steel die to produce a column of uniform girth. This is either cut into the desired length or used as a blank for other forming operations.

(iii) **Pressing**, this is used to compact and shape dry bodies in a rigid die or flexible mold. There are several types of pressing, based on the direction of pressure. Uniaxial pressing describes the process of applying pressure from only one direction, whereas isostatic pressing entails applying pressure equally from all sides.

(iv) **Slip casting**, in which slurry is poured into a porous mold. The liquid is filtered out through the mold, leaving a layer of solid porcelain body. Water continues to drain out of the cast layer, until the layer becomes rigid and can be removed from mold. If the excess fluid is not drained from the mold and the entire material is allowed to solidify, the process is known as solid casting.

2.7.2.4 Bisque – firing

After being formed, the porcelain parts are generally bisque – fired, which entails heating them at a relatively low temperature to eliminate volatile contaminants and minimize shrinkage during firing.

2.7.2.5 Glazing

After bisque firing, the porcelain wares are put through a glazing operation, which applies the proper coating. The glaze can be applied by painting, dipping, pouring, or spraying. Finally, the ware undergoes a firing step in an oven or kiln. After cooling, the porcelain insulator manufacturing process is complete. An undesirable reddish hue to the body if it oxidizes, removing it prior to firing is essential. If the body is to be formed dry, shell mixers, ribbon, or intensive mixers are typically used.

After raw materials for the glaze have been ground they are mixed with water. Like the body slurry, the glazy slurry is screened and passed through magnetic filters to remove contaminants. It is then applied to the ware by means of painting, pouring, dipping, or spraying. Different types of glazes can be produce by varying the proportion of the constituent ingredients such as alumina, silica, and calcia. For example, increasing the alumina and decreasing the silica produces a matte glaze.

2.7.2.6 Firing

Firing is a further heating step that can be done in one of two types of oven, or kiln. A periodic kiln consists of a single, refractory–lined, sealed chamber with burner ports and flues (or electric heating elements). It can fire only one batch of ware at a time, but it is more flexible since the firing cycle can be adjusted for each product. A tunnel kiln is a refractory chamber several hundred feet or more in length. It maintains certain temperature zones continuously, with the ware being pushed from one zone to another.

Typically, the ware will enter a preheating zone and move. During the firing process, a variety of reactions take place. First, carbon-based impurities burns out, chemical water evolved at $100^0C - 200^0C$ and carbonates and sulphates begin to decompose at $400^0C - 700^0C$. Gases are produced that must escape from the ware. On further heating, some of the minerals break down into other phase, and the fluxed present react with the decomposing minerals to form liquid glasses at $700^0C - 1100^0C$. These glass phases are necessary for shrinking and bonding the grains, after the desired density is achieved at $1,200^0C$. The ware as cooled which causes the liquid glass to solidify thereby forms a strong bond between the remaining crystalline grains. After cooling, the porcelain is complete.

2.8 QUALITY CONTROL

A number of techniques are employed in characterizing the porcelain insulators with a view to determine their qualities. Table 2.2 is a summary of Properties and methods used for characterizing porcelain insulators.

Table 2.2: Methods of Characterization of porcelain (Insulator) bodies

PROPERTY	METHOD
Shrinkage	Measurement of dimensions
Water absorption	Measurement of weight of samples before and after boiling and soaking in water
Porosity	Measurement of weight of samples before and after boiling and soaking in water
Bulk Density	Measurement of dimension and mass
Failing Load	Breaking load in a universal tensile machine
Insulation Resistance	Measurement of resistance before discontinuity by Digital High Voltage Insulation Tester
Particle size of materials	Sieving through standard sieves
Phase constitution	X-ray diffraction (XRD) Analysis on pulverized sample

2.8.1 Determination of Drying and Fired Shrinkages

When clay or pottery bodies or porcelain are subjected to a drying operation e.g. at 110^0C, the uncombined water is driver off. This result in a reduction of volume knows as drying Shrinkage or contraction. The particle of clay in the plastic state are surrounded by thin film of water. When water is dispelled some of these particles attain actual contact and a reduction in volume occurs. The amount of drying shrinkage

depends on a number of factors.

(i) The quantity of water present

(ii) The manner in which water is dispersed through the mass

(iii) The treatment the clay has received in the wet state

(iv) The sizes of the constituent clay particles. The fineness of the clay particles. The finer the particle the greater is the drying shrinkage. It is essential to know the total contraction from the wet to the fired state so that the model can be given those dimensions, which will furnish the required size after firing. With materials possessing of high drying contraction there is always a danger of cracking in mould or warping during drying:

A fresh made slab of the material is taken and two marks imprinted on it at a standard distance 5cm apart. After drying, the distance between the two marks is measured again. The wet to dry shrinkage is then obtained from this measurement by drying the amount of contraction by the original length (wet length) and multiplying the result by 100. The slab is then heated under known condition which must be specified and after cooling the distance between the marks is again ascertained from these data the dry-to-fired and total contraction can be determined and the result to percentage.

Shrinkage in percentage.

$$\text{Drying Shrinkage} = \frac{\text{Wet length} - \text{Dry length}}{\text{Wet length}} x\,100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

$$\text{Fired Shrinkage} = \frac{\text{Dry length} - \text{Fired length}}{\text{Dry length}} \; x \; 100 \quad \text{..... (2.2)}$$

$$\text{Total Shrinkage} = \frac{W_L - F_L}{W_L} \; x \; 100 \quad \text{..... (2.3)}$$

Where,

D_L is Dry length
W_L is Wet Length
F_L is Fired Length

2.8.2 Determination of Porosity

Porosity is the ratio of its pore's volume to the bulk volume. This is the percentage relationship between the volume of the pore space and the total volume of the porcelain. The porosity of a body is controlled by the:

(i) Particle size and

(ii) Particle shape

Porosity measure the degree of densification of clay. This depends on material composition and chemical reaction occurring during firing. Porosity can be apparent or true.

(i)Apparent Porosity: is the percentage relationship between the volume of the open pores space and the total volume of the sample.

(ii)True Porosity: is the percentage relationship between the volume of the combine open, closed pore spaces and the total volume of the sample.

Porosity is determined by soaking a weighted test piece in a glass of water .The test piece

is removed and the excess water is wiped off the surface. It is then weighed again and the increase in weight measures the amount of water. For water, the number expressing the volume in cubic centimeter is the same as the weight in (grams). After weighing, the soaked piece is suspended from the beam of a balance in a vessel of water so arranged that the test piece under condition is completely immersed in the water without touching the side of the vessel when the soaked piece is suspended in water. It displaces its own volume of water that is a volume equal to the volume of the solid matter in the test piece plus the volume of the pore spaces. The volume of this displacement is given by:

$$\text{Porosity } P = \frac{S_K - D_W}{S_K - S_P} \; x \; 100 \quad \text{.......... (2.4)}$$

Where,

S_K is soaked weight

D_W is dried weight

S_P is suspended weight

This is also known as apparent porosity.

2.8.3 Determination of Water Absorption

Water absorption is measured in percentage and this can be done via the option of two different water impregnation techniques:

(i) Boiling Method and

(ii)Vacuum Immersion.

The boiling method involves the testing of 10 test pieces that are dried to constant mass and subjected to a two-hour boil followed by an additional four-hour water soak. Water

absorption is calculated as a function of the specimen's weight difference prior to and after water submersion. The other impregnation technique, vacuum immersion, was established for purposes of measuring apparent porosity and apparent relative density, and can also be used as a "quick-check" alternative for measuring water absorption. However, the boiling method is the primary technique that is referenced by all ISO product classifications and specifications.

$$\text{Water Absorption} = \frac{S_K - D_W}{D_W} \times 100 \quad \ldots\ldots (2.5)$$

Where,

S_K is soaked weight after boiling at 100°C for 2hours
D_W is dried weight

2.8.4 Determination of Density

This is defined as the weight per unit volume of the specimen. This factor or measurement responsible for the overall weight of the porcelain insulator. Density can be bulk or true. True density is the weight per unit volume of the porcelain including the volume of its open and closed pore spaces.

$$\text{Bulk Density} = \frac{D_W}{S_K - S_P} \ (g/cm^3) \quad \ldots\ldots (2.6)$$

Where,

D_W is dried Weight
S_K is soaked weight
S_P is suspended weight

2.8.5 Tensile Strength

Tensile Properties of clay indicate how the material will react to forces being applied in

tension. Tensile strength of a material is the maximum amount of tensile stress that the material can be subjected to before failure. Tensile strength measures the engineering stress applied to material at the point when it fails. It is an intensive property of materials. Tensile test is used to determine the:

(i) Modulus of elasticity

(ii) Elastic Limit

(iii) Elongation

(iv) Proportional limit

(v) Reduction in area

(vi) Tensile strength

The main product of tensile test is a load versus elongation curve which is then converted into a stress version strain curve.

Tensile strength: Maximum load that a material can support without fracture when being stretched divided by the original cross-sectional area of the material.

$$\text{Tensile strength} = \frac{\text{Maximum load applied}}{\text{Original Cross-Sectional Area}} (N/m^2) \quad \ldots\ldots\ldots\ldots\ldots (2.7)$$

It has dimension force per unit area (N/m^2). Universal tensile meter is used to measure the tensile strength of the clay.

2.8.6 Determination of Dielectric Strength

The minimum voltage required to "violate" an insulator by forcing current through it is

called the breakdown voltage, or dielectric strength. The atoms in insulating materials have very tightly-bound electrons, resisting free electron flow very well. However, insulators cannot resist indefinite amounts of voltage. With enough voltage applied, any insulating material will eventually succumb to the electrical "pressure" and electron flow will occur. However, unlike the situation with conductors where current is in a linear proportion to applied voltage (given a fixed resistance), current through an insulator is quite nonlinear: for voltages below a certain threshold level, virtually no electrons will flow, but if the voltage exceeds that threshold, there will be a rush of current.

Once current is forced through an insulating material, breakdown of that material's molecular structure has occurred. After breakdown, the material may or may not behave as an insulator any more, the molecular structure having been altered by the breach. There is usually a localized "puncture" of the insulating medium where the electrons flowed during breakdown. Thickness of an insulating material plays a role in determining its breakdown voltage, otherwise known as dielectric strength. Specific dielectric strength is sometimes listed in terms of volts per mil (1/1000 of an inch), or kilovolts per inch (the two units are equivalent), but in practice it has been found that the relationship between breakdown voltage and thickness is not exactly linear. An insulator three times as thick has a dielectric strength slightly less than 3 times as much. However, for rough estimation use, volt-per-thickness ratings are fine.

$$\text{Dielectric strength} = \frac{\text{Breakdown Voltage}}{\text{Thickness}} (V/mm) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.8)$$

CHAPTER THREE

3.0 EXPERIMENTAL TECHNIQUES

3.1 MATERIALS

The raw materials used in this study were sourced from various locations and were taken to Federal Institute of Industrial Research Oshodi for processing.

3.2 MATERIAL PROCESING

The various materials used were subjected to various processing techniques:

3.2.1 Kaolin

The kaolin is the major constituent of the porcelain formulation. It was sourced from Ijapo a location in Akure, Ondo State. The raw materials were first soaked in water for three days to remove some deleterious materials followed by sun drying. The dried material was milled by a milling machine and then screened through a mesh of 200μm.

The chemical composition of the processed clay was determined by Atomic Absorption Spectrometry (AAS) at Federal Institute of Industrial Research Oshodi, Lagos State. Nigeria. The results obtained are presented in the Table 4.1

3.2.2 Ball Clay

Ball clay is the raw material used as a binder in the porcelain formulation. It was sourced from Ikere Ekiti, a town in Ekiti State. The clay is plunged (mixed) with water to form a thin suspension and passed through a fine screen to remove the coarse materials. The suspension

was allowed to stand until the fine grit settles out, and the suspended clay was then sieved through a mesh of 200μm and dried to remove water. The dried clay was crushed and milled with milling machine. The chemical composition of the processed clay was determined by Atomic Absorption Spectrometry (AAS). The results obtained are presented in the Table 4.1

3.2.3 Quartz and Feldspar

Quartz and Feldspar were both sourced from Abeokuta, Ogun State. The two raw materials were ground separately and sieved through a mesh of 200μm and dried to remove water vapour. The chemical composition of the processed clay was determined by Atomic Absorption Spectrometry (AAS). The results obtained are presented in the Table 4.1

3.3 ANALYSIS

3.3.1 Chemical Analysis

The chemical analysis of the clay samples was determined by using Atomic Absorption Spectrometer (AAS). 0.5g of the clay samples were grounded to 150mesh and transferred into crucible, 1.4g of flux (Na_2CO_3 and boric acid) was added .they were mixed separately and well covered, heated at 1200^0C for 25minutes. The furnace is removed and 1g of K_2CO_3 was added to melt the surfaced and heated at 1200^0C for 5mins. The samples were removed and quenched the base of the crucible in distilled water. The crucibles were placed in a 250ml beaker and 60ml of 1:1 HCl was added.

They were left warm and the solutions were agitated at interval until dissolution is complete, dilute to the appropriate volume. The results obtained are presented in the Table 4.1

3.3.2 Physical Analysis

3.3.2.1 Plasticity

A little treated dried clay samples of kaolin and ball clay were taken and wet with small quantity of water and then mixed together (separately) to form a semi solid mass. The two clay mass were left to mature (ageing) and then rolled into a little rope about thickness of a pencil and coiled to bend into a ring .The same test was carried out on Oregun clay and FIRRO clay. The results of the tests are shown in Table 4.2

3.3.2.2 Moisture Content

Moisture content is the percentage of water in clay based on the dry weight Moisture content was determined by weighing a sample of wet clay 100gram and placed in a dish and dried at 110^{0}C in an oven until it reaches a constant weight. It takes 10-12hrs. The dried sample was weighed again and the moisture content is then calculated in percentage by the equation

$$\text{Moisture content} = \frac{\text{weight of wet clay - weight of dried clay}}{\text{Weight of the dried clay}} x\,100 \quad \ldots\ldots (3.1)$$

This means if 1000gram of dry clay is needed for a batch the percentage mass of the moisture content plus 1000gram will be weighed

3.3.2.3 Linear Shrinkage

Each sample of clay rolled into rope were cut into pieces and marked 10cm apart and dried in air for three days and the distance apart was measured. They were latter placed in the oven where they were fired to 110^0C and allow to cool to measure the distance apart again. The results of the linear shrinkage of kaolin, Ikere-Ekiti ball clay, Oregun ball clay, FIRRO ball clay is shown in Table 4.2

3.3.2.4 Permeability Test

Water permeability tester was used to test the permeability of the treated clay material. Small quantity of treated clay samples of kaolin and Ikere-Ekiti ball clay were sprinkled separately with water to have moisture and mixed together. Each sample was then put into a cylindrical cup of 5.08cm length and 5.08cm diameter and rammed to form a cylindrical block specimen which was mounted on the permeability tester. The instrument was arranged in such a way it controls the amount of water to pass through the clay samples, the volume of water used was 2000ml. The time taken in seconds was recorded at the count of 20 when the instrument was set to start. The average time for kaolin and the ball clay were used to determine their permeability. The results of the test were shown in Table 4.2

3.3.2.5 Compression Test (Modulus of Rupture)

The cylindrical block specimen formed by ramming the powdered samples of kaolin and ball clay were placed on compression tester model and a load of 130KN was applied.

During the application of the load there was no rupture for both samples of kaolin and ball clay. The results of the compression test is shown in the Table 4.2

3.4 EXPERIMENTAL PROCEDURES OF PORCELAIN INSULATOR

3.4.1 Mould Making

Plaster of Paris was used to make the mould for casting the electrical insulator .The powdered plaster of Paris was purchased from market and mixed with water at ratio 2 to 1 by weight. The setting time was 15mins. The original model of porcelain insulator was covered with a separator (a bar soap dissolved in hot water was used as the separator) and laid half way in a plastics clay slab enclosed with wooden barricades like box and rubber stripe was used to hold the wooden barricade together. All form of under cut was blocked for easy removal at the end of casting process. The powdered plaster of Paris (POP) mixed with water in a plastic container was poured on the model embedded half way in a clay slab and allowed to set. After the POP has become solid the mould was trimmed by scraping and key holes were put in place without removing the model yet. The other half part of the mould was made by repeating the application of separator and pouring process of the POP. The model which was in the plaster of Paris was then removed from the mould made and the mould was ready for use.

3.4.2 Formulation of Porcelain Body

Seven samples of porcelain insulators S-1 to S-7 were formulated from Kaolin, Ball clay, Feldspar and Quartz in proportion indicated in the Table 4.3. The raw materials are wet

milled separately. Kaolin, Ball clay, Feldspar and Quartz were sieved through 200μm. The resultant materials were dried and mixed. The mixture was wet milled for 3hours (each composition was mixed with 1litre of water and 16cm^3 of sodium silicate solution which was used as deflocculant in the jar mill. Pebbles were added to facilitate the milling process) to form a uniform mix. The mixture was made to pass through a magnetic sieve of 200μm to remove the iron content before it was cast into the mould.

3.4.3 Casting Process

Two piece type of mould was used to produce the electrical porcelain insulator. The clay slip prepared was poured into the mould in casting and the mould after half of an hour is drained of excess slip to avoid unnecessary thickness especially at the bottom of the insulator. After some hours when the cast insulator was strong enough it was released from the mould.

When the cast insulators were removed they were stored in a dry cool place for 4 weeks to dry gradually until it was bone dried -a stage usually refers to as green stage. There are two stages of Firing, Bisque (biscuit) firing and glaze firing.

3.4.4 Bisque Firing

When the cast insulators were removed from the moulds, they were stored in a dry cool place for 4 weeks to allow to dry gradually until it was bone dried -a stage usually refer to as green stage. Bisque firing was done using digital electric Kiln. The insulators were fired from 0^0C to 900^0C for 6hours. At 900^0C firing temperature the porcelain becomes

impervious to water or moisture because at this temperature there would have been phase transformation changes from alpha to beta phase which also brought about colour changes. This firing process prepared the insulators for final firing to avoid or prevent cracks, breaking of insulators in the kiln when fired at high temperature and to minimize loss during the firing. It also facilitates the adhesion of glaze on insulator during glaze application.

3.4.5 Glazing and Glaze Firing

The firing was carried out at Esca-Tonis Ceramic Products & services Company Mushin, Lagos. Prepared glazed was purchased and used for coating the bisque fired porcelain insulators to enhances the insulation properties of electrical insulators and to reduce the porosity or water absorption of insulators. The glaze was applied on the insulators by dipping method. The bisque fired insulators were dipped in the glazed for 8seconds then allowed to dry before they were placed in the gas kiln.

A gas-operated kiln was used to fire the materials with analog pyrometer to measure the temperature schedule with respect to time in hours. The insulators were fired for 8 hours, the graph showing the temperature schedule for the firing process is in Figure 4.1

3.5 DETERMINATION OF INSULATION PROPERTIES

3.5.1 Linear Shrinkage after Firing

The dimensional changes in length were taken and the results were used to determine the

linear shrinkage using the equation below. The results is are presented in Table 4.4

$$\text{Drying Shrinkage} = \frac{\text{Wet length} - \text{Dry length}}{\text{Wet length}} x\ 100 \quad \ldots\ldots (3.2)$$

$$\text{Fired Shrinkage} = \frac{\text{Dry length} - \text{Fired length}}{\text{Dry length}} x\ 100 \quad \ldots\ldots (3.3)$$

$$\text{Total Shrinkage} = \frac{W_L - F_L}{D_L} x\ 100 \quad \ldots\ldots (3.4)$$

Where,

D_L is Dry length

W_L is Wet Length

F_L is Fired Length

3.5.2 Water Absorption

The boiling method was used for this test at 100^0C for 2 hours. The test piece fired at 1200^0C are dried to constant mass and subjected to a two-hour boil followed by an additional four-hour water soak. Water absorption is calculated as a function of the specimen's weight difference prior to and after water submersion. The results obtained by the equation below are presented in Table 4.4

$$\text{Water Absorption} = \frac{S_K - D_W}{D_W} x\ 100 \quad \ldots\ldots (3.5)$$

Where,

S_K is soaked weight after boiling at 100^0C for 2hours

D_W is dry weight

3.5.3 Porosity

The boiling method was used for this test at 100^0C for 2 hours. The test piece fired at 1200^0C are dried to constant mass D_w and subjected to a two-hour boil followed by an

additional four-hour water soak and then weighed S_k. The soaked piece is now suspended from the beam of a balance in a vessel of water so arranged that the test piece under condition is completely immersed in the water without touching the side of the vessel. When the soaked piece is suspended in water and it was then weighed S_p. Porosity is then calculated as a function of the specimen's weight difference between soaked weight and dry weight to specimen's weight difference between soaked weight and suspended weight. The results also obtained by the equation below are presented in Table 4.4

$$\text{Porosity, P} = \frac{S_K - D_W}{S_K - S_P} x\ 100 \quad \text{..... (3.6)}$$

Where,

S_K is soaked weight

D_W is dried weight

S_P is suspended weight

3.5.4 Bulk Density

Bulk density is calculated using a direct volume measurement method. The equation below was used to obtain the bulk density. The results are presented in Table 4.4

$$\text{Bulk Density} = \frac{D_W}{S_K - S_P}(\text{g/cm}^3) \quad \text{..... (3.7)}$$

Where,

D_W is dried Weight

S_K is soaked weight

S_P is suspended weight

3.5.5 Failing Load

This test was carried out at Mechanical Engineering workshop of The Polytechnic of Ibadan. Universal tensile machine was used to test the failing load of the samples. The insulators were coupled on the tensile machine and force of 20kN was applied. The force at which the materials failed was recorded. The results obtained are presented in Table 4.4

3.5.6 Insulation Resistance after Firing

Digital High Voltage Insulation Tester (Model TIN6N-Manufacturer-TOPTRONIC) was used to test the insulation resistance of each sample at power Holding Company of Nigeria (PHCN) Oshodi, Lagos. Different voltages were injected into the samples to determine the breakdown voltage for each sample. The positive and negative terminals of the instrument were clipped at either end of the insulators and different voltages were injected by pressing the desire voltage button per time until the screen shows discontinuity sign on the screen which indicate the breakdown voltage. The voltage and the corresponding resistance at which the materials shows discontinuity were recorded and the results are presented in Table 4.5

CHAPTER FOUR

4.0 RESULTS AND DISCUSION

4.1 RESULTS

The results of all studies and researches described in chapter 3 are presented in the tables below:

Table 4.1: Chemical Composition of Kaolin, Ball Clay, Quartz and Feldspar

Elements	Kaolin	Ball Clay	Quartz	Feldspar
1 SiO_2	46.56	57.70	94.60	70.73
2 Al_2O_3	35.60	32.50	0.70	16.42
3 TiO_2	0.85	1.76	0.001	0.40
4 Fe_2O_3	0.69	2.15	0.05	1.00
5 CaO	0.05	0.48	0.65	0.03
6 MgO	0.06	0.07	0.06	0.06
7 K_2O	0.70	2.30	0.30	1.30
8 Na_2O	0.08	0.40	0.07	2.30
L.O.I	12.94	7.10	0.22	0.40

Table 4.2: Physical Properties of Raw Materials

Parameters/Clay	Ijapo Clay	Ikere-Ekiti Clay	Oregun Clay	FIIRO Clay
Dry Length (cm)	9.75	8.84	9.04	9.58
Wet Length (cm)	10.00	10.00	10.00	10.00
Fired Length (cm)	9.30	8.00	8.60	9.38
% Dry Shrinkage	2.5	11.60	9.60	4.20
% Fired Shrinkage	4.62	9.60	4.86	2.11
% Total Shrinkage	7.00	20.00	14.46	6.20
% Loss of Ignition	1.14	0.91	4.32	1.11
Moisture content	10.1	13.2	15.3	8.9
Plasticity	Not Plastic	Plastic	Very Plastic	Not Plastic
Colour before firing	Gold	Creamy White	Reddish Brown	Buff White
Colour after Firing	Creamy White	White	Brown	Buff White
Screen Residue (g)	61.95	26.58	35.60	70.50
Permeability (2000ml of water/S)	71.03	71.21	71.67	1.43
Green Compression (KN/m^2)	>130	>130	>130	>130

Table 4.3: Constituent Percentage Composition of Sample Porcelain

Specimen	S1	S2	S3	S4	S5	S6	S7
Kaolin	38	33	30	27	36	39	32
Ball Clay	10	15	15	15	15	15	15
Feldspar	32	32	35	38	29	26	28
Quartz	20	20	20	20	20	20	25
Total	100	100	100	100	100	100	100
Remark	Not castable	castable	castable	castable	castable	castable	castable

(Onaji P.B and Usman 1988; Peter Wilbeforce Olupot, 2006)

Table 4.4: Physical Properties of Porcelain Insulators

Properties/Specimen	S2	S3	S4	S5	S6	S7	Local	Imported
Total Shrinkage (%)	14.9	13.5	12.2	16.2	16.2	3.5	-	-
Water Absorption (%)	1.55	4.58	2.78	2.44	0.27	1.52	5.65	0.82
Porosity (%)	4.64	7.84	7.05	5.33	0.15	4.87	7.68	1.24
Bulk Density (g/m^3)	1.73	1.74	1.74	1.71	1.89	1.78	0.98	2.40
Failing Load (KN)	8.0	4.2	2.9	6.6	6.0	8.4	1.2	13

Table 4.5: Results of Insulation Resistance (Mega Ohms) and Voltage Variations of Various Samples

Samples	S2	S3	S4	S5	S6	S7
Voltage Injected (V)			(Mega Ohmns)			
1000	50000	48788	50000	50000	12180	50000
2500	16794	29302	40127	125000	10012	12685
5000	6630.4	21230.5	10906	38044	6980.1	8038.1
10000	784.38	230.57	3027.6	4287.8	5775.8	3849.2

Table 4.6: Results of Linear Shrinkage of Porcelain Samples

Sample	Wet Length (cm)	Dry Length (cm)	Fired Length (cm)	Total Shrinkage (%)
S2	7.4	7.1	6.3	14.9
S3	7.4	7.2	6.4	13.5
S4	7.4	7.1	6.5	12.2
S5	7.4	7.2	6.2	16.2
S6	7.4	7.0	6.2	16.2
S7	7.4	7.2	6.4	13.5

Table 4.7: Results of Water Absorption

Samples	Dry Weight (g)	Soaked Weight (g)	Water Absorption (%)
S2	25.80	26.20	1.55
S3	24.26	25.37	4.58
S4	20.53	21.10	2.78
S5	18.45	19.00	2.44
S6	22.34	22.40	0.27
S7	11.20	11.37	1.52

Table 4.8: Results of Porosity

Samples	Dry Weight (g)	Soaked Weight (g)	Suspended Weight (g)	Porosity (%)
S2	23.22	23.84	10.49	4.64
S3	24.90	26.02	11.74	7.84
S4	21.16	22.02	9.83	7.05
S5	20.58	21.14	8.96	5.33
S6	24.74	24.76	11.68	0.15
S7	13.53	13.90	6.30	4.87

Table 4.9: Results of Bulk Density

Samples	Dry Weight (g)	Soaked Weight (g)	Suspended Weight (g)	Bulk Density (g/m^3)
S2	23.22	23.84	10.49	1.73
S3	24.90	26.02	11.74	1.74
S4	21.16	22.02	9.83	1.74
S5	20.58	21.14	8.96	1.71
S6	24.74	24.76	11.68	1.89
S7	13.53	13.90	6.30	1.78

Table 5.0: Results of Failing Load

Samples	S2	S3	S4	S5	S6	S7
Failing Load (KN)	8.0	4.2	2.9	6.6	6.0	8.4

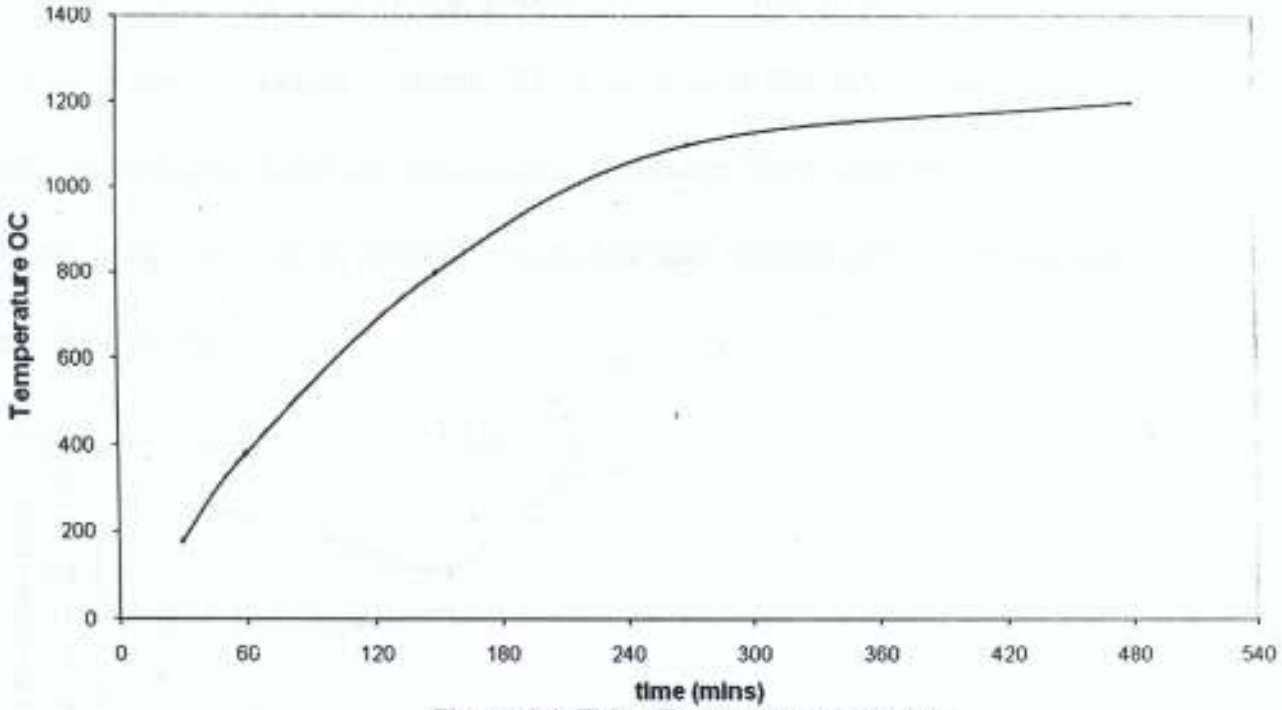

Figure 4.1: Firing Temperature Schedule

4.2 DISCUSSION OF RESULTS

After drying and firing the formulated samples listed in the tables showed the trends in figure 4.2 to figure 4.7. Although sample 1 was not castable because the plasticity of Ikere-Ekiti ball clay is not high enough so Oregun clay in Lagos was used as bentonite which was kept constant in all the compositions. The result obtained shows that the electrical porcelain insulator produced has better insulation properties than the locally made electrical porcelain insulator, but insulation properties for imported insulator could not be achieved due to the method of forming process used.

4.2.1 Linear Shrinkage

Linear shrinkage is plotted in figure 4.2a-b, the results and observations from

these studies reveal that as the percentage composition of both feldspar and quartz increases the shrinkage reduces. More so where the percentage composition of both feldspar and quartz are the same equal shrinkage were observed. This is due to increase in percentage of kaolin content which has low volume shrinkage because of its coarse particle texture.

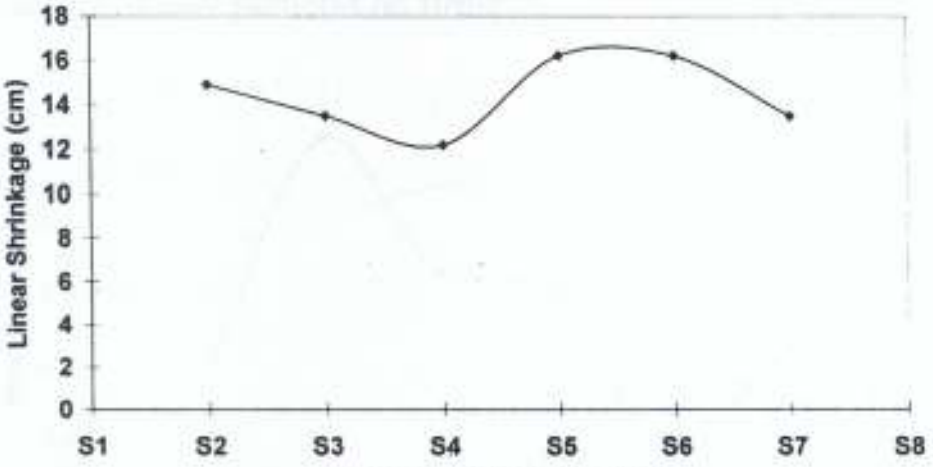

Figure 4.2a: Graph showing variation of percentage linear shrinkage with samples percentage composition.

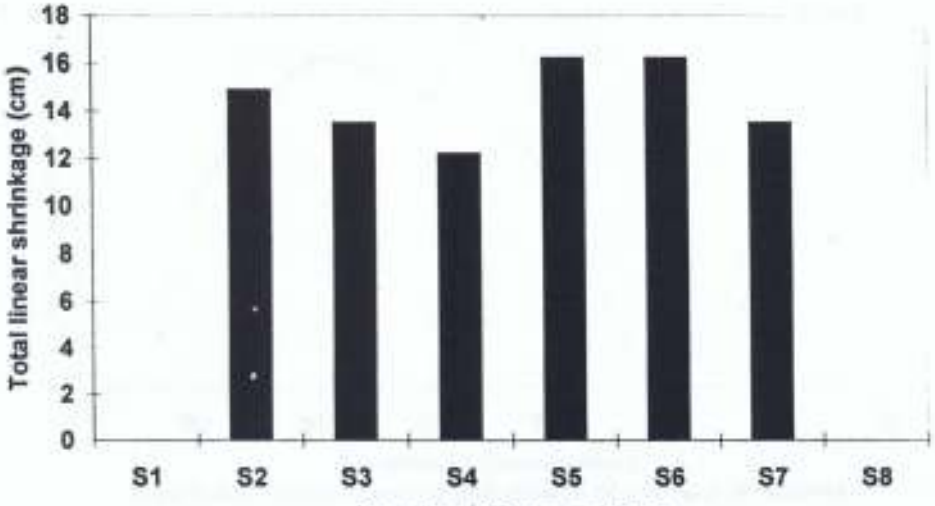

Figure 4.2b: Total linear shrinkage of various samples

4.2.2 Water Absorption and Porosity

Water absorption and porosity are plotted against percentage composition in figure 4.3 and figure 4.4 respectively. The studies show that they correlate. It was observed that the water absorption and porosity of insulators decreases with increases in percentage composition of kaolin probably due to firing process or change in shape or structure of clay particles on firing.

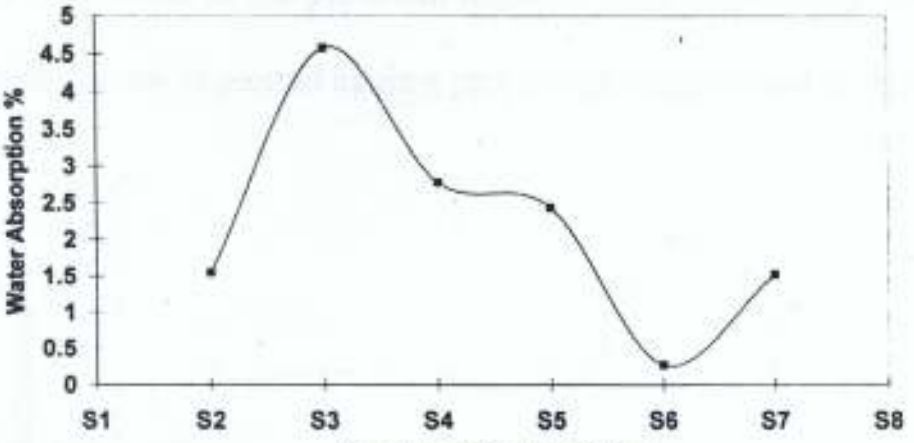

Figure 4.3: Graph showing percentage of water absorption of various samples

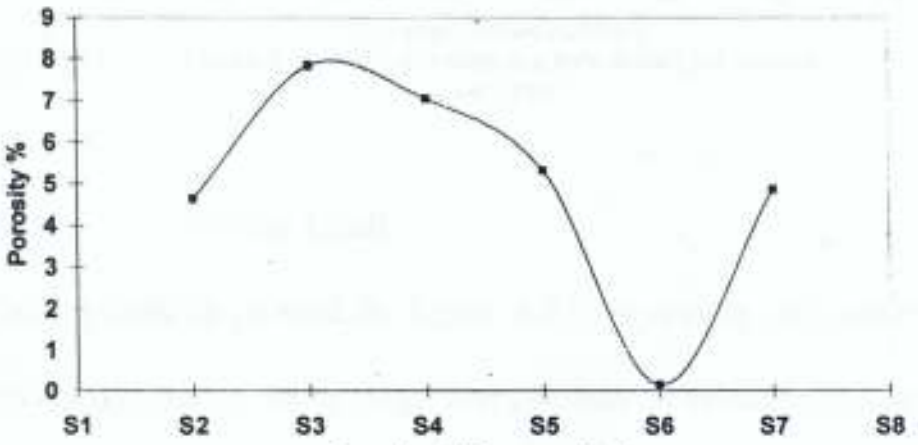

Figure 4.4: Graph showing percentage of porosity of various samples

4.2.3 Bulk Density

The correlation of bulk density, water absorption and porosity is of great interest. Where the bulk density is high the water absorption and porosity are low and where bulk density is low the water absorption and porosity are high. It is also observed that the bulk density reduces with increase in percentage composition of kaolin and reduction in percentage composition of feldspar. Although there is no much gap or differences in the bulk densities of the porcelain insulator samples probably due to equal particle size. The bulk density is plotted against percentage composition is shown in figure 4.5.

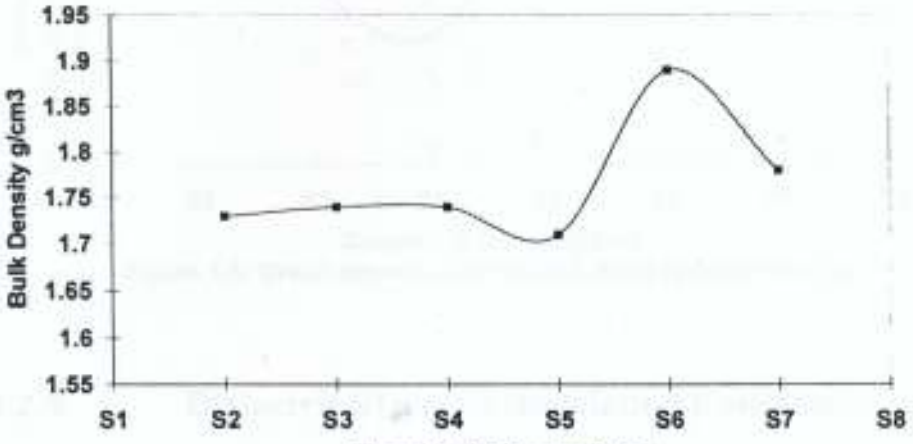

Figure 4.5: Graph showing the bulk density of various samples

4.2.4 Failing Load

Failing load is plotted in figure 4.6, the results and observations from these studies reveal that as the percentage composition of feldspar increases while the percentage of kaolin reduces the strength of the insulator reduces. Consequently, when percentage

composition of kaolin was increased while the percentage of feldspar was reduced, increase in strength was observed. Also when the percentage of quartz increased, it was observed that the failing load increased. This is due to increase percentage of non plastic constituent, types of phase and shape of mullite needles formed during firing (Norton F.H, 1980; Peter Wilberforce Olupot, 2006).

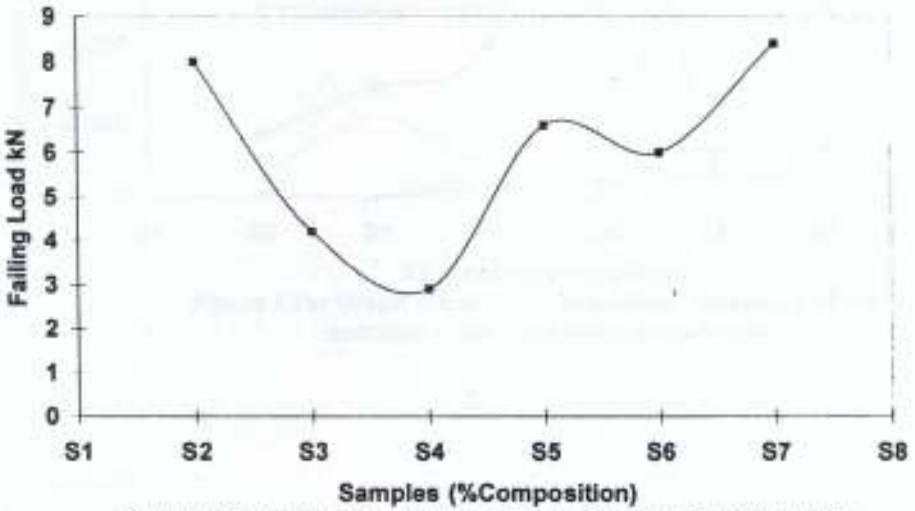

Figure 4.6: Graph showing the failing load of various samples

4.2.5 Dielectric Strength (Insulation Resistance)

The insulation resistance against percentage composition is shown in Figure 4.7a and 4.7b.The results of insulation resistance reveals that at the injection of 1000volts the porcelain samples show nearly the same resistance against the voltage injected. At the injection of 2500volts and 5000volts it is observed that the insulation resistance against the voltage injected respectively increases with decrease in percentage composition of kaolin and decreases with increase in percentage composition of kaolin, but conversely

with feldspar.

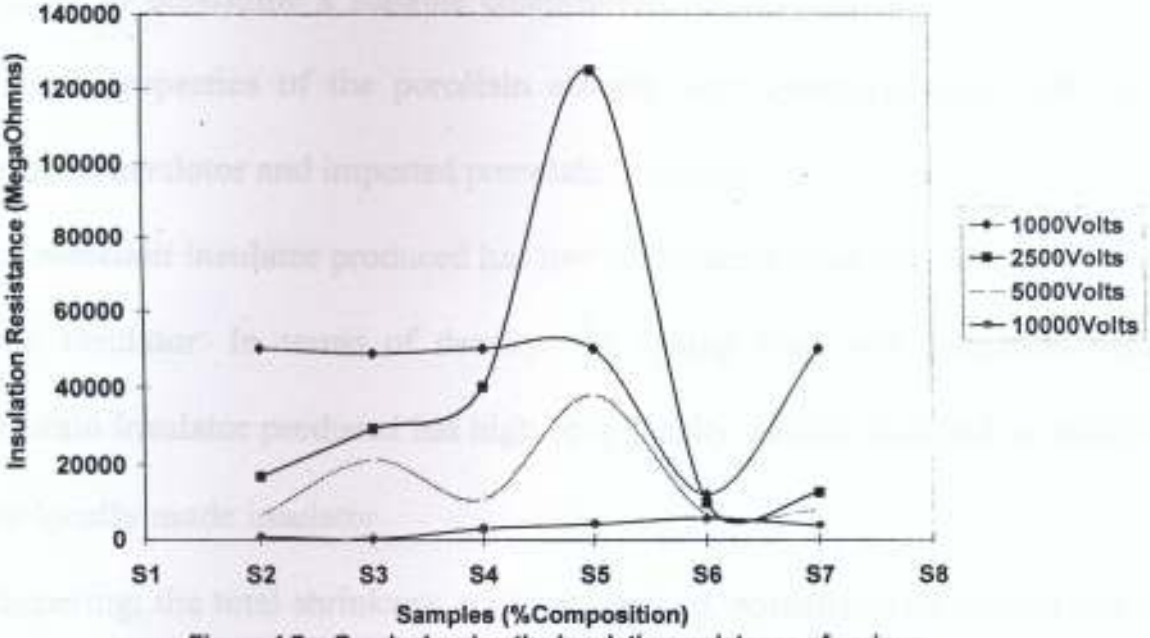

Figure 4.7a: Graph showing the insulation resistance of various samples at different voltage injections

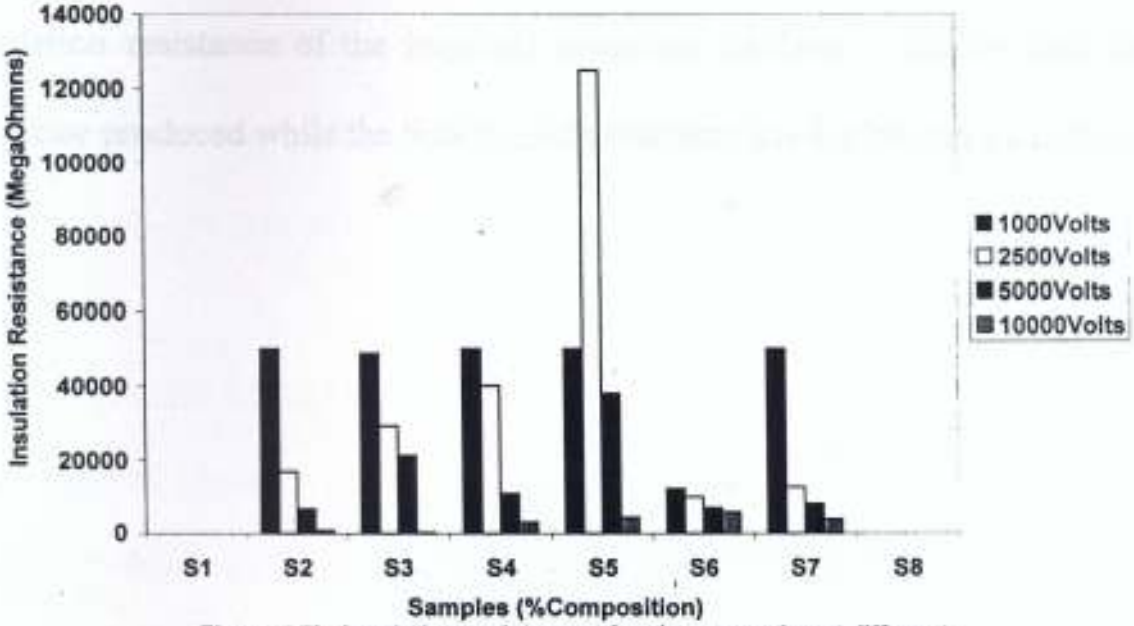

Figure 4.7b: Insulation resistance of various samples at different voltage injections

4.2.6 COMPARISON OF PHYSICAL PROPERTIES

In order to determine a suitable composition for the electrical porcelain insulator the physical properties of the porcelain sample were compared with both locally made porcelain insulator and imported porcelain insulator.

The porcelain insulator produced has low water absorption and porosity than the locally made insulator. In terms of density, the failing load and insulation resistance, the porcelain insulator produced has high bulk density, failing load and insulation resistance than locally made insulator

Comparing, the total shrinkage, water absorption, porosity, bulk density and failing load properties of the electrical porcelain insulator produced, the imported porcelain insulator has better insulation properties because of the method of production process. The insulation resistance of the imported porcelain insulator is higher than the porcelain insulator produced while the locally made insulator has the least in insulation resistance.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

- Better quality low voltage porcelain bodies were produced from Ijapo Kaolin clay, Ikere Ekiti ball clay, Abeokuta feldspar and quartz than the locally produced porcelain insulator.
- The sample with composition of 32% Kaolin, 15% ball clay, 28% feldspar and 25% quartz was found the best due to low water absorption (1.52%), high bulk density (1.78), highest failing load (8.4KN) with the appreciable insulation resistance properties 8,038.1 Megaohms at injection of 5000volts compare with other porcelain samples.
- However, satisfactory low voltage properties for imported insulators could not be attained due to the method of forming process employed in the production of porcelain insulator.

5.2 RECOMMENDATION

In order to obtain better results, further research work should be carried out on the internal structure of clay or porcelain particles, before and after firing to determine their effect on the physical and electrical properties of porcelain insulators likewise their thermal analysis and another method of forming process should be employed.

REFERENCES

Anderson J.C, Leaver K.D, Rawlings R.D and Alexander J.M. (1990): Material Science 4th Edition, chapman & hall, London. Pp150-151, 294 - 317

Ajaka Oyedele Ebenezer (1999): Development of A Suitable Processing Techniques For Kaolin Clay for Industrial Application (Unpublished M. Eng Thesis Federal University of Technology, Akure). Pp 42 - 50

Asuquo L.O. and Bobo- Jama S.A. (1991): Foundry Technology, ABIC Publishers, Enugu, Nigeria. Pp 29-45

Buchanan R.C. (1991): Ceramic Material for Electronics, Dekker, New York. Pp 1 - 86

Charlotte Speight and John Toki (1999): Hand in Clay: An Introduction to Ceramics, 4th Edition, McGraw-Hill, New York, Pp 20-150, 180-450

Donald R. A. (1990): The Science and Engineering Materials; 2nd ed., Chapman and Hall; London Pp 143 - 159

Federal Ministry of Science and Technology (FMST) (2004): Profile on Selected Commercialization 2004. http//www First .Gov. Ng / Docs/ Profile Technology Selected RD 2004:

Ibrahim Banjoko (2000): Visual Arts Made Easy For School, Movic publishing company Ltd. Lagos. Pp 98 - 110

Kingery W.D, Bowen H.K and Uhlmann D.R (1976): Introduction to ceramics, John Huley and son inc, New York.Pp 30 – 60

Heinskanen K. (1993): Particle Classification, Chapman and Hall, London, pp71-97,159-239

Magidan F. (1986): Construction of power transport line and substation, MIR publisher, Moscow. Pp 60 - 61

Michael F. Ashby & David R.H (1986): Engineering of Material 2, pergamon press England. Pp 147 - 178

Norton F.H (1980): Ceramics For The Artist Potter, Addison –Wesley Publishing Company Inc. Cambridge, Massachusset. Pp34 - 220

Norton F.H. (1970): Fire ceramic Technology and applications, McGraw – Hill Book Co. New York. Pp 24 - 188

Nosker, H. and Danish J. (1993): Glazes for the Self –Reliant Potter, Fried View & Sohn Verlagsgesellschaftmblt; Brainchweio, Germany. Pp 223 - 239

Onaji P.B and Usman (1988): Development of Slip Cast Electrical Porcelain Body: Bomo Plastic Clay. Nigeria Journal of Engineering NJE Vol.5, No 2 Pp 89 - 96

Peter Wilbeforce Olupot (2006): Assessment of Ceramic Raw Materials in Uganda for Electrical Porcelain. www. Assessment of Ceramic Raw Materials

Schroeder E.J (1978): Inexpensive high Strength Electrical Porcelain, Am Ceramic Society . London. Pp 57, 526.

Seidu Saliu Ojo (1999): Optimisation of Blending Characteristics of Local Deposit for Refractory Application (B. Eng Thesis FUT, Akure.) Pp. 10- 15

Shashidha N. and Reed J.S. (1990): "Recycling Fired Porcelain" Ceramic Bulletin Vol 69 No. 5, Pp 834 -841

Veglio F, Pagbgrini A., and Toro L. (1993): Factorial Experiment for the Development of Kaolin Bleaching Process, International Journal of Mineral Processing No.39

Von Hippel A. R. and Alexander S. Labounsky (1995): Dielectric Materials and Application. Artech House Publishers, Pp198- 220

White Anighoro (2001): Foundry Properties of Beach Sand Using Ode – Omu Clay as a Binder (B. Eng Thesis. FUT, Akure) Pp. 12-18

Annon: Electrical Insulator: http//www. En.wikipedia.org/wiki/insulator_(electrical) (Accessed 20/05/2004)

Annon: Electrical Insulator: http//www. En.wikipedia.org/wiki/insulator_(electrical)# material (Accessed 20/05/2004)

Annon: Porcelain Insulator: http//www. Insulator.info/porcelain/history.htl (Accessed 20/05/2004)

Annon: Ceramic Raw material for Porcelain Insulator: http//www.dart-europe.en/full-php?id=15805 (Accessed 10/06/2006)

Annon: Porcelain: http//www. answer.com/topic/procelian (Accessed 20/05/2004)