A STUDY OF ELECTRICAL INSULATION MATERIALS DEVELOPED USING SELECTED CLAY MINERALS IN UGANDA

BY

NASEJJE STELLA

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DECLARATION

I NASEJJE STELLA do hereby declare that this dissertation was carried out by me and has never been submitted to any institution or University for an academic award.

Signed: ………………………………………………………………..

Date: …………………………………………………………………..

APPROVAL

This is to certify that NASEJJE STELLA has been working on this research under our supervision. The dissertation is hereby approved for submission to the Board of Graduate Examiners and Senate of Kyambogo University.

Signed: ....

Supervisor one: Dr. Obwoya Kinyera Sam

(Associate Professor)

Date: ....

Signed: ....

Supervisor two: Mr. Oriada Richard

Date: ....

DEDICATION

This research report is dedicated to my family especially my two sons, Nathan Nankunda and Ernest Baganzi.

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TABLE OF CONTENTS

PAGE

Declaration....................i

Approval....................ii

Dedication....................iii

Acknowledgement....................iv

List of Figures....................viii

List of Tables....................ix

Acroynyms....................x

Abstract....................xi

CHAPTER ONE: INTRODUCTION

1.1 Introduction....................1

1.2 Background of the Study....................1

1.3 Statement of the Problem....................3

1.4 Purpose of the Study....................4

1.5 Objective of the Study....................4

1.6 Significance of the Study....................5

1.7 Scope of the Study....................5

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction....................6

2.2 Ceramic ingredients for electrical insulation.....6

2.3 Porcelain as a material for electrical insulation.....10

2.4 Properties of clay materials used as electrical insulators in Uganda.....12

2.5 Mixture of Locally available Clays.....13

2.5.1 Shaping or forming of Clays.....14

2.5.2 Bisque-firing.....15

2.5.3 Glazing of Clays.....16

2.5.4 Firing of Clays.....16

2.5.5 Sintering.....18

2.6 Dielectric strength of electrical insulators.....20

CHAPTER THREE: METHODOLOGY

3.1 Research Design.....22

3.2 Sample collection.....22

3.3 Sample Preparation.....23

3.3.1 Sieving.....23

3.3.2 Sample formation.....24

3.4 Sample Forming Methods.....25

3.4.1 Slip casting.....25

3.4.2 Wet pressing.....25

3.4.3 Dry pressing.....25

3.5 Sample Firing.....26

3.6 Experimental Measurement..27

3.6.1 Dielectric strength...27

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Record of Results..30

4.2 Presentation of Results..30

4.2.1 Batch formability..37

4.2.2 Forming methods in relation to voltage break down and Dielectric strength.........37

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion..39

5.2 Recommendations..40

REFERENCES..41

Appendix A: SPSS ANALYSIS DETAILS..45

LIST OF FIGURES

PAGE

Figure 3.1 Sieves stacked together with the largest size on top and the smallest size at the bottom....24

Figure 3.2 The hydraulic press with a die mould (Hydraulina Laboratory Manual Press-PW40)....26

Figure 3.3 Some of the Fired samples formed by wet and dry forming methods....27

Figure 3.4 Setup for testing voltage breakdown 28

Figure 4.1 A graph of voltage breakdown against kaolin content for samples tested in transformer oil....31

Figure 4.2 A graph of dielectric strength against kaolin content for samples tested in transformer oil....32

Figure 4.3 A graph of dielectric strength against batch formulations for samples tested in transformer oil....33

Figure 4.4 A graph of voltage breakdown against kaolin content for samples tested in air....35

Figure 4.5 A graph of dielectric strength against kaolin content for samples tested in air....36

Figure 4.6 A graph of dielectric strength against batch formulations for samples tested in air....37

LIST OF TABLES

PAGE

Table 2.1 The changes caused by heat on wet clay..18

Table 3.1 Composition of Sample porcelains (wt %)..24

Table 4.1 Results obtained for samples tested in transformer oil...................................30

Table 4.2 Results obtained for samples tested in air...34

Table A 1 Spss analyzed values of voltage breakdown for samples tested in oil.....................45

Table A2 Spss analyzed values of voltage breakdown for samples tested in air....................46

Table A3 Spss analyzed values of dielectric strength for samples tested in oil.......................47

Table A4 Spss analyzed values of dielectric strength for samples tested in air. 48

ACROYNYMS

Ψ - Densification.

ε_g - Density of a body in the green condition.

ε_s - Density of a body in the sintered condition.

ε- Fractional density.

P - Fractional porosity.

V_B - Break down voltage.

d- Thickness of the samples

ABSTRACT

This study was to investigate appropriate mixtures of different ceramic mineral ingredients needed to make electrical porcelain insulators and to determine the best method of developing the electrical insulator of slip casting, dry pressing, and wet pressing. The mixing of the clay minerals was done using percentage ratios of ball clay, kaolin, feldspar and flint, of which the quantity of flint was kept constant at 20% in all compositions and that of ball clay to kaolin changed through a range of 1:1.75, 1:2 and 1: 2.5, well as that of feldspar took up any remaining percentage. These samples were formed by slip casting, wet, and dry pressing and then fired at a constant heating rate to a temperature of 1250°C. Then the dielectric strength was tested using the oil test set, Avo Megger foster OTS100AF/2.

The mixtures of the clay minerals with a ratio of ball clay to kaolin of 1:2 showed good formability in all forming methods, but those with a ratio of 1:1.75 and 1:2.5 could not easily form good casted and wet pressed samples. The best formulation was that with 55% clay, where the ratio of ball clay to kaolin was 1:2. The sample compositions of the various minerals were found to affect both voltage breakdown and dielectric strength.

The voltage break down, V was found to be proportional to the thickness, t of the samples according to the expression $V=at + b$; where a and b are constants of testing conditions like room temperature and frequency. Conversely, the values of dielectric strength; D was found to be inversely proportional to the thickness, d of the samples according to the expression;

$$D = \frac{V_B}{d}$$

where V_B is the breakdown voltage and d is the thickness of the sample.

Values of both the voltage breakdown and dielectric strength of samples tested in air were much lower than those of samples tested in transformer oil due to generated carbon around them when in air as a result of corona discharge. The samples tested in transformer oil had values above 10kV/mm. Thus, the electrical insulation properties of the formulation of the samples developed in this study were found to match that required for international standards.

CHAPTER ONE: INTRODUCTION

1.1 Introduction

The earliest ceramics artifacts were mainly pottery objects made from clay. Ceramics now include; domestic, industrial and building products and art objects. This chapter gives some background to what this study was aimed at finding out. The major areas covered include; availability of clays in Uganda, characteristics of ceramic materials, traditional ceramics, technological applications of ceramics, growth of the demand for electricity, its transmission and why insulation materials are needed in transmission line among others.

1.2 Background of the Study

Uganda is well endowed with a large amount of ceramic minerals found in different parts of the country. Large deposits of kaolin are found in Mutaka, Kasai, and Namasera. Feldspar deposits are found in Mutaka, Karamoja, Mbarara, Lubaale, and Lunya. Ball clay is found in Mukono deposits, and Quartz is found in Mutaka, Entebbe, and along the Lake Victoria shores. Information from the country's Geological Survey and Mines Department emphasizes the occurrence of the high quality deposits, which can be used in the production of different domestic and industrial products, Olupot, (2006)

Most ceramics are hard, wear-resistant, brittle, non-magnetic, refractory, oxidation resistant and prone to thermal shock. They are also chemically stable and can be utilized as thermal and electrical insulators. However, there are many exceptions to the above generalizations for example, borosilicate glasses, glasses that contain a crystalline phase, and sodium zirconium phosphate (NZP) ceramics are very resistant to thermal shock and are used in applications such as ovenware, stove tops, kiln furniture, respectively, Olupot, (2006).

Traditional ceramics used to make pottery often have a glassy structure. These cover a wide range of ceramic materials like porcelain, stoneware, earthenware, and steatite and cordierite ceramics. They differ in chemistry, phase composition, porosity, and in thermal, mechanical and dielectric properties according to Shüller, (1997). They include such products as electrical, chemical, technical porcelains and chinawares, and such commonly used products as fire dinnerware, wall tile, pottery, vitreous plumbing fixtures and dental porcelains according to Jones, and Berard, (1993).

Ceramics can be used for many technological applications. In the 20th century, new ceramic have been developed for advanced use in electronic engineering. The typical example is in the production of semiconductors products. The NASA's Space Shuttle, for example utilizes the use of ceramic tiles to protect it from the searing heat it experiences during the reentry into Earth's atmosphere. Future supersonic space planes may likewise be fitted with such tiles. Ceramics are now widely used in production of electronics and optical components. They are used for example in the manufacture of capacitors, integrated circuit packages, and semi-conductor based transducers, (en.wikipedia.org/wiki/pottery).

When there is current leakage, it is unsafe to use the electrical equipment, thus electrical circuits control the flow of current to reduce on these leakages. For that matter also, insulators do prevent unintended current flow. For example, power cords are insulated to keep one from getting a shock, and also to prevent short circuits that can cause a fire. At breakdown voltage, all insulators can conduct since a high voltage makes the insulator lose its insulating ability. Thus insulators are tested for their breakdown voltages. A plastic covering on a wire might be a good insulator especially when exposed to one thousand volts but not beyond. For transmission lines, thick ceramic parts might be the only good insulators, since these might be exposed to million volts. Insulators must satisfy a variety of technical, economic and safety requirements to be suitable for an application, (http://www.ehow.com/electrical-insulator).

Insulators are often used as a flexible coating on electric wires and cables. Since air is an insulator, no other substance is needed as an insulator for High- voltage power lines. Use of a solid (e.g., plastic) coating in this case would be impractical. However, wires which touch each other will produce cross connections, short circuits, and fire hazards. In coaxial cable, the center conductor must be supported exactly in the middle of the hollow shield in order to prevent electromagnetic wave reflections. And any wires which present voltages higher than sixty volts can cause human shock and electrocution hazards. Insulating coatings prevent all of these problems.

Porcelains are widely used as insulators in electrical power transmission systems due to the high stability of their electrical, mechanical, and thermal properties in the presence of harsh environment. Porcelains are vitrified and fine grained ceramic white wares. They are primarily composed of clay, feldspar and a filler material, usually quartz or alumina. These materials are widely available in Uganda though they have not yet been used to develop electrical insulators, Olupot, (2006).

Except superconductors which don't have any resistance, all materials have some resistance. For a material to be a good electrical insulator, it has to have a high electrical resistance. Insulators have extremely high resistance that is in billions of ohms. Resistivity of a material is also related to the current that a conductor can carry continuously (ampacity of a material), (http://www.ehow.com).

It is very important to perform insulation resistance testing in order to determine the safety of the electrical equipment. To test insulation resistance, a voltage is applied to the material and measured. The amount of electricity that escapes from the insulation is called the leakage current. This warms up the insulation and results in slight power loss, (http://www.ehow.com).

An insulator degrades quickly when exposed to humidity because high humid conditions can lead to high current flow, local heating, cracking, and thermal break down. This is because, in humid conditions, microstructure features such as cracks and porosity in porcelain can lead to ionization of entrapped gases at high fields. And also, the larger the pores, the more likely it is to lead to insulator failure, Olupot, (2006).

Electrical insulation is generally a vital factor in both the technical and economic practicability of complex power and electronic systems. The generation and transmission of electric power depend critically upon the performance of electric insulator, and now plays an even more crucial role because of the energy shortage.

1.3 Statement of the Problem

Today, there are an increased number of people using electricity as a source of energy in the country. This has led to an increase in the need for transmission of electricity to every part of Uganda. This demand for electricity has been continuously rising since 1986. The annual growth rate of grid connectivity was estimated to be between 5.5% and 7 %, according to the Ministry of

Energy and Mineral Development, (2001). In order to make electricity available, it has to be transmitted, most times over long distances using overhead cables. Insulators play an important role in supporting the overhead conductor cables, in supporting electrical equipment, and in isolating conductors from other objects and from each other. Porcelains are among the major materials used for insulation on power transmission and distribution lines.

Despite the existence of the requisite materials for the production of porcelain insulators locally, the national demand continues to be met by importation. Thus a lot of monetary resources that could have been used for other services are used to import electrical insulators.

The abundance of the requisite materials and the corresponding demand for insulation materials has created a need to develop electrical insulators using the widely available minerals in Uganda.

1.4 Purpose of the Study

The aim of the study was to develop electrical insulators using locally available clay minerals in Uganda.

1.5 Objectives of the Study

1. To determine appropriate mixtures of different ceramic mineral ingredients used to make electrical porcelain insulators.
2. To develop electrical insulators from the mixture of locally available clay minerals by the methods of slip casting, dry pressing, and by wet pressing.
3. To test the dielectric strengths of the locally developed insulators formed using the three forming processes.

1.6 Significance of the Study

The significance of the study was, if the results of the study are applied in setting up an industry for production of the electrical insulators, it will lead to creation of jobs for Ugandans in the various areas of production and distribution of the insulators.

It will lead to provision of quality insulators produced from Ugandan natural resources.

The study has provided data or information about the dielectric strength of the locally developed insulators and this will open avenues for further research.

The country will save foreign exchange from production of the electrical insulators since it will reduce costs of importing electrical insulators.

1.7 Scope of the Study

The study was limited to the use of minerals from Bushenyi, and Mukono districts in Uganda.

The study was limited to three forming methods, that is; slip casting, dry pressing and wet pressing as methods of forming the samples.

The study was also limited to three variables; the composition of the locally available clay minerals, the methods of forming the electrical insulation materials which were considered as the independent variables and the dielectric strengths of the materials was considered as the dependent variable.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Introduction

The literature reviewed provides more information on issues dealing with different aspects of the study objectives. The literature covers the relationship between conductors and insulators which includes types of ingredients required to make insulators, porcelain as a material for electrical. insulation, properties of clay materials used as electrical insulators in Uganda, how local clays are mixed and dielectric strength of electrical insulators.

2.2 Ceramic ingredients for electrical insulation

The electrical current is transferred through conductors by the movement of free electrons if the conductor is a metal or ions if the conductor is an electrolyte by migration in the electrolyte. Materials with a greater number of free electrons that move freely in the crystal structure under application of an electric force are said to be good conductors. These have a low resistance to the electron flow. In the case of insulators, a large amount of energy is required to break the electrons from the attraction of the nucleus to set them free. A material's ability to conduct electricity also depends on its dimensions, U.S, Bureau of Naval Personnel, (1970).

In metallic conductors, conduction of electricity is due to the movement of free electrons from a higher negative potential to a lower one without producing chemical changes. Metallic conductors include; alloys, graphite and metals. In metallic conductors, conductance decreases with increase in temperature due to the resistance offered to the moving electrons by the vibration of atoms or ions composing the conductor. Metallic conduction is more at low temperatures that is 3-4 kilo amperes. At these temperatures, the conductors are supper conducting since the resistance of many conductors is very low and practically no resistance is offered to the flow of the electrons.

Copper and aluminum have low electrical resistivity and thus are some of the good electrical conductors. Aluminum has a weight advantage over copper and thus when used, lower installation costs are met. However, when there is formation of aluminum oxides and also when under pressure, aluminum has a cold flow characteristic - The oxide forms easily in minutes when aluminum surface is exposed; the oxide is a poorly conductive film and should be removed and stopped from reforming since if not done, the oxide causes high heat generation and high resistance at the joint. Also to reduce or overcome the oxide problem, copper-clad aluminum wires are used, Grondzik, et al, (2009).

In the electrolytic form of conductors, flow of current is due to movement / migration of ions towards oppositely charged electrodes and is accompanied by chemical changes at the electrodes (electrolysis). Examples include; molten salts, bases, acids and aqueous solutions of salts. Here new products are formed at the electrodes due to movement of ions from one electrode to another. In a positively charged electrode, oxidation takes place well as a reduction takes place in a negatively charged electrode. Electrolytic conduction increases with rise in temperature. This is because rise in temperature increases the mobility of the ions and the degree of ionization of the electrolytes, Negi, and Anad, (1985).

Materials such as germanium and silicon are neither good conductors nor good insulators, they are semiconductors. These materials under certain conditions act as conductors and under other conditions act as insulators. This is attributed to their peculiar crystalline structure. However, with these materials, as temperature is raised, the number of free electrons available for conduction is reduced, U. S, Bureau of Naval Personnel, (1970).

Conduction current carrying capacity of conductors also referred to as ampacity is determined by the maximum safe operating temperature of the insulation used on the conductor. As a result of current flow, heat is generated and this is dissipated off into the surrounding. Conductor size and maximum permissible insulation temperature determine ampacity of a conductor that is as these are increased, ampacity increases. To maintain safe operating conditions as temperature is increased, deration (a reduction in the ampacity of a conductor due to correction factors) of the conductor is necessary, Grondzik, et al, (2009).

When electrical conductors are in operation, temperature is increased an d this may lead to damaging of the insulating materials or mechanical damage to the electrical conductor. To prevent this, mobile equipment should not run over power conductors nor should loads be dragged over power conductors unless the conductors are properly bridged or protected, Office of the Federal Register, U.S, (2009).

The first insulation system used materials that were common in industry. These paced the development of machine insulation systems, for example, natural fibres from cellulose, cotton, wool, and silk flax where used as insulation materials. Solids such as sand, mica, asbestos, quartz, and other minerals were often used as fillers in ground or powdered form. Around the 1940s and 1960s, early versions of synthetic polymers and resins were used though these lacked sophistication and properties of current offerings, Greg, (2004).

Insulating materials are used in parts of electrical equipment. Insulating materials are intended for supporting or separating electrical conductors without conducting current themselves. They are used as insulating supports which attach electric power transmission wires to utility poles or pylons, Rajput, (2006).

The valence electrons of the insulator's atoms are tightly bounded to their atoms and therefore not free to be influenced by an electric field. The best insulators have seven or eight electrons in the valence shell. The electrons are held tightly in the orbit and any energy gained is divided between all of them, making them difficult to move from the atom. Insulators are characterized by having a large band gap. This occurs because the valence band containing the highest energy is full, and a large energy gap separates this band from the next band above it ca lled the conduction band. There is always some voltage called the breakdown voltage, which will give the electrons enough energy to be excited into the conduction band. Once this voltage is exceeded, the material ceases being an insulator, and charge will begin to pass through it. However, it is usually accompanied by physical or chemical changes that permanently degrade the material's insulating properties, (en.wikipedia.org/wiki/ceramic-electric-insulator).

The electronic band theory predicts that a charge will flow whenever there are energy states available into which the electrons in a material can be excited. This allows them to gain energy and thereby move through the conductor (usually a metal), Langley, (2000) Materials that lack electron conduction are insulators if they lack other mobile charges as well. For example, if a liquid or gas contains ions, then the ions can be made to flow as an electric current, and the material is a conductor. Electrolytes and plasmas contain ions and will act as conductors whether or not electron flow is involved.

In terms of compositions, ceramic insulators can be conveniently grouped as glasses, glass ceramics, porcelains and dense single-phase or mixed-phase materials. This distinction largely reflects the amount of glassy phase in the ceramics, which tends to control the dielectric properties, Buchanan, (1991). Where high dielectric performance is required, therefore, glassy-phase content and the mobile ion content must be minimized in the insulator, as far as practicable composition, Chaudhuri, (2000). Thus, the content of feldspar has a major influence on the electrical properties of the insulator.

Some materials such as glass, paper or Teflon are very good electrical insulators though they may have lower bulk resistivity. Others include; most plastics and rubber-like polymers which insulate electrical wirings and cables. These can serve as practical and safe insulators for low to moderate voltages (hundreds, or even thousands, of volts), (en.wikipedia.org). Insulators used for high-voltage power transmission are made from glass, porcelain, or composite polymer materials. Porcelain insulators are made from clay, quartz or alumina and feldspar, and are covered with a smooth glaze to shed water. Insulators made from porcelain rich in alumina are used where high mechanical strength is a criterion. Porcelain has a dielectric strength of about 4-10KV/mm. Glass has a higher dielectric strength, but it attracts condensation and the thick irregular shapes needed for insulators are difficult to cast without internal strains. Some insulator manufacturers stopped making glass insulators in the late 1960s, switching to ceramic materials, (en.wikipedia.org).

Insulators suffer from the phenomenon of electrical breakdown. A rapid decrease in the resistivity of an electrical insulator can lead to a spark jumping around or through the insulator. In any location of the substance, if the electric field applied across an insulating substance exceeds the threshold breakdown field for that substance, the insulator suddenly turns into a resistor, sometimes with catastrophic results. This is because the electric field is proportional to the band gap energy, according to Bube, (1992).

During electric breakdown of an insulator, any free charge carrier being accelerated by the strong electric field will have enough velocity to knock electrons from any atom it strikes. These freed electrons and ions are in turn accelerated and strike other atoms, creating more charge carriers, in a chain reaction. Rapidly the insulator becomes filled with mobile charge carriers, and its resistance drops to a low level, according to Bube, (1992).

In air, "corona discharge" is normal current near a high-voltage conductor; an "arc" is an unusual and undesired current. Similar breakdown can occur within any insulator, even within the bulk solid of a material. Even a vacuum can suffer a sort of breakdown, but in this case the breakdown or vacuum arc involves charges ejected from the surface of metal electrodes rather than produced by the vacuum itself, Bube, (1992), en.wikipedia.org; www.solarsales.ca/terms/solartermsb.php).

The art of potters dates from the beginning of mankind. It was known from earliest times that some kind of "mud" would be molded into any shape and on drying the shape formed would be retained. In pre-history later on, the potter discovered that fire would harden the clay shape so it was no longer fragile and it would also hold liquids. In most traditional societies of the world today, working properties of clay, fire and tools have been discovered for specific functional needs for over 30000 years. This is because when a material is proven to be a good thermal insulator, it is as well a good electrical insulator. About 3000 years ago, the Chinese developed a porcelain clay body and glazes; the Egyptians, about 5000 years ago made the first potter's wheel and developed glass too; Asian countries used white clays while the world used common low fire rust-colored clays for utilitarian wares for a long time; in the 13^{th} century, Europeans started using cobalt blue brush decorations as glazes, to improve on the density and translucency on white wares, Peterson, (2002).

2.3 Porcelain as a material for electrical insulation

In this study, porcelain is central to the materials that were used. Porcelain is a term which refers to a wide range of ceramic products that have been baked at high temperatures to achieve a vitreous, glassy, quality such as translucency and low porosity. Among the most familiar porcelain goods are table and 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, (www.madehow.com). Hard-paste or "true" porcelain originated in China during the T'ang dynasty (618-907A.D); however, high quality porcelain comparable to modern ware did not exists until the Yuan dynasty (1279-1368A.D). In 1707, Germans combined clay with ground feldspar instead of glass previously used. Later in the 18^{th} century, the English improved the recipe for porcelain when they invented bone china by adding ash from cattle bones to clay, feldspar and quartz, (www.madehow.com)

According to Mwakali, (2006), porcelains are mainly composed of ball clay, feldspar, quartz and kaolin. This study used these as ingredients for making the electrical insulators.

Ball clay is secondary clay formed from the parent rock. It has smaller crystal sizes than other clays. It is often mixed with other clays and minerals, and organic matter is frequently present. Ball clays commonly exhibit high plasticity and high dry strength. The amount of ball clay in a white ware however, has to be controlled since in most cases they contain substantial amounts of iron oxide and titania, which impair the whiteness of the fired bodies and reduce the translucency of vitreous ware.

Feldspar are aluminosilicates of; sodium ($NaAlSi_3O_8$) which exhibit a low viscosity when melted at a given temperature. This enables vitrification at lower temperatures but carries the risk of increased deformation. Potassium feldspar ($KAlSi_3O_8$) enables the broadest firing range and the best stability of the body against deformation during firing. Calcium feldspar ($CaAl_2Si_2O_8$) has extremely narrow firing range. Feldspars are used as fluxes to form a glassy phase in bodies, thus promoting vitrification and translucency.

Quartz is added to ceramic bodies as a filler. Fillers are minerals of high melting temperature that are chemically resistant at commercial firing temperatures less than 1300°C. They reduce the tendency of the body to warp, distort or shrink when it is fired to temperatures that result in substantial qualities of viscous glass. The quartz used in ceramics is silica, (SiO_2) in the form of silica sand.

Kaolin is also called china clay, white or off white firing Kaolinitic [$Al_2Si_2O_5(OH)_4$] used to make porcelain. When pure, kaolinite crystals have the composition of Al_2O_3. $2SiO_2$, $2H_2O$, giving it a theoretical composition of 39.8wt% Al_2O_3, 46.3wt% SiO_2, and 13.9wt% H_2O. Kaolin is difficult to form into objects if used alone, thus other materials are normally added to it to increase its workability. It has little dry strength and a low firing shrinkage since it has a coarse grain structure.

2.4 Properties of Clay materials used as electrical insulators in Uganda

D'ujang, (2001), carried out a research on modeling the porosity dependence of the electrical conductivity of sintered kaolin. In the study, the researcher compacted kaolin powder into pellets of about 25mm diameter and 2-3mm thickness by uniaxial pressing, where the powder of a given particle size was compacted at pressures ranging from 40-500MPa and sintered to 1200°C, other powder were also compacted at constant pressure of 122MPa, and sintered to 1200°C.

These samples were tested for dielectric strength by applying an ac voltage with a frequency of 50 cycles per second on each. The voltage was increased and when break down was reached, the circuit breaker tripped and the voltmeter reading was taken.

The researcher found that the dielectric strength increased as the porosity decreased. Samples that had been sintered to a temperature of 1200°C had dielectric strengths ranging from 5 to 8kV/mm, and those with a compaction pressure of 122MPa.

The researcher concluded that increasing the compaction pressure alone to reduce porosity did not give desired dielectric strengths. Variation of sintering temperature was also required since it provides the necessary diffusion among the grains.

Olupot, (2006), carried out studies on the evaluation of properties of raw materials used in the production of electrical porcelains, the characterization of feldspar and quartz raw materials in Uganda for the manufacture of electrical porcelains, and optimization of mixing proportions and firing temperature of Ugandan minerals for high strength electric porcelains. The study found that, Mutaka feldspar consisted of only microcline and has strong kaolinitic characteristics well as Lunya feldspar consisted of microcline, albite minerals, and a high amount of Fe_2O_3 which had to be removed if the material is to be used in the production of porcelain insulators. Also the quartz deposits had the qualities desirable for the production of various white ware products in their raw form. It was also found that excessive amounts of sand or flint is detrimental to formability and must be limited to 25% in the batch composition. Also firing at 1250°C gives optimum mechanical and dielectric strength which was connected to optimum vitrification and the presence of small closely packed mullite needles. This is because at this temperature, the porcelain composition of 30% feldspar, 30% kaolin, 25% quartz and 15% ball clay yielded a body with the highest mechanical and dielectric strength.

The researcher concluded that; the values of both dielectric strength and modulus of rapture attained made the body formed suitable for use as an electrical insulator. These studies revealed that the local materials had the desired properties for making porcelain insulators.

2.5 Mixture of Locally available Clays

Electrical insulation materials also include clays, which are the ingredients intended for use in this study. Clay mass when wet can readily be moldable and retains its shape, but if dried it becomes hard and brittle. Clay has been defined as an earth that forms a coherent, sticky mass when mixed with water. Clay is decomposed and aged granite and consists of mainly alumina, silica, and water, Worrall, (1986). Properties of clays vary from place to place and this gives the clay products (wares) a unique character to a locality and also attachment to a particular use. For example clay wares from different places are used for different purposes since also their formulations vary from one culture or region to another.

When a material is formed (shaped) from clay, it is allowed to dry completely in air before it is heated in a kiln. During heating, the object or material shrinks considerably since the chemical bond with water is lost at about 1100°F- This reaction leads to permanent chemical changes. These changes include increasing the strength and hardness of the body and also its shape. To produce a desired effect in the fired wares, clay bodies can be worked with additives before forming. These can include sand and grog as coarse additives. These additives give the final product a desired texture, increase its strength, decrease on the shrinkage of the material during drying and also if in contrasting colors, they produce patterns in the final ware, (en.wikipedia.org/wiki/pottery).

For better results on the characteristics of the clay materials, the various clays are mixed in various proportions. This manufacturing process involves; crushing the raw materials, where the raw materials' particles are reduced to the desired sizes in a jaw crusher which uses swinging metal jaws. They are then crushed further using hammer mills to reduce the particles to 0.25

centimeters or less in diameter. The materials are then cleaned and mixed; this is done by passing the ingredients through a series of screens to remove under or over sized particles. The materials are then mixed with water if they are to be formed wet. Since iron occurs in most clays, magnetic filtration helps to remove iron from the slurries, (www.madehow.com).

After cleaning and mixing, the materials are shaped into wares, bisque fired, glazed and then finally fired in a kiln. After cooling, the ware is complete.

2.5.1 Shaping or forming of clays

Clays can be shaped in so many ways depending on the type of ware being produced. These include;

Soft plastic forming where the clay is shaped by manual molding, wheel throwing, jiggering, or ram pressing, (www.madehow.com).

Hand work or hand building (manual molding) involves molding of clay into desired shapes by hand which can be fitted together using a runny mixture of clay and water acting like glue to stick pieces together, (en.wikipedia.org/wiki/pottery).

Throwing on the potter's wheel is where a ball of clay is placed in the center of a turning table (wheel-head) which the potter rotates with a stick or foot power, this is followed by making a central hole into the solid ball of clay and a flat or rounded inside the pot, then it is drawn up and shaping of the walls to an even thickness or even removing excess clay to refine the shape, (en.wikipedia.org/wiki/pottery).

Jiggering and jollying is where a shaped tool is brought into contact with a plastic clay of a piece under construction and the piece is set onto a rotating plaster mold on the wheel, (en.wikipedia.org/wiki/pottery). Here, the clay is put on a horizontal plaster mold of the desired shape; the mold shapes one side of the clay, while a heated die is brought down from above to shape the other side, (www.madehow.com).

Roller-head machine is where the machine used is a rotating mold but with a rotary shaping tool replacing the fixed profile used in jiggering and jollying, (en.wikipedia.org/wiki/pottery).

RAM pressing is where a bat of a prepared clay body is pressed into a required shape between two porous molding plates, (en.wikipedia.org/wiki/pottery). The two plaster molds shape the clay while forcing water out. The mold is then separated by applying a vacuum to the upper half of the mold and pressure to the lower half of the mold. Pressure is then applied to the upper half to free the formed body, (www.madehow.com).

Stiff pressing is used to shape less plastic bodies. The body is formed 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, (www.madehow.com).

Pressing is used to compact and shape dry in a rigid die or flexible mold. There are several types of pressing, based on the direction of pressing. Uniaxial pressing is the process of applying pressure from only one direction. Isostatic pressing is the applying of pressure equally from all sides. In both pressing methods, dry or wet materials can be formed, (www.madehow.com). During this forming method, particles are compacted and therefore there is elimination of both the macro pores using low pressures and the micro pores using a higher pressure. This are because particles around a large pore are easily accommodated and rearranged, and the stress is higher due to stress concentration, Zeng, (1992).

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

2.5.2 Bisque-firing

After being formed, the porcelain parts are generally bisque-fired, which involves heating them at a low temperature (about 120°C) to vaporize volatile contaminants and minimize shrinkage during firing, (www.madehow.com).

2.5.3 Glazing of clays

A glaze is a liquid mixture containing a glass former applied to pottery. This helps in decoration and protection of the ware. They also render the ware impermeable to water and other liquids. Glazing is done by dusting the glaze over the ware, spraying, dipping, trailing or brushing on thin slurry composed of glaze minerals and water. It can be done before or after firing. Glazes when fired, they fuse to the ceramic surface, creating a permanent coating, Amber, (2008).

A glaze suspension can consist of finely ground quartz sand mixed with sodium salts such as bicarbonates, chlorides, carbonates, sulfates, or plant ash. After application of a glaze, the ware is then refired, usually at a lower temperature, Norton, (2007).

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

2.5.4 Firing of clays

Firing is heating a material to high temperatures, above about 600°C. Heat supplied during the firing process provides sufficient energy to dislodge atoms from their positions from the clay and cause them to migrate to more favorable sites; the final result of the firing process is that the clay is converted to a new hard and rigid ceramic material that is stable to water, high temperatures and weathering, Goffer, (2007).

Firing 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 element). It can only fire 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 which maintains a certain temperature zone continuously, with the ware being pushed from one zone to another. The ware enters a prefiring zone, then through a firing zone (at the centre of the kiln) before leaving the kiln through the cooling zone. This type of kiln is more economical and energy efficient than a periodic kiln, (www.madehow.com).

Firing of clays leads to the alteration of the physical, chemical and mineralogical properties of the constituents in the body for example the case of porcelain. Fired bodies are permanently hardened if firing is done appropriately to the characteristics of the materials used to make the clay products, (en.wikipedia.org/wiki/pottery).

According to Goffer, (2007), the changes caused by heat on wet clay are indicated in table 2.1.

Table 2.1: The changes caused by heat on wet clay.

Temperature (°C)	Change
Room temperature -100	Drying (loss of water of formation).
100-500	Loss of water of plasticity.
500-600	Dehydration (loss of chemically combined water and modification of clay structure).
600-900	Breakdown of clay structure and incipient vitrification.
900- about 1700	Vitrification and formation of new structures.
Above 1700	Melting.

(Adapted from Goffer, (2007)).

Also during the firing process, a variety of reactions take place. Carbon-based impurities burnout, chemical water evolves (at 100 to 200°C) and carbonates and sulfates begin to decompose (at 400 to 700°C). Gasses are produced which must escape from the ware. On further heating, some of the minerals break down into other phases, and the fluxes present (feldspar, and flint) react with the decomposing minerals to form liquid glasses (at 700 to 1100°C). After the desired density is achieved (at greater than 1200°C), the ware is cooled, which causes the liquid glass to solidify, thereby forming a strong bond between the remaining crystalline grains. After cooling, the porcelain is complete, (www.madehow.com).

2.5.5 Sintering

Sintering is the process of transforming a powder in to a solid body using heat. Sintering is aimed at controlling the grain size in ceramics (to make dense ceramics). Changes that occur during the firing process are related to changes in grain size and shape. Before firing, a powder compact is composed of individual grains and may contain as much as 60vol% porosity. The amount of porosity will depend on the size and size distribution of the powder particles and the shaping mentioned. Firing is aimed at maximizing the properties (compressive strength, translucency, and thermal conductivity), porosity has to be eliminated as much as possible, Cater, (2007).

Sintering may also be the processing technique of applying thermal energy to produce density-controlled materials and components from metal or / and ceramic powder. Sintering is used in the fabrication of sintered parts of all kinds, including powder-metallurgical parts and bulk ceramic components. Sintering is aimed at producing sintered parts with reproducible and, if possible, designed microstructure through control of sintering variables. Microstructure control means the control of grain size, sintered density, and size and distribution of other phases including pores. In most cases, the final goal of microstructure control is to prepare a fully dense body with a fine grain structure, Kang, (2005).

According to Kang, (2005), the different types of sintering include; solid state sintering, liquid phase sintering, viscous flow sintering, and transient liquid phase sintering.

Solid phase sintering occurs when the powder compact is densified wholly in a solid state at the sintering temperature. In solid state sintering, densification is a result of atomic diffusion in solid state. Densification requires mass transport and hence solid state sintering is carried out at temperatures where material transport due to diffusion is appreciable. However, densification will not occur if material transport occurs by surface diffusion, Angelo, (2008), Kang, (2005).

Liquid phase sintering occurs when a liquid phase is present in the powder compact during sintering. This allows easy control of microstructure and reduction in processing cost, but degrades properties like the mechanical properties, Kang, (2005).

Viscous flow sintering occurs when the volume fraction of liquid is sufficiently high, so that the full densification of the compact can be achieved by a viscous of grain-liquid mixture without having any grain shape change during densification, Kang, (2005).

Transient liquid phase sintering is a combination of liquid phase sintering and solid state sintering. Here a liquid phase forms in the compact at an early stage of sintering, but the liquid disappears as sintering proceeds and densification is completed in the solid state.

Densification (Ψ) is the change in porosity from the green condition due to sintering, divided by the initial porosity.

$$\Psi = \frac{\varepsilon_g - \varepsilon_s}{\varepsilon_g} \qquad 2.1$$

where: g is green conditions (unsintered conditions), s is sintered conditions and ε is density.

Porosity (p) is the fractional void space in a compact.

$$\varepsilon + p = 1 \qquad 2.2$$

where: p is fractional porosity and ε is fractional density, German, (1985).

A sintering type depends on the material system and or the sintering purpose. Variables related to raw materials (material variables) are; powder (shape, size, size distribution, agglomeration, mixedness), chemistry (composition, impurity, homogeneity, non-stoichiometry). Variables related to sintering conditions (process variables) are; time, temperature, pressure, atmosphere, heating and cooling rate, Kang, (2005).

2.6 Dielectric strength of electrical insulators

The characteristics that indicate that a material is good for electrical insulation are: dielectric strength, mechanical strength, apparent porosity, water absorption and surface properties. These are the major characteristics that should be tested for when developing electrical insulators, Olupot, (2006).

Dielectric strength can be defined as the maximum potential gradient to which the materials can be subjected without insulation breakdown. It can be calculated using equation (2.3).

$$Dielectric\ strength\ (kV/mm) = \frac{V_B}{d} \qquad 2.3$$

where V_B is the breakdown voltage and d is the thickness of the sample.

Dielectric strength of an insulator is affected by; phase composition, microstructure, grain growth, and test conditions. These factors are highlighted as follows;

In Phase composition, constitutional parameters such as the amount of mullite, quartz, cristobalite, glass and the size of mullite crystals simultaneously affect the dielectric properties. Higher surface currents and low breakdown voltage are a result of surface porosity, surface alkali, and moisture. Hence these effects are minimized in porcelain bodies for high voltage application by glazing, Chaudhuri, (2000). Porcelain insulators made from materials rich in alumina are used where high mechanical strength is a criterion, and these porcelain have a dielectric strength of about 4-10kV/mm, Product spec sheet,(2008).

Grain sizes depend on the details of the structure of the sample. The smaller the grains, the higher the dielectric strength thus reflecting reduced conduction in the solid. Chaudhuri, (2000).

Test conditions such as A.C voltage, the frequency, wave form, and test temperature influence the heat generated in the specimen. Also the break down voltage decreases with decrease in electrode area. Due to high fields involved, point contacts can stimulate breakdown through field injection of electrons into the specimen. Therefore to minimize this effect, measurements are carried out with the samples immersed in a high - dielectric-grade (silicon) oil. This fixes the surface heat transfer and the humidity conditions, Buchanan, (1991). Also things like dirt, pollution, salt, and particularly water on the surface of high voltage insulators can create a conductive path across it, causing leakage currents and flash overs. The flash over voltage can be more than 50% lower when the insulator is wet, Holtzhausen, (2008).

Micro structural features such as cracks and porosity in porcelains can lead to ionization of entrapped gasses at high fields (particularly at high humidity) conditions. This can result in high current flow, local heating, cracking and thermal break down. Larger pores are more likely to lead to insulator failure, Olupot, (2006).

CHARPTER THREE: METHODOLOGY

3.1 Research Design

The research was based on the exploratory and descriptive designs. Here the researcher used a variety of compositions and dimensions to test how the materials behave during formation and firing and thereafter made a decision on what compositions and dimensions are fit for use in the study. These compositions and dimensions were determined by trial and error.

Thereafter getting the test results, the researcher described the performance of the insulator and related the values from the study to the recommended values of dielectric strength of electrical insulators.

3.2 Sample collection

The systematic sampling technique was used in sampling the clay minerals to be used. The choice of the samples was based on the predetermined criterion about the clay minerals available, where each type is found and also which areas have the most pure clay minerals. Thus the clay minerals were collected from local deposits of clay identified by other researchers.

The following clay minerals were collected from different mineral deposits; kaolin, and feldspar from Mutaka deposit (Bushenyi district), flint or sand from Lido Beach (Wakiso district), and ball clay from Mukono ball clay deposit (Mukono district) all in Uganda.

In this study, the composition of the locally available clay materials and the methods of formation of the insulation materials were considered as the independent variables and the dielectric strength was considered as the dependent variable.

3.3 Sample Preparation

3.3. 1 Sieving

Flint (sand) was wet milled for 120 hours to reduce on the particle size. It was then wet sieved through a 25μm sieve. This flint was then poured on a flat surface of plaster of Paris to remove most of the water, and then it was dried in the sun to form back fine powder which is 25μm and below.

Ball clay was soaked for four days so that the clay can uniformly ad solve in water and the sand and roots settle at the bottom of the container. The slip was then sieved through 45μm in stages as shown in Figure 3.1. It was then dried first on plaster of Paris then in the sun. The dry clay was crashed into powder.

Feldspar was wet milled for 72 hours to reduce its particle size. Then it was dried and dry sieved through 53μm, this was also done in stages as shown in Figure 3.1.

Kaolin was sieved through 45μm as shown in Figure 3.1. Sieving through various stages of sieve sizes helps to ease the sieving work and to protect the sieves from getting clogged and damage.

These particle sizes were chosen because the smaller the grain sizes the higher the dielectric strength according to Chaudhuri, (2000).

Figure 3.1: Sieves stacked together with the largest size on top and the smallest size at the bottom.

3.3.2 Sample formation

The individual sample materials for all the three forming methods were weighed in proportions to form samples A, B, C, D, E, F, and G as shown in Table 3.1 for each forming method.

Table 3.1: Composition of sample porcelains (wt %).

Samples	*A*	*B*	*C*	*D*	*E*	*F*	*G*
Kaolin	30	33	35	37	38	40	42
Ball clay	15	17	20	18	17	20	18
Feldspar	35	30	25	25	25	20	25
Flint	20	20	20	20	20	20	20
Total (grammes)	100	100	100	100	100	100	100

For each sample formulation, the compositions were thoroughly mixed by dry milling for 30 minutes to ensure that the powders were properly mixed. This was done in such a way that after each formulation, the ball mill was well cleaned and another formulation poured in for milling.

3.4 Sample Forming Methods

3.4.1 Slip casting

For each formulation, a mass 600g was weighed off and then water of 613.6 g was added. A drop of silica (5ml) was added to each solution to be casted. This was to help the solution not to settle at a fast rate and to give the slip an oily form. This solution was then mixed by shaking manually for 5minutes to mix well in regular intervals of 10 minutes. Then the slip was left to mature for two days.

The individual samples from each formulation were formed by pouring the slips in a plaster mold which was specifically prepared to form discs of diameter 3.5 cm and a thickness of 1 cm. As the plaster mold sacked out water from the sample, more slip was added until a completely solid sample was formed in the mould.

3.4.2 Wet pressing

A mass of 20g of each sample formulation was weighed off and mixed with 20% grames of water. This was then compacted to a pressure of 100MPa to form discs of diameter 40mm and thickness of 2.5mm using a hydraulic press machine as shown in Figure 3.2.

These samples were left to dry in air for at least two days before firing in a kiln.

3.4.3 Dry pressing

A mass of 20g of each sample formulation was weighed off and then compacted to a pressure of 100MPa to form discs of diameter 40mm and thickness of 2.5mm using a hydraulic press machine as shown in Figure 3.2 before firing in a kiln.

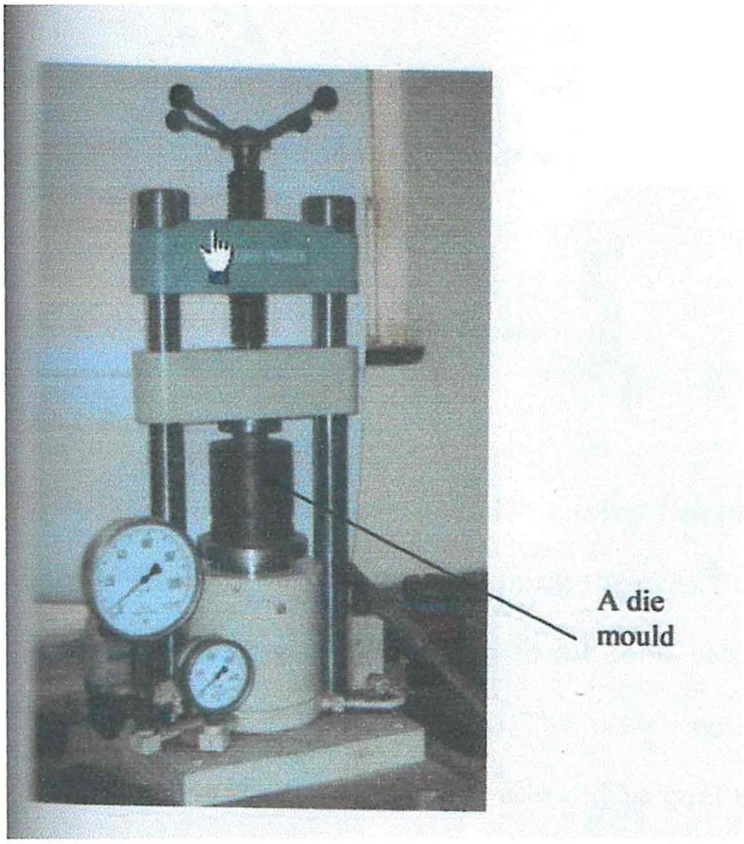

Figure 3.2: The hydraulic press with a die mould (Hydraulina Laboratory Manual Press-PW40)

3.5 Sample Firing

The samples were first dried in air and then placed in an electrical furnace at a temperature of 21°C. The samples were then fired at a rate of 100°C/hour to a temperature of 110°C and held at this temperature for 3 hours in the furnace. This was done to remove the remaining water from the samples. The samples were then fired to a temperature of 1250°C at a heating rate of 6°C/min and held at the top temperature for two hours before air cooling them in the furnace. Holding for two hours improves the mechanical and dielectric properties, and the microstructure of the samples, Olupot (2006).

However, firing above a temperature of 1250°C, results in progressive deterioration of the properties of the samples according to Olupot (2006). This explains why a firing temperature of 1250°C was chosen.

The fired samples were white due to having less ball clay in all sample compositions as shown in Figure 3.3.

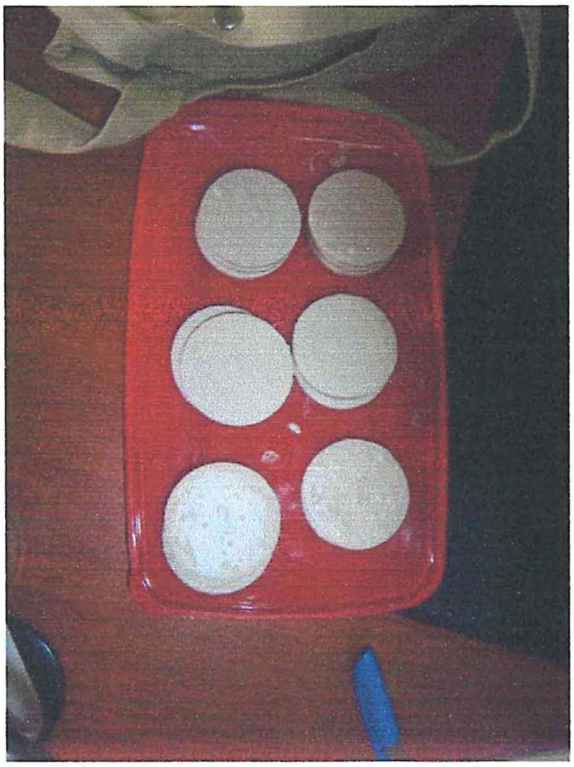

Figure 3.3: some of the fired samples formed by wet and dry pressing forming methods.

3.6 Experimental Measurement

3.6.1 Dielectric strength

The dielectric break down voltage was measured using a D.C voltage loading at a temperature of 21°C and with a frequency of 61.8Hz applied through a transformer to the testing equipment (The oil test set, Avo Megger foster OTS100AF/2), with the sample being tested, placed between two electrodes across high voltage terminals and then immersed in high grade transformer oil as shown in Figure 3.4. This helps to fix the surface heat transfer so as to minimize stimulation of breakdown through injection of electrons at point contacts into the sample being tested, Buchanan,(1991).

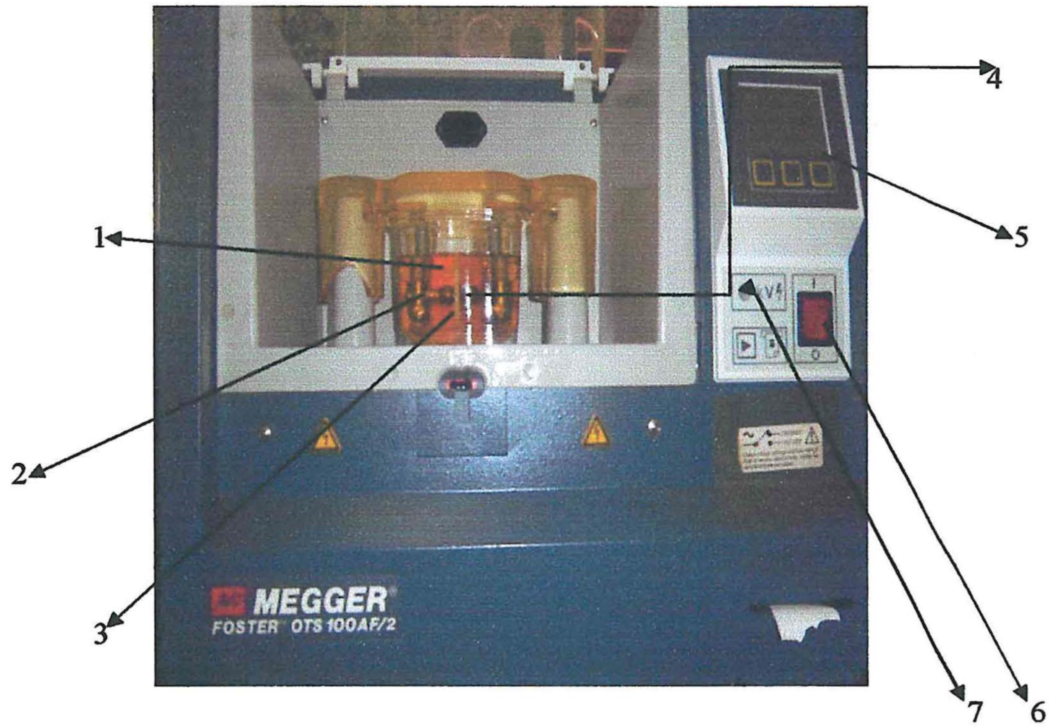

Figure 3.4: Setup for testing voltage breakdown

1- High grade transformer oil

2-Sliding arm connected to the electrode support.

3- Sample being tested.

4- Electrode.

5-Liquid crystal display / screen with control keys.

6- Power supply (On / off switch).

7- High voltage indicator.

The test to be carried out was highlighted and selected from the main menu and the START key was pressed to install the selected test (i.e. BS 148: 1984). The display appeared and it indicated the initial stand time being undertaken and the remaining time was shown in minutes and seconds. After this initial stand time was complete (3minutes), a high voltage was switched on and was applied to the test sample. The display showed the voltage rising at a rate of 2kV/s being applied. This voltage rise continued until break down occurred, (or up to a maximum). The number of the test in the sequence was displayed together with the words 'IN PROGRESS'.

When break down occured, (or when the maximum voltage was reached) the test voltage was automatically cut off, the high voltage indicator light went out and the test set began its intermediate stirring period. This took 2minutes as the previous break down voltage was also retained on the display. This was recorded as the first value for voltage break down for the sample.

Time remaining for stirring was displayed, alternating with the word 'STIRRING'. When stirring was finished the display screen indicated that the intermediate standing period was being undertaken. Time remaining was displayed alternating with the word 'STANDING'.

The test voltage began to rise again until break down was reached and the value displayed was recorded as the second voltage breakdown for the sample. The cycle of events was repeated and the third voltage breakdown recorded.

The same test was carried out when the samples were not immersed in high grade transformer oil as comparisons of results were done.

The dielectric strengths for each forming method was then calculated using equation (2.3)

$$Dielectric\ strength\ (kV/mm) = \frac{V_B}{d} \qquad 2.3$$

where V_B is the breakdown voltage and d is the thickness of the sample.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Record of Results

For each sample formulation, 5 samples were tested and three values of voltage breakdown were recorded. Thus a total of fifteen (15) results were recorded for a particular formulation.

The mean values of voltage breakdown obtained were used to calculate dielectric strengths for the respective formulations using equation 2.3.

4.2 Presentation of Results

The results for the voltage breakdown and the dielectric strength of the samples tested in transformer oil were obtained as shown in Table 4.1.

Table 4.1 Results obtained for samples tested in transformer oil

Sample formulations	Kaolin content/g	Voltage breakdown/kV			Dielectric strength/kVmm^{-1}		
		Dry pressed	Wet pressed	Slip casted	Dry pressed	Wet pressed	Slip casted
A	30	48.18	47.27	60.80	19.3	18.9	8.7
B	33	47.42	53.20	60.32	19.0	21.3	6.7
C	35	50.60	48.76	47.71	20.2	19.5	6.8
D	37	56.20	50.98	62.39	22.5	20.4	6.2
E	38	47.27	46.63		18.5	18.7	
F	40	52.50	43.97	56.35	20.2	17.6	7.0
G	42	45.01	38.12		18.0	15.2	

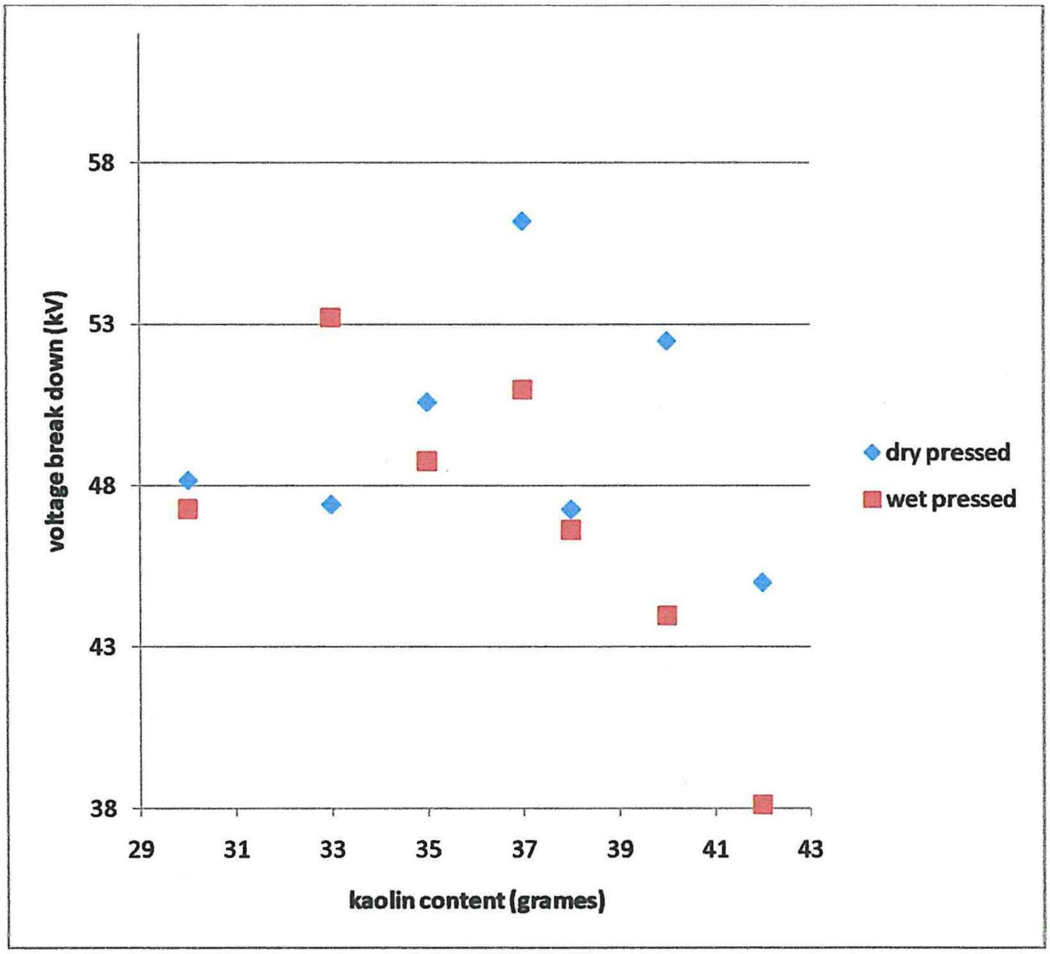

Figure 4.1: *A graph of voltage break down against kaolin content for samples tested in transformer oil*

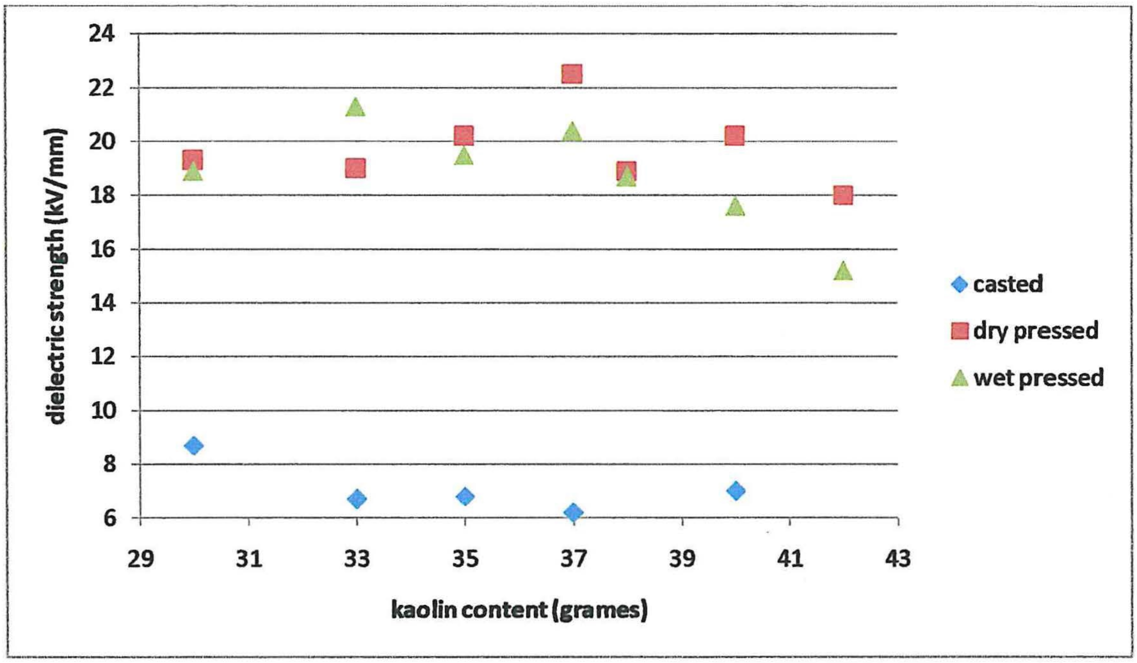

Figure 4.2: *A graph of dielectric strength against kaolin content for samples tested in transformer oil*

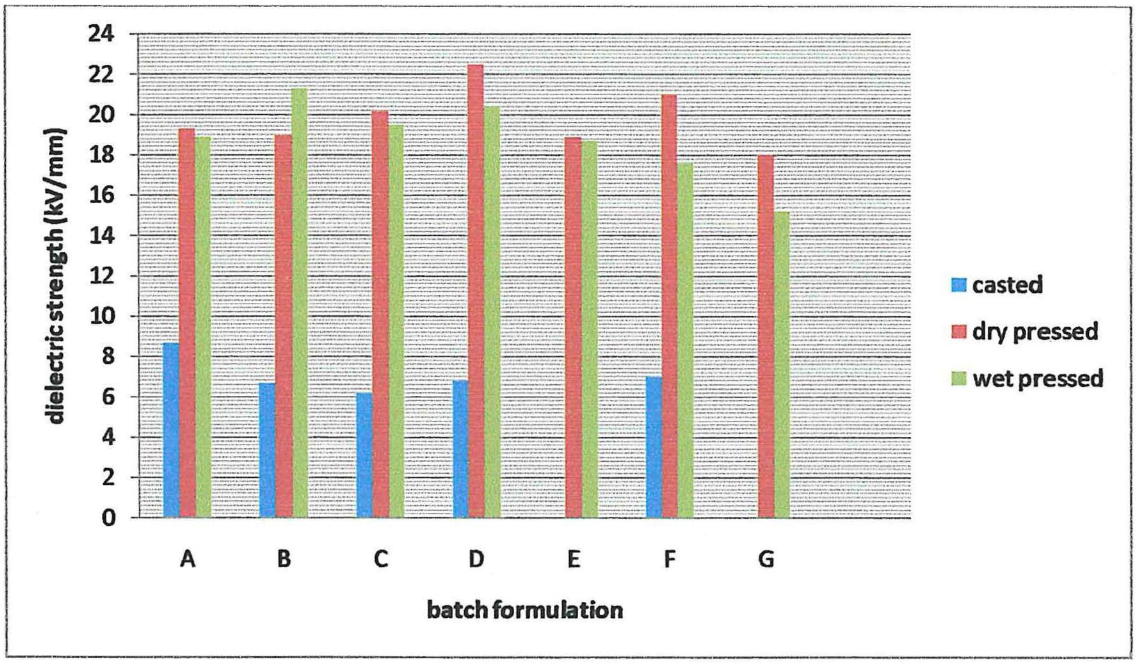

Figure4.3: *A graph of dielectric strength against batch formulations for samples tested in transformer oil*

The results for the voltage breakdown and the dielectric strength of the samples tested in air were obtained as shown in Table 4.2.

Table 4.2 Results obtained for samples tested in air

Sample formulations	Kaolin content/g	Voltage breakdown/kV			Dielectric strength/kVmm^{-1}		
		Dry pressed	Wet pressed	Slip casted	Dry pressed	Wet pressed	Slip casted
A	30	21.41	21.41	19.71	8.6	10.5	2.8
B	33	25.25	26.81	21.94	10.1	10.7	2.4
C	35	13.21	15.82	20.27	5.3	6.3	2.9
D	37	24.63	17.05	21.11	9.9	6.8	2.1
E	38	26.38	26.19		10.6	10.5	
F	40	24.61	22.98	20.25	9.8	9.2	2.5
G	42	20.86	26.11		8.3	10.4	

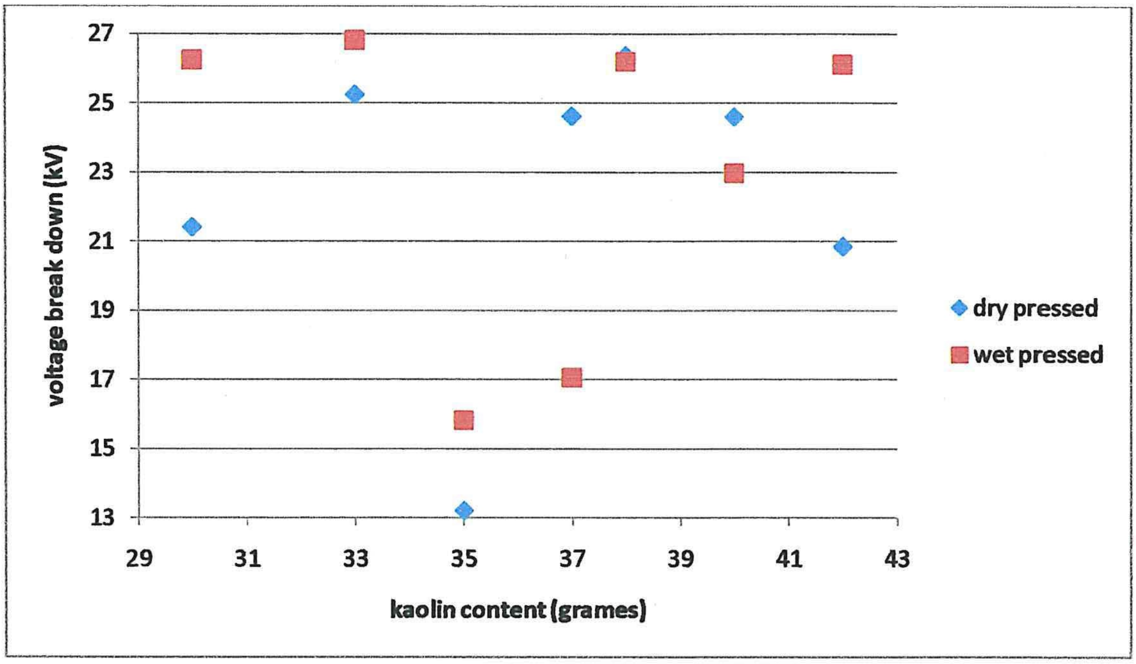

Figure 4.4: *A graph of voltage break down against kaolin content for samples tested in air*

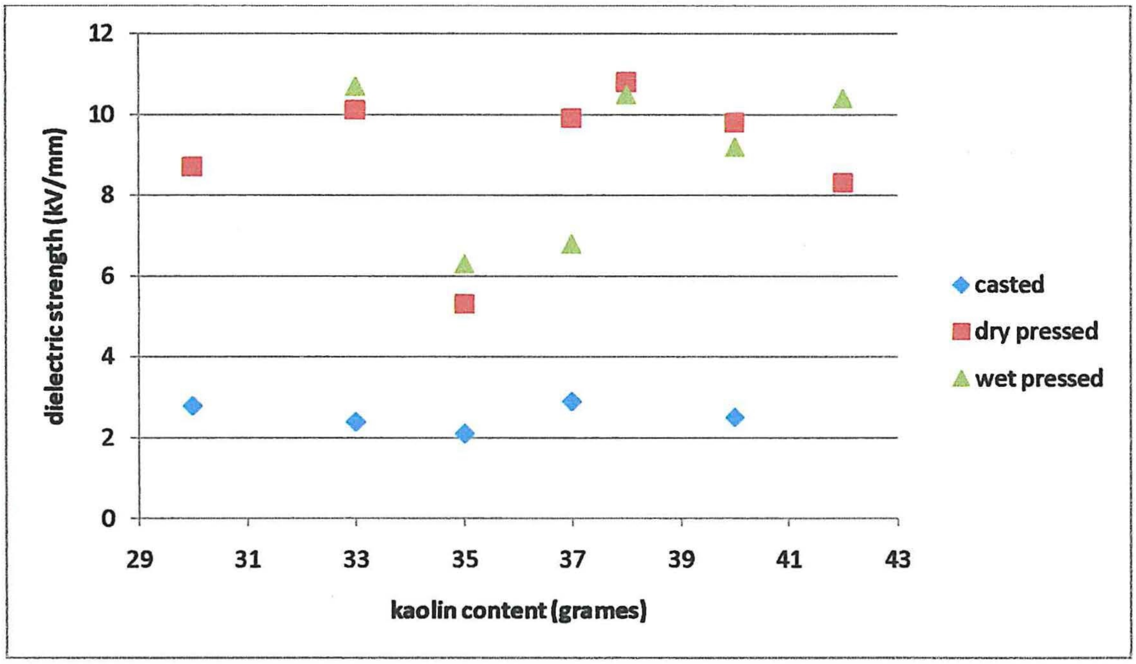

Figure 4.5: *A graph of dielectric strength against kaolin content for samples tested in air*

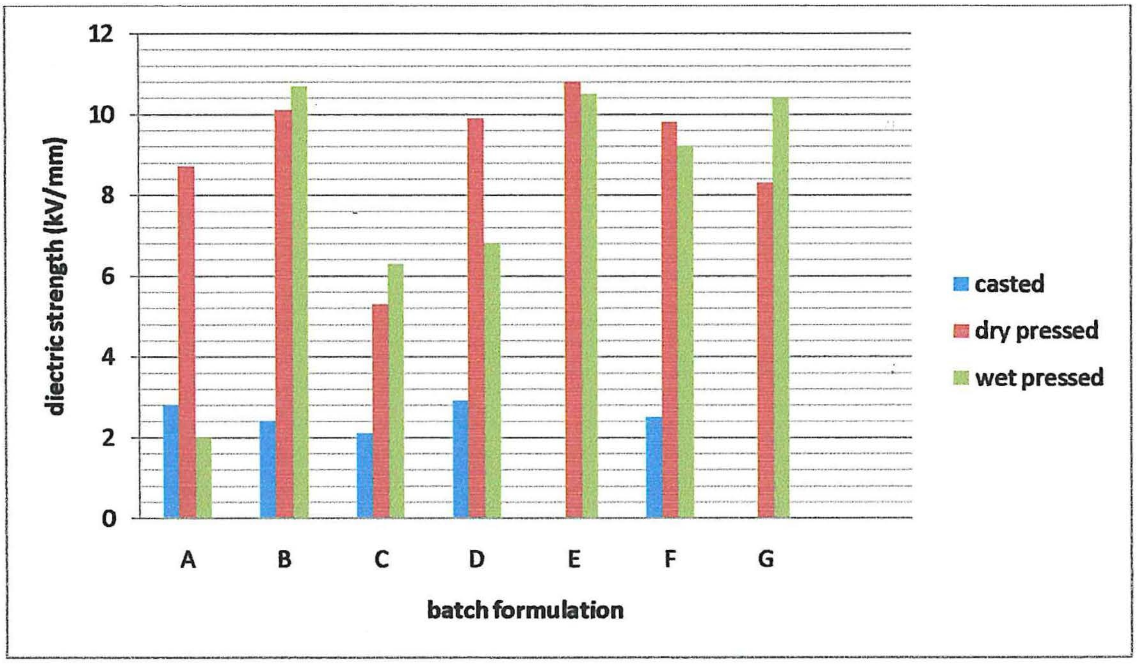

Figure4.6 A graph of dielectric strength against batch formulations for samples tested in air

4.2.1 Batch formability

Batches A, B, D, and F, showed good formability in slip casting well as batch C even after 14 days could not easily form good casted samples. That is, many samples broke on getting them out of the slip casting mold.

Batches A, B, D, and F formed well and easily in dry and wet pressing well as batch C only formed well in dry pressing but many samples cracked during firing of wet pressed samples. Batches E and G could not be slip casted and often broke in the mold during dry pressing. They could only form well during wet pressing. This was attributed to the ratio of ball clay to kaolin which was 1:1.75 and 1: 2.25 respectively thus ball clay which was the binder could not work well with bigger amounts of kaolin without any amount of water being added to it. This is because water helps to bring out its elastic property.

4.2.2 Forming methods in relation to Voltage break down and Dielectric Strength

Casted samples had lower dielectric strength compared to those which were wet pressed and those dry pressed as shown in Figures 4.3, 4.4, 4.5, and 4.6. This was attributed to the large amounts of water used to form the slip and as water dries out, it leaves some pores. These pores may not all fill up during sintering. Respectively, those wet pressed compared to dry pressed samples without any water content thus approximately no pores are left after sintering. This is because, in liquid phase sintering (when a liquid phase is present in powder compact during sintering), leads to a reduction in processing costs, but degrades the mechanical and dielectric properties of the material, Kang, (2005).

With a confidence interval of 95%, mean values of dielectric strength of samples tested in transformer oil show that dry pressing has the highest dielectric strength, followed by wet pressing which are both above 10kV, and that slip casting gives dielectric strength between 4-10kV (see Appendix A).

Values of both the voltage breakdown and dielectric strength of samples tested in air were much lower than those of samples tested in transformer oil as shown in Tables 4.1 and 4.2. The samples generated carbon around them easily when in air as a result of corona discharge and thus experienced a reduced value of voltage break down and in dielectric strength. The oil helps to cover up the samples' pores, to fix the surface heat transfers, and the humidity conditions, Buchanan, (1991), and, Amber, (2008). Thus improving on the insulation properties of the sample, therefore better values are registered.

Therefore, the best formulation of all was batch D as shown by Figures 4.3 and 4.6 which showed good formability in all forming methods and gave the best dielectric strength at 22.5kV/mm in dry pressing method. This was attributed to the elimination of coarse micro pores and macro pores during the dry pressing forming method, since pores have a great influence on the properties of ceramics and hence the need to be carefully controlled, Salib, (1990).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

According to the Product spec sheet, (2008), porcelain has a dielectric strength of about 4-10kV/mm and above, therefore, formulations from A – G are all good for electric insulation for power lines below 33kV.

However, to avoid wastage of minerals during the forming process, the ratio of ball clay to kaolin in the sample formulation should be 1:2.

The best formulation was batch D with 55% clay of which ball clay should be 18% and kaolin 37%. Feldspar should be 25% and flint 20% since this formulation showed the best results during forming and also the highest dielectric strength at 22.5kV/mm when dry pressed.

The best forming method of the three was dry pressing though to ease on forming, it is best if 5% of the total weight of the material formulation is added as water content. This helps to improve or increase on the elasticity of the ball clay which is the binder.

Sample compositions of the various minerals affects both voltage breakdown and dielectric strength since the significance value or the P-value is below 0.05 i.e. this was 0.000 at 95% confidence interval, (see Appendix A, Tables A2, A3 and A4).

For an insulator which needs high voltage breakdown like the 66kV lines, bigger thickness of more than 5mm should be used.

These electric insulators cannot work very well in air since they are affected by humid conditions and therefore will require a glaze to help them shed off water and cover them from humid conditions for better results. The flash over voltage can be more than 50% lower when the insulator is wet. Glazes also minimize effects of surface porosity, surface alkali and moisture, Chaudhuri, (2000).

5.2 Recommendations

From the results of this study, the following works are suggested for further study;

- The mechanical properties especially porosity of these sample formulation. This is because dielectric strength is also affected by micro structure features such as cracks and pores.
- The effect of glazes on the dielectric and the mechanical strength of these sample formulations. This is due to the fact that the samples tested in air and unglazed showed less values of voltage break down and dielectric strength.

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APPENDIX A: SPSS ANALYSIS DETAILS

Table A1: Spss analyzed values of voltage break down for samples tested in oil

Descriptives

content

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Minimum	Maximum
Dry pressed	7	49.5971	3.79112	1.43291	46.0909	53.1033	45.01	56.20
Wet pressed	7	46.9900	4.92650	1.86204	42.4337	51.5463	38.12	53.20
Casted	5	58.0400	5.91971	2.64738	50.6897	65.3903	47.70	62.40
Total	19	50.8584	6.43685	1.47671	47.7560	53.9609	38.12	62.40

ANOVA

content

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	373.764	2	186.882	8.037	.004
Within Groups	372.030	16	23.252		
Total	745.794	18			

Table A2 Spss analyzed values of voltage break down for samples tested in air

Descriptives

content

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
dry pressed	7	22.3357	4.50183	1.70153	18.1722	26.4992	13.21	26.38
wet pressed	7	23.0300	4.68821	1.77198	18.6941	27.3659	15.82	26.81
Casted	5	20.6560	.87515	.39138	19.5694	21.7426	19.71	21.94
Total	19	22.1495	3.89701	.89404	20.2712	24.0278	13.21	26.81

ANOVA

content

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16.822	2	8.411	.525	.602
Within Groups	256.538	16	16.034		
Total	273.360	18			

Table A3 Spss analyzed values of dielectric strength for samples tested in oil

Descriptives

content

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Dry pressed	7	19.843	1.5175	.5736	18.439	21.246	18.0	22.5
Wet pressed	7	18.800	1.9883	.7515	16.961	20.639	15.2	21.3
Casted	5	7.080	.9524	.4259	5.897	8.263	6.2	8.7
Total	19	16.100	5.7593	1.3213	13.324	18.876	6.2	22.5

ANOVA

content

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	555.895	2	277.947	108.032	.000
Within Groups	41.165	16	2.573		
Total	597.060	18			

Table A4 Spss analyzed values of dielectric strength for samples tested in air

Descriptives

content

method	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	Upper Bound	Minimum	Maximum
Dry pressed	7	8.9857	1.83342	.69297	7.2901	10.6813	5.30	10.80
Wet pressed	7	9.2000	1.88149	.71114	7.4599	10.9401	6.30	10.70
Casted	5	2.5400	.32094	.14353	2.1415	2.9385	2.10	2.90
Total	19	7.3684	3.33484	.76507	5.7611	8.9758	2.10	10.80

ANOVA

content

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	158.360	2	79.180	30.293	.000
Within Groups	41.821	16	2.614		
Total	200.181	18			