Evaluation of dielectric and mechanical strength of high voltage porcelain insulators made from Tanzania ceramic materials

Ngayakamo, Blasius

NM-AIST

https://doi.org/10.58694/20.500.12479/273

EVALUATION OF DIELECTRIC AND MECHANICAL STRENGTH OF HIGH VOLTAGE PORCELAIN INSULATORS MADE FROM TANZANIA CERAMIC MATERIALS

Blasius Ngayakamo

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Materials Science and Engineering at the Nelson Mandela African Institution of Science and Technology

Arusha, Tanzania

March, 2019

ABSTRACT

The study has evaluated the dielectric and mechanical strength of high voltage porcelain insulators made from Tanzania local ceramic raw materials. The ceramic raw materials involved were; Pugu Kaolin Same clay, vermiculite, and feldspar. The chemical, mineralogical phases and microstructural characterization of the ceramic raw materials was carried out using the X-ray fluorescence (XRF), X-ray diffraction (XRD), and Scanning electron microscopy (SEM) techniques respectively. The XRF characterization revealed that vermiculite deposit has a higher content of hematite (Fe_2O_3) compared to other three deposits. Its use for porcelain insulators production can be ruled out unless it is beneficiated as it may affect the composition of the glassy phase at high firing temperature.

The X-ray diffraction (XRD) patterns of the raw materials showed that Pugu kaolin and Same clay contain mineral clay kaolinite, quartz and tridymite. Kaolinite is a source of alumina while quartz, and tridymite are sources of silicon dioxide (SiO_2) whereas with fluxing oxides ($K_2O$and Na_2O) promote the formation of glassy and mullite phases during the sintering process. Both phases promote densification and vitrification which improve the mechanical and dielectric properties of porcelain insulators.

The porcelain samples were made by varying the composition of Pugu kaolin, Same clay, vermiculite, and feldspar. Sixteen porcelain samples with dimensions 160 mm x 40 mm x 10 mm were fabricated by using the dry pressing method. The dried rectangular samples were sintered at 1200 to 1250 °C for 1.5 hrs at the ramp rate of 10^0C/min. The SEM micrographs showed the progressive change in densification of the porcelain samples during sintering process confirming that densification took place at 1250^0C. The mechanical and dielectric strength of each porcelain sample was investigated. The porcelain sample with composition, 20 wt% Pugu kaolin, 20 wt% Same clay, and 20 wt% vermiculite and 40 wt% feldspars sintered at 1250^0C gave the highest dielectric strength of 61.3 kV/mm, bending strength of 30.54 MPa and low water absorption value of 0.36% which satisfied the main requisite properties for high voltage porcelain insulators production. The study showed that, a high-quality high voltage porcelain insulator can be achieved from locally sourced ceramic raw materials from Tanzania.

DECLARATION

I, Ngayakamo Blasius do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

.... 03/04/2019

Blasius Ngayakamo **Date**

Name and Signature of a Candidate

The above declaration is confirmed

.... 4/04/2019

Prof. Eugene Park **Date**

Name and Signature of Supervisor

COPYRIGHT

CERTIFICATION

This is to certify that the dissertation entitled "Evaluation of the dielectric and mechanical strength of high voltage porcelain insulators made from Tanzania ceramic materials" submitted by Mr. Blasius Ngayakamo (M274/T.15) in partial fulfillment of the requirements for the award of Master's in Materials Science and Engineering at Nelson Mandela African Institution of Science and Technology, Tanzania is an authentic work carried out by him under my guidance.

....

Prof. Eugene Park **Date**

Name and Signature of Supervisor

4/04/2019

ACKNOWLEDGEMENT

With great honour, I would like to extend special thanks to my supervisor Prof. Eugene Park for his supportive and constructive guidance throughout the period I was doing this research work. I would like also to extend my sincere thanks to Prof. Tatiana Pogrebnaya and Joyce Elisadiki for their advice, commitment, and encouragement lastly made this research successful.

I extend my sincere thanks to British Gas Tanzania (BG) for sponsoring my studies and this research. In advance, I would like to thank the Management and all staff members of Nelson Mandela African Institution of Science and Technology for their cooperation and moral support. Furthermore, I would like to thank the management and all workers of the Geological Survey of Tanzania (GST), Tanzania Twiga Cement Company Limited, and Tanzania Electric Supply Company Limited (TANESCO) and the University of Connecticut for their material and moral support during data collection time.

Finally, I extend special thanks to my mother Mary Blasius. Special thanks to my wife Winfrida Fussi, my beloved sons Henry Blasius and Victor Blasius and my daughter Doreen Blasius for their love and support all the way through my studies.

DEDICATION

This dissertation is dedicated to my late father Henry Benedict Ngayakamo for the love, material and moral support he had to me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

KIDT	Kilimanjaro Industrial Development Trust
$kVmm^{-1}$	Kilovolt per millimeter
$kVcm^{-1}$	Kilovolt per centimeter
kg/cm^2	Kilogram per centimeter square
MPa	Mega Pascal
Wt	Weight
%	Percent
µm	Micrometer
Mm	Millimeter
XRD	X-ray diffraction
SEM	Scanning Electron Microscopy
XRF	X-ray fluorescence
ISO	International Standards Organization
ASTM	American Society for Testing and Materials
Wd	Dry weight
Ws	Soaked weight
Wsp	Suspended weight
Ld	Dry length
Lf	Fired length
SC	Same clay
PK	Pugu kaolin
VK	Kalalani vermiculite
F	Feldspar
DC	Direct current
NM-AIST	Nelson Mandela African Institution of Science and Technology
TBS	Tanzania Bureau of Standards
TANESCO	Tanzania Electric Supply Company

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Insulators are devices which inhibit the flow of current in the electrical circuits when inserted as an electrical barrier between transmission conductors (Islam *et al.,* 2004). Porcelain is a ceramic body achieved by firing clay raw materials in the furnace to high temperatures ranging from 1200 to 1400°C (Oladiji *et al.,* 2010). Porcelain insulators are widely used electrical devices in electrical power transmission system due to their high stability in terms of electrical, mechanical and thermal properties in the presence of harsh environments (Anih, 2005). These are the reasons for their continued use over the centuries despite the emergence of new materials like plastics and composites. Porcelain insulators present a huge base of frequently used insulators for both low and high-stress insulation application (Anih, 2005). Porcelain insulators play an important role in withstanding electrical stress which may result from the working voltage and lightning that may cause flashover on insulators under harsh environmental conditions (Gorur and Burnham, 1999). For the electrical insulation application, the most required properties are the dielectric and mechanical strength (Islam *et al.,* 2004). Dielectric strength measures the ability of an insulator to withstand large electric field strength without electrical breakdown. For high-tension electrical insulation, the dielectric strength has to be greater than 30 kV/mm (Haertling and Buchanan, 1991).

Pugu kaolin, Same clay, vermiculite, and feldspar are locally available ceramic raw materials which are in plentiful supply in Tanzania. The clay deposits have been reported in places like Singino-Lindi, Pugu-Dar Es Salaam, Malangali-Iringa, and Matamba-Mbeya, Same-Kilimanjaro, Arusha and Mwanza (Lobitzer, 1982; Schwaighofer and Muller, 1987). The location, physical and chemical properties have been reported in the literature (Ekosse, 2010; Hamisi *et al.,* 2014; Njau and Park, 2015; Schwaighofer and Muller, 1987; Wiik and Akwilapo, 2003) as well as their suitability as raw materials for the production of useful ceramic tiles (Akwilapo and Wiik, 2003; Hamisi *et al.,* 2014; Kimambo, 2014; Lugwisha, 2006) on the other hand, less is reported for their use for the production of electrical insulators (Moyo and Park, 2014). Despite the availability of local ceramic materials which are in plentiful supply in the country. Tanzania is only manufacturing low voltage insulators at Kilimanjaro Industrial Development Trust (KIDT). Therefore, the work intended to come up and establish high voltage porcelain insulators data so as to enable their immediate production in Tanzania. However, the aim of this study is to evaluate the effect of composition and firing temperature on the dielectric and mechanical strength of the porcelain samples.

1.2 Statement of the Research Problem

Regardless of the availability of potential ceramic raw materials in Tanzania for production of high voltage porcelain insulator, the country still manufactures only low voltage ceramic insulators at Kilimanjaro Industrial Development Trust (KIDT) which are restricted to the low voltage power transmission. As a result, the growing demand for high voltage porcelain insulators in Tanzania is potentially enormous for power transmission and distribution. Consequently, to meet the demand, the country expends much in foreign exchange in importing high voltage porcelain insulators from abroad. While there is plentiful supply of local ceramic raw materials, which can be developed to meet our local needs and reduce cost and overdependence on porcelain insulators imported from abroad.

Since the need for high voltage porcelain insulator is huge in Tanzania. The most desirable electrical properties for high voltage ceramic insulators are the dielectric and mechanical strength (Islam *et al.,* 2004). Ohya *et al.* (1999) reported that a high voltage porcelain insulator should have excellent dielectric and mechanical strength such as tensile strength. To achieve the desired porcelain insulator properties proper sintering of the porcelain body and suitable selection of raw materials composition is required. Since Tanzania local ceramics materials can be employed for electrical insulation application. Therefore, there was a need to evaluate our own clay resources and establish their potential for production of high voltage porcelain insulators. Therefore, the work intended to establish high voltage porcelain insulators data made from locally sourced-ceramic raw materials so as to enable their immediate production in Tanzania. On the other hand, the effect of composition and firing temperature on the dielectric and mechanical strength of the porcelain samples fabricated was also the focus of this study.

1.3 Rationale

The study intended to evaluate the potential of the available ceramic raw materials for production of high voltage porcelain insulators. This is due to the fact that, regardless of the availability of the essential ceramic raw materials for production of high voltage porcelain insulator. Tanzania is still manufacturing only low voltage ceramic insulators at Kilimanjaro

Industrial Development Trust (KIDT) which are restricted to the low voltage power transmission. As a result, the growing demand for high voltage porcelain insulators for power transmission and distribution in Tanzania is potentially enormous. Consequently, Tanzania expends a lot of foreign exchange in importing porcelains insulators while a lot of clay deposits are available in the country which can be developed to meet our local needs.

1.4 Objectives

1.4.1 General Objective

The general objective of the study was to evaluate the dielectric and mechanical strength of high voltage porcelain insulator made from Tanzania local ceramic raw materials.

1.4.2 Specific Objectives

(i) To determine the chemical composition of Pugu kaolin, Same clay, feldspar, and vermiculite.

(ii) To design formulation and fabricating the porcelain green samples by semi-dry pressing method.

(iii) To investigate the effect composition and firing parameters (firing temperature, ramp rate and soaking time) on the dielectric and mechanical strength of the prepared porcelain samples.

1.5 Research Questions

(i) What are the chemical compositions of Pugu Kaolin, Same clay, vermiculite, and feldspar?

(ii) What porcelain green body formulation gave the best requisite properties for high voltage porcelain insulators?

(iii) What is the effect of composition and firing parameters (temperature, ramp rate and soaking time) on the dielectric and mechanical strength of the prepared porcelain samples?

1.6 Significance of the Study

The study provided high voltage porcelain insulators data made from locally sourced-ceramic raw materials which are available in Tanzania. The data will facilitate the immediate production of high voltage ceramic insulators in the country for adequate provision at an affordable price and reduce overdependence on porcelain insulators imported from abroad which are more expensive. The work will promote the creation of jobs due to immediate commercial interest in the porcelain insulators industry development in Tanzania as well as shedding light on the suitability of using Tanzanian Pugu kaolin, Same clay, feldspar, and vermiculite as raw materials for the production of high voltage porcelain insulators.

CHAPTER TWO

LITERATURE REVIEW

2.1 Porcelain Insulators

Porcelains are vitrified ceramic white wares which are used widely in household, laboratory and industrial applications (Olupot, 2006). Porcelain body is achieved by heating clay raw materials in the furnace between firing temperature range 1200 to 1400°C (Oladiji *et al.*, 2010). The porcelain toughness, strength, and translucence are due to the development of glass and the mullite phase within the fired porcelain body. However, the sintering behavior of porcelain body tends to exhibit densification between firing temperature range 1200-1250°C and development of pores above 1250°C (Olupot, 2006). Therefore, porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares application (Olupot, 2006).

Insulators are devices which inhibit the flow of current in the electrical circuits when inserted as an electrical barrier between transmission conductors (Islam *et al.,* 2004). Porcelain insulators maintain the reliability of power transmission system due to their high stability in terms of electrical, mechanical and thermal properties (Okolo *et al.,* 2014). These are the reasons for their continued use over the centuries despite the emergence of new materials like plastics and composites. During high voltage transmission porcelain insulators withstand electrical stress due to working voltage and lightning which may cause flashover of insulators under harsh environmental conditions (Moulson and Herbert, 2003). Porcelain insulators form a large base of the commonly used insulators for both low and high tension insulation application (Anih, 2005).

For the electrical insulation application, the most required properties of the porcelain insulator are the dielectric and mechanical strength (Islam *et al.*, 2004). Dielectric strength measures the ability of an insulator to withstand large electric field strength without failure which has to be greater than 30 kV/mm for high-tension electrical insulation (Buchanan, 2004). According to Ohya *et al.* (1999) a high voltage porcelain insulator should have excellent properties such as dielectric breakdown strength and mechanical strength such as tensile strength. It should have the following chemical composition by weight 35 to 75% SiO_2 and 15 to 55% Al_2O_3. It should have approximately 1.5% of Na_2O, 7% of K_2O, 7% of BaO and less than 3% of MgO and 3% of CaO. The total amount of the last five components should be in the range of 4 to 11 % by weight, however, the amount of Na_2O and K_2O should not be more than 7% by weight (Ohya *et al.*, 1999).

2.2 Ceramic Raw Materials

Clay, feldspar, and quartz are the potential raw materials for the production of porcelain insulators. The properties of porcelain insulators are influenced by variations in the composition of the raw materials, the method of production, and the firing temperature adopted (Olupot, 2006). The raw materials play specific roles in influencing the properties and performance of the final products. Clay provides plasticity and is a source of alumina which together with quartz and alkaline fluxing elements forms mullite and glassy phase during the firing process. Both phases contribute to the improvement of the mechanical and dielectric strength of a porcelain insulator. Feldspar promotes vitrification and densification of the porcelain sample at the end of the firing process. Quartz tends to maintain a porcelain structure as well as regulating the ratio between SiO_2 and Al_2O_3 to form mullite ($3Al_2O_3 \cdot 2SiO_2$). Therefore the composition of the raw materials and the firing temperature influence the physical-chemical properties of the resulting ceramics due to series of transformation which occur within the sintered body (Bragança and Bergmann, 2003).

Vermiculite refers to a group of hydromicas species in which the process of hydration or weathering is completed. Vermiculite is readily available and is found in Kalalani village in Korogwe Tanga and Nyang'wambe village in Mikese Morogoro in Tanzania. Vermiculite melts at 1350^0C and has an optimum sintering temperature of 1260^0C which make it an ideal insulating material. Vermiculite's low density, good thermal and insulation properties as well as chemically inert and fire resistance makes it attractive for use as lightweight aggregate and filler for heat insulation applications (Sutcu, 2015). However, there is a very limited information on the usage of vermiculite on ceramic production (Kornmann, 2007; Valášková and Študentová, 2009).

Pugu kaolin, Same clay, vermiculite, and feldspar are locally available ceramic materials which are in plentiful supply in Tanzania. Information about their location has been reported in the literature in places like Singino-Lindi, Pugu-Dar Es Salaam, Malangali-Iringa, and Matamba-Mbeya, Same-Kilimanjaro, Arusha and Mwanza (Lobitzer, 1982; Schwaighofer and Muller, 1987). The physical and chemical properties of Pugu kaolin, Same clay, and feldspar which are locally available in Tanzania have been reported in the literature (Ekosse, 2010; Hamisi *et al.*, 2014; Lobitzer, 1982; Moyo and Park, 2014; Schwaighofer and Muller, 1987; Wiik and Akwilapo, 2003). Their suitability as raw materials for the production of useful ceramic tiles has been reported (Akwilapo and Wiik, 2003; Hamisi *et al.*, 2014; Kimambo, 2014; Lugwisha, 2006) however, less is reported for their use in electrical insulation application (Moyo and Park, 2014). Therefore, the work intended to evaluate these locally available ceramic materials for high voltage porcelain insulators production. Nevertheless, the effect of their composition and firing temperature on the dielectric and mechanical strength of the porcelain samples was also the focus of study.

2.3 Strength Consideration

Higher strength porcelain insulator is a need for power industry as far as transmission lines and power distribution industry is concerned (Morita and Nozaki, 1997; Sedghi and Noori, 2012). However, it becomes challenging when the porcelain insulator fails to withstand high voltage stress (Jawale and Majhi, 2016). Hence porcelain insulator's strength interest for power transmission and distribution and the wide research on the porcelain materials have resulted in three major hypotheses describing the strength of porcelains materials. These hypotheses were described by Carty and Senapati (1998) as the mullite hypothesis, the matrix reinforcement hypothesis, and the dispersion strengthening hypothesis.

The mullite hypothesis suggests that porcelain strength depends on the interlocking of fine mullite needles. Specifically, the higher the mullite content and the higher the interlocking of the mullite needles, the higher is the strength (Palatzky and Werner, 1958; Zoellner, 1908). Hence, the strength of porcelain depends on the factors that affect the amount and size of mullite needles, like the firing temperature and composition of alumina and silica in the raw materials (Carty and Senapati, 1998).

The matrix reinforcement hypothesis concerns the development of compressive stresses in the vitreous phase as a result of the different thermal expansion coefficients of dispersed particles, or crystalline phases, and the surrounding vitreous phase. The larger these stresses are, the higher is the strength of the porcelain. This phenomenon is known as the pre-stressing effect (Hamano and Hasegawa, 1991; Tomizaki and Sugiyama, 1995)**.**

The dispersion strengthening hypothesis, on the other hand, states that dispersed particles in the vitreous phase of a porcelain body, such as quartz and mullite crystals in the glassy phase, limit the size of Griffith flaws resulting in increased strength (Hasselman and Fulrath, 1966).

The above hypotheses are supported by the works of Maity and Sarkar (1996), Stathis *et al.* (2004), Islam *et al.* (2004) and Carty and Senapati (1998) who reported that the typical strength controlling factors in multiphase polycrystalline ceramics are thermal coefficients of the phases, elastic properties of the phases, volume fraction of different phases, particle size of the crystalline phases and phase transformations**.**

Islam *et al.* (2004) reported that high mullite and quartz content with low glassy phase and absence of microcracks may give the best mechanical properties. However, high amount of SiO_2 may result to a high amount of glassy phase which is detrimental to the development of high mechanical strength. Both dielectric and mechanical properties of ceramic wares are affected by mullite and glassy phases which develop during the sintering process. Nevertheless, high amount of glassy phase may influence the free movement of ions which may result in poor insulation properties of an insulator (Islam *et al.*, 2004).

Stathis *et al.* (2004) reported that bending strength is affected by quartz grain size due to the development of vitreous phase and favorable microstructure. The author reported that both phases are strongly dependent on the particle distribution of quartz. However, the optimum quartz grain size between 5 to 20 μm gave the maximum bending strength. The author observed that the use of coarser grain sizes resulted in the reduction of bending strength due to the development of a detrimental microstructure which affects the mechanical properties.

Olupot (2006) assessed the ceramic raw materials in Uganda for electrical porcelain production. However, the effect of composition on porcelain bodies and the sintering temperature between 1175 °C and 1375^0C was evaluated. The author reported that electrical porcelain body with composition 30% of Mutaka kaolin, 15% of Mukono ball clay, 30% of Mutaka feldspar and 25% of Lido beach flint yields a body with the highest mechanical strength of 72 MPa and dielectric strength of 19 kV/mm when fired at 1250°C. The porcelain insulator's mechanical and dielectric strength were found to decrease with the increase of the firing temperature. The author observed the decrease of undissolved quartz and the increase of glass content and development of pores at the high sintering temperature. However, mullite content did not change at temperatures above 1200°C though significant changes in mullite crystals morphologies in the sample were observed. Maximum vitrification and small closely packed mullite needles microstructure gave the best mechanical and dielectric strength of porcelain insulators.

Islam *et al.* (2004) studied the structure-property relationship in high-tension ceramic insulator fired at high temperature. The bending and the dielectric strength were measured on various samples fired at 1350^0C. The authors reported that the bending strength and the dielectric strength of ceramic insulator at 1350^0C were found to be 757 kg/cm^2 and 28.36 kV/mm which are not good for high tension ceramic insulator. The author gave reasons for low dielectric and mechanical strengths. The author reported that the bending and the dielectric strength of the ceramic insulator were affected by the mullite phase and the quartz particle. The undissolved quartz maintains ceramic structure and disconnects the conductivity within the insulator whereas the mullite needles strengthen the insulator. However, the glassy phase was observed to reduce the bending and dielectric strength of ceramic insulator when its amount was quite high. The author reported that when the presence of glassy phase is high in the structure facilitate free movement of Na^+, K^+, Al^{3+}, and Li^+ which increases the conductivity. The presence of microcracks in the ceramic insulator affects the dielectric and mechanical properties of ceramic insulator.

Oladiji *et al.* (2010) investigated the development and production of porcelain insulators from locally sourced materials in Nigeria. By varying the composition of kaolin, ball clay, feldspar, and quartz the physical-mechanical and electrical properties of the samples of porcelain insulators were investigated to evaluate their suitability for mass production and commercial viability. It was observed that the physical-mechanical and electrical properties varied when there was the increase of kaolin content and reduction of feldspar. However, the sample with composition of 33% Kaolin, 15% ball clay, 32% feldspar and 20% quartz was found to possess the highest failing load of 8 kN, corresponding to water absorption (1.55%), porosity (4.64%), bulk density (1.73 g/cm^3), with appreciable insulation resistance of 6630 Mega ohms at injection of 5000 volts. The investigation had shown that high-quality electrical porcelain insulators could be achieved from locally sourced materials. Nevertheless, the author recommended that investigation of the internal structure of clay or porcelain particles, before and after firing to determine their effect on the physical, thermal and electrical properties of porcelain insulators should be done.

Moyo and Park (2014) characterized the ceramic raw materials from Tanzanian deposits in order to investigate their potential as raw materials for the production of electrical insulators. The increase of Pugu kaolin beyond 48% and reducing Kilimanjaro quartz content below 6% led to the reduction of electrical insulation and bending strength. However, the composition of 48 % Pugu kaolin, 46% feldspar and 6% quartz gave the highest strength of 53.525 MPa and the insulation resistance of 34 812 Mega ohms at injection of 1000 volts. The study showed that high-quality electrical insulator may be achieved from Tanzania originated ceramic materials.

Olupot (2006) reported that there are several modifications which have been done on the triaxial porcelain system, which have proven to be successful such as the replacement of clay with aluminous cement (Tai and Jinnai, 2002), substitution of feldspar with nepheline syenite (Esposito *et al.,* 2005), use of recycled glass powder to replace feldspar to reduce firing temperature (Bragança and Bergmann, 2003) and use of fluxes such barium carbonate and magnesium dioxide to increase electrical porcelain strength (Sedghi *et al.,* 2012).

Sedghi *et al.* (2012) studied four fluxes, nepheline syenite, talc, manganese dioxide, and barium carbonate used to produce porcelain insulators with 30% alumina and then their electrical and mechanical properties were investigated. The author reported that adding 1% barium carbonate, gave the maximum bulk density, bending strength and electrical strength up to 2.7 g/cm^3, 1608 kg/cm^2 and 34 kV/mm. The increase of electrical porcelain strength may be due to melting phase in the body during sintering process which promoted better sintering, porosity removal and formation of suitable phases in the body such as including mullite.

Jawale *et al.* (2016) studied the use of zirconium oxide as a doping agent to analyze bending strength and electrical strength of the three samples at 1200^0C. The author reported that adding 10% of ZrO_2 in the composition of electrical porcelain gave the bending strength of 70 MPa and the dielectric strength of 35 kV/cm. So bending and dielectric strength increased by increasing zirconium oxide content due to tetragonal phase form of zirconium oxide which is the best phase of having good strength.

On the basis of the above previous literature studies, the current study focused on the evaluation of Pugu kaolin, Same clay, vermiculite and feldspar as the ceramic raw materials for the production of high voltage porcelain insulators. However, the evaluation of the effect of composition and firing temperature on the dielectric and mechanical strength of the porcelain samples made from Tanzania ceramic raw materials was also the focus of the study.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Materials Collection

The study involved ceramic raw materials from Tanzanian deposits called Pugu kaolin from Pugu Dar es Salaam, Same Clay from Same Kilimanjaro, and Vermiculite from Kalalani Korogwe Tanga and Mikese at Nyang'wambe village in Morogoro region. Pugu Kaolin sample was collected from the Pugu Hills, 35 km west of Dar es Salaam, Same Clay and feldspar from Same, Kilimanjaro region in the northern zone of Tanzania, and Vermiculite samples were collected from kalalani village south-east of Korogwe Tanga and in Mikese at Nyang'wambe village in Morogoro region.

Vermiculite, Mikese Morogoro

Same clay, Same-Kilimanjaro

Vermiculite, Kalalani Tanga

Pugu kaolin, Pugu Dar- es Salaam

Figure 1: Pictures of raw materials collected

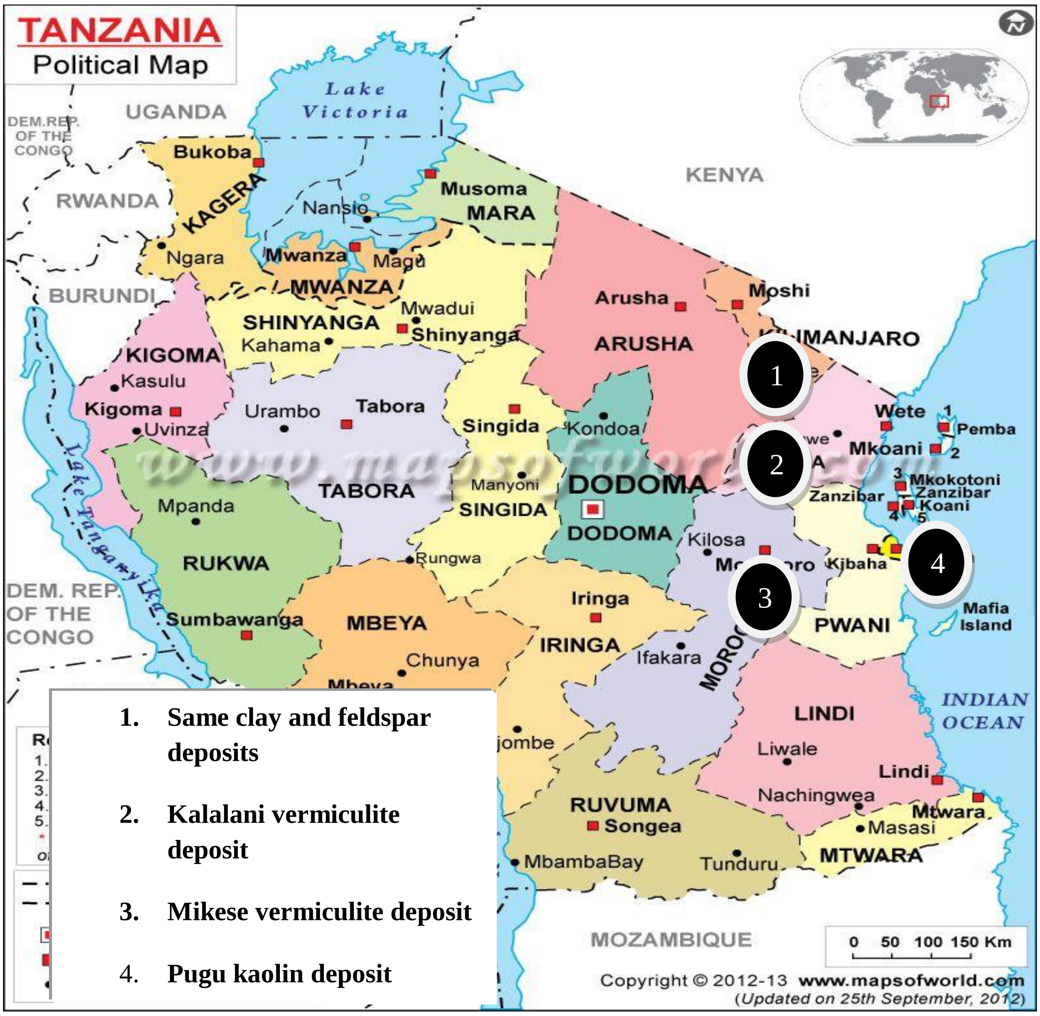


Figure 2: Map of Tanzania showing location of ceramic raw materials studied.

3.2 Materials Preparation

Pugu kaolin (PK), Same clay (SC), Kalalani vermiculite (VK) and feldspar (F) were crushed by using a WEDAG JAW GRANULATOR to reduce their sizes; afterward, they were milled by using stainless steel ball mills for the duration of 3 hrs for each sample. The powder size of the raw materials with less than 106 µm was achieved by using sieve shaker (Model RX-29-10 digit) manufactured by W, styler Inc. in the United States of America and a sieve shaker (Model AS200 digit) manufactured by Retsch Inc. Germany.

3.3 Determination of the Chemical Composition of Ceramic Raw Materials

The chemical composition of Pugu kaolin, Same clay, and vermiculite were done by using X-Ray Fluorescence (XRF) PANalytical, Model: Minipal4 (PW4030)-Rh X-Ray Tube, 30 kV, 0.002 mA. The XRF results are presented in Table 4.

3.4 Formulations of Ceramic Raw Materials

A formulation was achieved by varying the compositions of Pugu kaolin (PK), Same clay (SC) and Kalalani vermiculite (VK) and feldspar (F) in order to achieve a good alumina-silica ratio to influence mullite phase formation during sintering. During formulation, both samples were measured by using electric beam balance at the Nelson Mandela African Institution of Science and Technology Laboratory. Mullite is a very important phase in promoting the mechanical and dielectric properties. The increase in mechanical strength seems to be correlated with mullite content (Akwilapo and Wiik, 2003). The mullite hypothesis suggests that porcelain strength depends on the interlocking of fine mullite needles. The higher the mullite content and the higher the interlocking of the mullite needles, the higher is the strength. Hence, the strength of porcelain depends on the factors that affect the amount and size of mullite needles, like the firing temperature and composition of alumina and silica in the raw materials (Usman, 2015).

Table 1: Samples of Interest

Sample	Components of Interest	Concentration in Percentages (%)
PK	SiO_2	60.0
	Al_2O_3	30.3
SC	SiO_2	60.4
	Al_2O_3	13.9
VK	SiO_2	26.3
	Al_2O_3	13.0
F	SiO_2	57.1
	Al_2O_3	14.0

Table 2: Determination of Alumina Silica Ratio

Sample	Al_2O_3	SiO_2	$Al_2O_3:SiO_2$
P1	19.1	47.8	1:2.5
P2	13.6	47.9	1:3.5
P3	17.8	50.95	1:2.7
P4	19.4	59.2	1:3.1

Table 3: Porcelain Bodies Formulations in Percentages Weight (%)

Sample	Pugu kaolin	Same Clay	vermiculite	Feldspar
P1	30	0	30	40
P2	0	30	30	40
P3	20	20	20	40
P4	50	35	0	15

3.5 Fabrication and Drying of Porcelain Green Samples

Four (4) porcelain compositions were formulated by following the procedures in Fig. 3 and varying the compositions of raw materials as shown in Table 4. The powder mixtures were wetly homogenized in a laboratory milling jar for 30 mins to obtain the normal size distribution. Afterwards, the powder mixtures were uniaxially compacted into the rectangular shape, at 10 MPa. The molded rectangular specimens with dimensions 160 mm x 40 mm x 10 mm were seasoned at a room temperature for 5 days. This was done to remove water at a slow rate enough to prevent shrinkage and cracks that could occur due to rapid drying. The specimens were turned once per day while they dry to prevent warping. The four fabricated rectangular ceramic green bodies were oven dried at the temperature of 110^0C for 24 hrs with the oven model: 10 AF-1 manufactured by Humboldt Inc, in the USA.

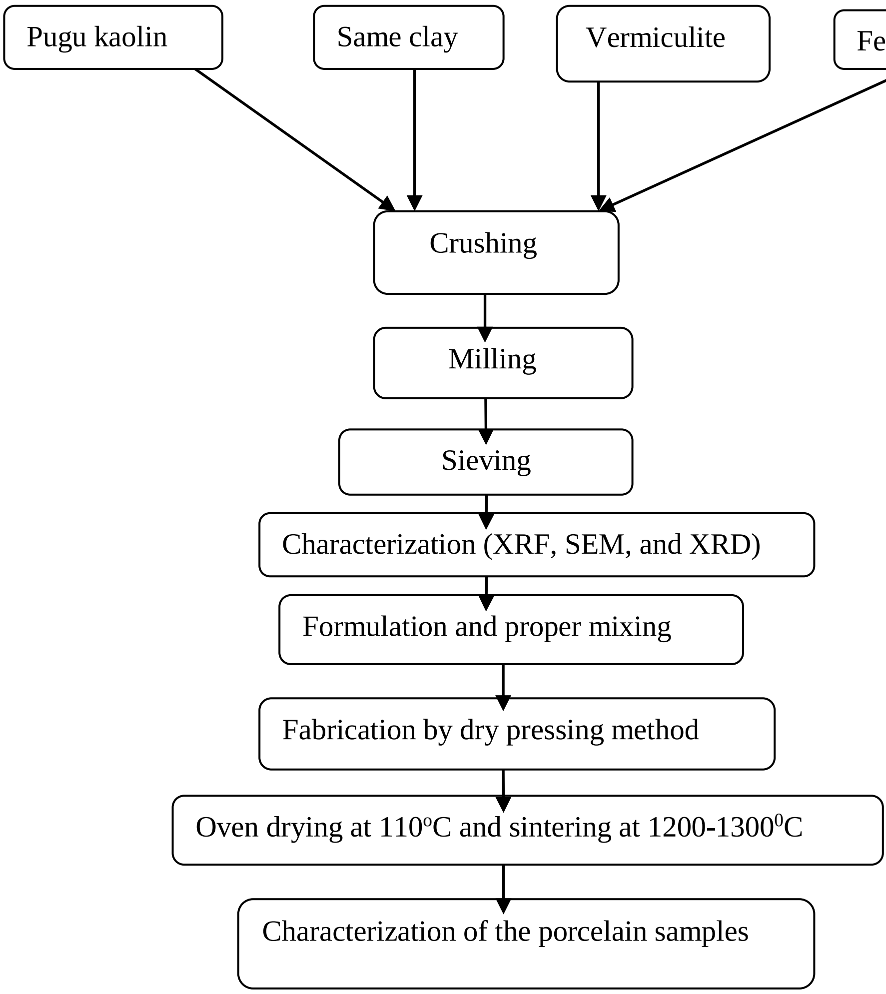
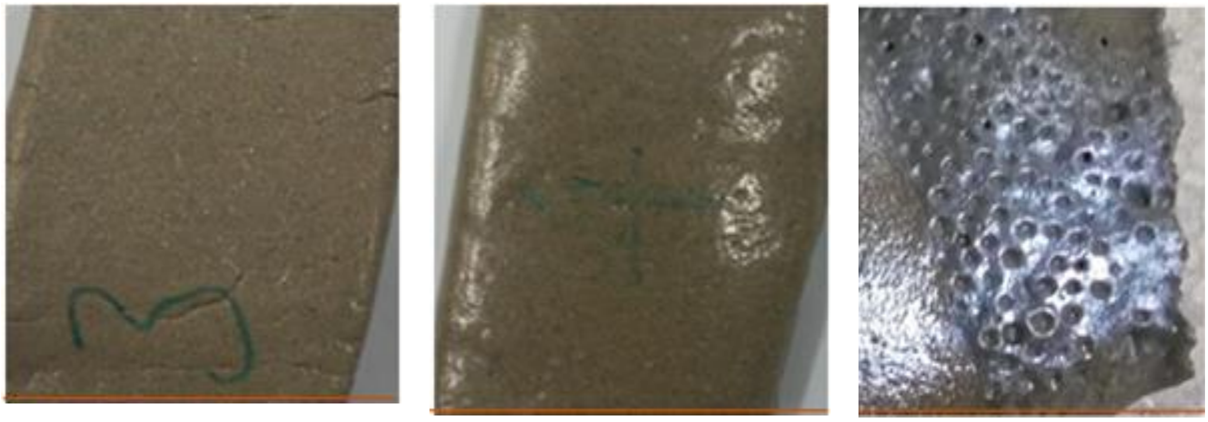


Figure 3**:** Flow diagram for the production of porcelain samples.

3.6 Sintering of the Dried Porcelain Green Samples

Sintering was done by Carbolite box furnace Model: RHF 14/8 manufactured by Keison products Inc, UK. The dried rectangular ceramic samples were sintered at 1200 to 1300°C for 1.5 hrs at the ramp rate of 10°C/min in each firing. After firing the sintered porcelain samples were left to cool at room temperature. Each of the porcelain samples was subjected to physical-mechanical properties and dielectric strength analysis. Sintering is a process of consolidation of particles under the temperatures below the melting point (Kitouni and Harabi, 2011). It involves the removal of the pores between starting particles accompanied by shrinkage of the ceramic material and compaction of powder at elevated temperature (Callister and Rethwisch, 2012; Reed, 1995). When processing ceramic products, sintering of the ceramic material is considered to be an important stage to adjust several desired properties of the final product and occurs in general through the liquid-phase formation, thus the presence of components such as low-melting clays is very important (Alcântara *et al.*, 2008). During sintering, changes occur in the microstructure because of decomposition or phase transformations. Three major changes commonly occur during sintering. The sintering behavior of the fired samples was evaluated by using the vitrification curves, which present the variation in properties of a ceramic as a function of firing temperature for otherwise identical firing schedules in terms of heating rates, cooling rates and holding times at peak temperatures (Kitouni and Harabi, 2011). Vitrification curves allow establishing the optimum firing temperature and the firing range at which the open porosity reaches a minimum, which usually corresponds to higher values of mechanical strength (Kasrani *et al.*, 2016).



(a) Porcelain sample sintered at 1200^0C.

(b) Porcelain sample sintered at 1250^0C.

(c) Porcelain sample sintered at 1300^0C.

Figure 4: Showing porcelain samples sintered at the different temperature.

Porcelain sample in (a) shows minimum vitrification, densification and considerable amounts of cracks while in (b) shows maximum vitrification and densification at 1250^0C as a result of consolidation of particles and melting of feldspar (c) shows bloating effect caused by development and expansion of closed pores in the porcelain sample at 1300^0C.

3.7 Testing of Physical Properties of Porcelain Samples

Water absorption, porosity and bulk density was performed on ceramic samples fired at 1200 to 1250^0C using Archimedes method in accordance with (ASTM, 1999).

3.7.1 Water Absorption

The dry weight (W_d) of the sintered porcelain samples was taken before the samples were boiled in distilled water for 5 hrs. The samples were then removed and the new weight after boiling (W_s) was recorded. The water Absorption (A) was calculated by the expression given below (ASTM, 1999).

$$A = \frac{Ws - Wd}{Wd} X100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.7.2 Apparent Porosity

The dry weights (W_d) of the sintered porcelain samples were taken before the samples were boiled in distilled water for 5 hrs. The porcelain samples weight after boiling (*Ws*) was measured. The porcelain samples were then suspended in water using beaker placed on a balance. The suspended weights (*Wsp*) were then measured. The expression for apparent porosity is given by the equation (ASTM, 1999).

$$\text{Apparent Porosity} = \frac{Ws - Wd}{Ws - Wsp} X100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

3.7.3 Bulk Density

The dry weights (W_d) of the sintered porcelain samples were taken before been boiled in distilled water for 5 hrs. The porcelain samples weight after been boiled (Ws) were recorded. The porcelain samples were then suspended in water using a thin thread in a beaker placed in a balance. The suspended weight (W_{sp}) for each porcelain sample was measured. The bulk density, B (g/cm^3), of the specimen, was calculated from the equation (ASTM, 1999).

$$\text{B} = \frac{Wd}{Ws - Wsp} X \text{ } Density \text{ } of \text{ } Water \ldots\ldots\ldots\ldots (3)$$

3.8 Mechanical Properties Testing

3.8.1 Linear Shrinkage

The length before firing at this stage was taken as dry length (L_d). The samples were then fired to 1200 to 1250°C for 1.5 hours. The samples were cooled to room temperature and the fired length (L_f) was recorded. Then the linear shrinkage was calculated from the equation below and expressed as a percent according (ASTM, 1988).

$$\text{Linear Shrinkage} = \frac{Ld - Lf}{Ld} X100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

3.8.2 Bending and Compressive Strength Measurement

Bending and compressive strengths were measured at Twiga Cement Company Limited in Dar es Salaam, Tanzania by compressive strength tester (Model MEGA 10-200-10 DS) manufactured by Prufsyteme Inc. in Germany, 2001. The bending and compressive strength testers were calibrated by Tanzania Bureau of Standards (TBS). Bending strength results were obtained by a three-point testing. The load was applied uniaxially on porcelain rectangular samples until failure occurred. Then the rectangular porcelain samples were placed on a compressive tester and load was applied uniaxially by turning the hand wheel until failure occurred. The manometer readings for bending and compressive strength were recorded in MPa.

3.9 Dielectric Strength Measurement

The dielectric strength test was done at Tanzania Electric Supply company limited (TANESCO), head office in Dar es Salaam. The dielectric strength test was done by DC high voltage tester (Model Megger 220163-47) manufactured by Biddle Instruments Incorporation in the USA having a maximum output voltage of 160 kV. The dielectric tester is calibrated by Mark L from Biddle Instruments Incorporation in the USA. During dielectric strength measurement, the voltage was applied to the sintered porcelain sample using two electrodes at the rate of rising of 1 kilovolt per second until a cracking sound was heard from the porcelain sample. The reading for each test porcelain sample was recorded in kV/mm.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterization of the Ceramic Raw Materials

The XRF results revealed that all raw materials have the higher content of silica than alumina in their composition as it appears in Table 4. Same clay and feldspar have considerable higher content of alkaline oxide, K_2O than other deposits. The alkaline oxide (K_2O and Na_2O) from Same clay and feldspar promote liquid phase formation during firing process. The alkaline oxides (K_2O and Na_2O) contribute to vitrification and densification at higher temperatures due to the formation of a liquid phase. The alkaline oxides (K_2O and Na_2O) play a significant role towards vitrification, phase transformation and mullite grain growth in the porcelain body as reported in the works of the authors (Chaudhuri, 1974; Das and Dana, 2003), where the presence of feldspar and alumina-silica mixture was observed to enhance porcelain properties. Vermiculite has the higher content of hematite by 38.24% compared to feldspar with 8.08% and Pugu kaolin with 3.95%. The amount of TiO_2 was found to be 3.79% in feldspar and 3.04% in vermiculite. The literature reports that small amount of coloring oxides such as Fe_2O_3 less than 0.9% may be accepted for porcelain wares production (Acchar and Dultra, 2015) . However, a considerable high amount of TiO_2 and Fe_2O_3 in vermiculite and feldspar may not be accepted as they impart yellowish and reddish color in porcelain wares. A high percentage of Fe_2O_3 in vermiculite may rule out its application in the production of porcelain wares due to decrease and change in the composition of glassy phase caused by the formation of FeO_4 unless the clay is beneficiated.

The results of the chemical composition analysis from the current study are close to those of previous studies as reported in the literature of Akwilapo and Wiik (2003), Kimambo (2014), Hamisi *et al.* (2014) and Moyo and Park (2014) that high fraction of silica and alumina were observed . However, there is slight variation in the chemical composition of the materials presented in the current and previous studies. This might be due to geological net-transfer reactions, chemical weathering, and transportation history of the ceramic materials under study which make the chemical composition of the deposits to vary from time to time.

Table 4: Chemical Composition of the Raw Materials in percentage (%)

Sample	SiO_2	Al_2O_3	TiO_2	Cr_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	LOI	Total
VK	26.3	13.0	3.04	0.20	38.24	0.19	2.90	4.85	0.06	5.85	5.37	100
F	57.1	14.0	3.79	0.922	8.08	0.32	0.01	1.0	0.20	12.09	2.488	100
PK	60.0	30.3	0.14	0.097	3.95	0.021	0.00	0.39	0.00	2.14	2.962	100
SC	60.4	13.9	1.22	0.00	1.40	0.00	0.00	0.00	0.04	22.6	0.44	100

4.2 Mineralogical Composition and Phase Analysis of the Raw Materials

The mineralogical composition and phase analysis for each ceramic raw material was done using X-ray diffractometer Model: Bruker D2 PHASER-40 kV/44 mA. The X-ray diffraction patterns of the raw materials sintered at 1200^0C are presented in Fig. 5. Pugu kaolin sample was found to contain clay mineral kaolinite ($Al_2Si_2O_5(OH)_4$) and non- clay mineral quartz (SiO_2). Same clay was found to contain kaolinite and quartz whereas feldspar was found to contain and tridymite whereas expanded vermiculite contained pure crystalline vermiculite which does not contain a hydrated phase. The XRD results show that phase compositions of Pugu kaolin and Same clay have kaolinite which was a source of alumina (Al_2O_3) during sintering of the porcelain samples.

Alumina supplied by the kaolinite forms alumina-silicate compound at the end of the sintering process as mullite phase ($3Al_2O_3{\cdot}2SiO_2$) which increases the mechanical strength (Acchar and Dultra, 2015) . The raw materials were found to have quartz and tridymite, the source of silica (SiO_2) which maintains a porcelain structure during sintering. It is evident that alumina (Al_2O_3), silica (SiO_2) and fluxing agents (K_2O and Na_2O) supplied by raw materials form glassy and mullite phase at the firing temperature of 1200 to 1250^0C.The glassy and mullite phase [(K, Na) $_2$O-Al_2O_3-SiO_2)] promote maximum vitrification and densification which improve the mechanical and dielectric properties of porcelain samples under study as it shown in Fig. 6.

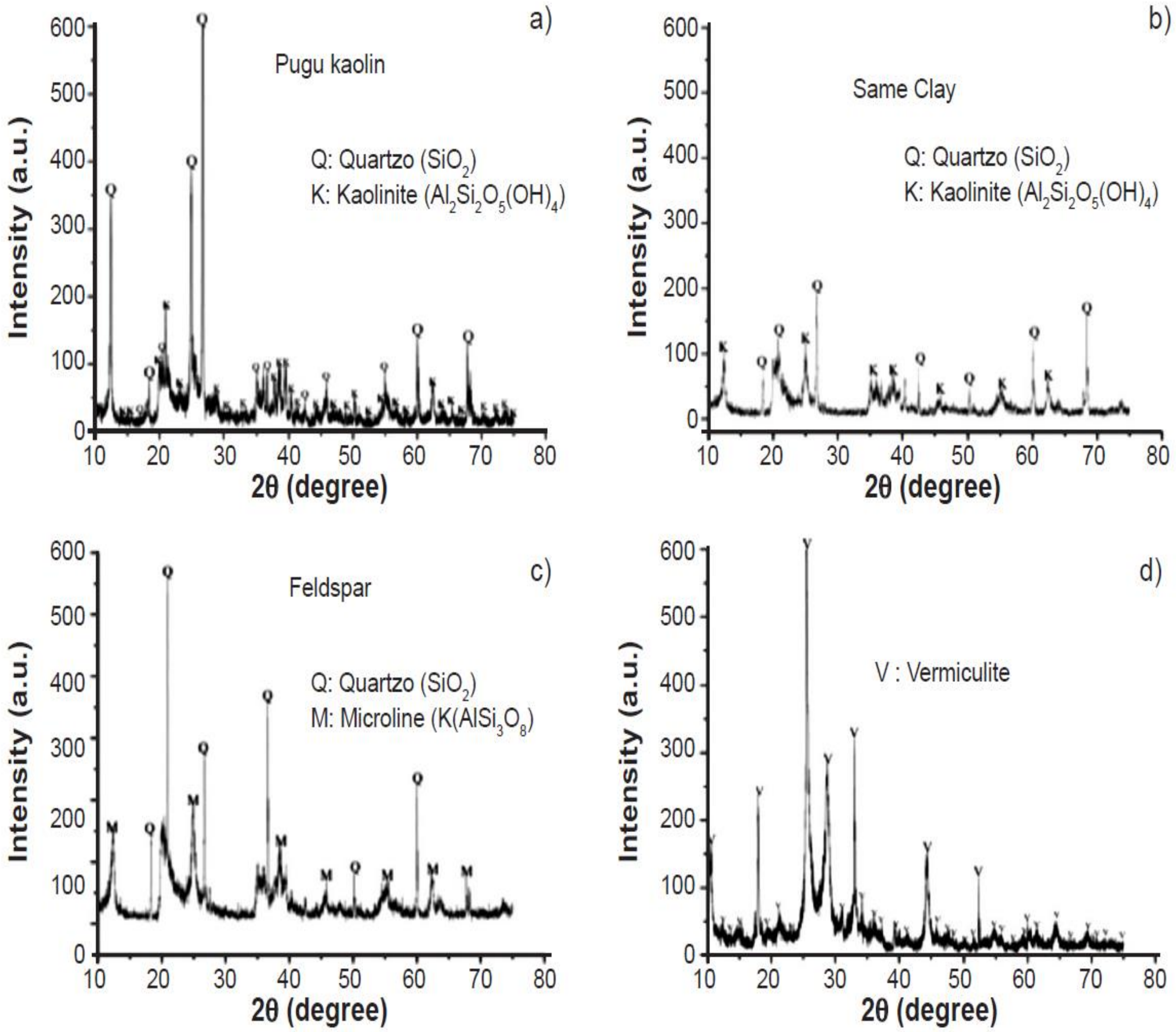


Figure 5: X-ray diffractograms of (a) Pugu kaolin (b) Same clay (c) feldspar and (d) vermiculite.

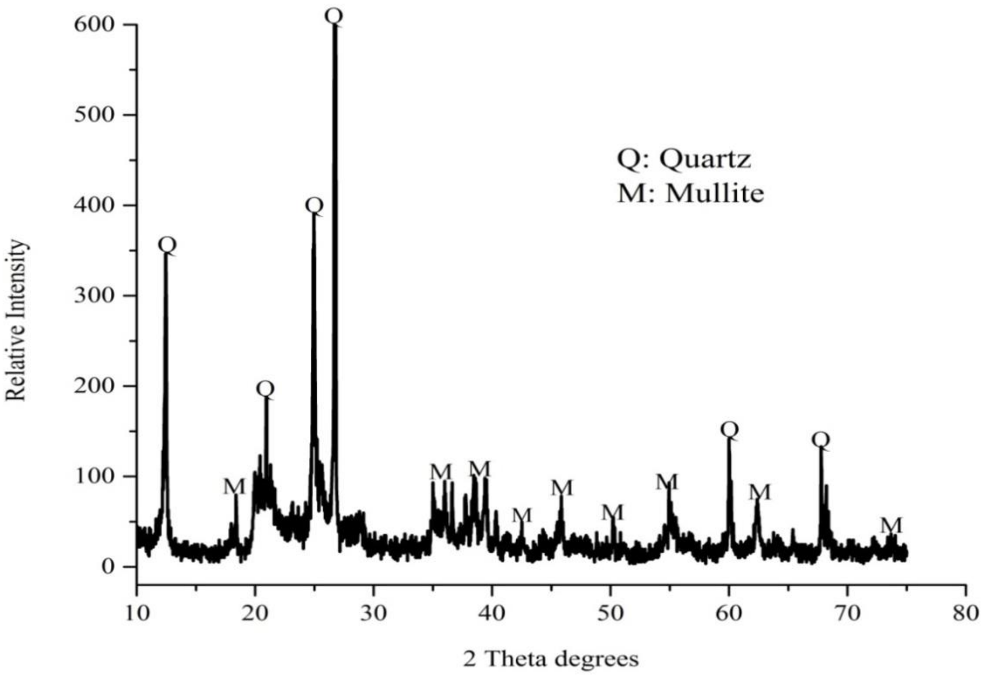


Figure 6: X-ray diffractogram of Porcelain sample fired at 1250^{0}C

4.3 Surface Morphology Analysis of the Porcelain Samples

The examination of the surface morphology was done by Scanning Electron Microscope (SEM) Model: JEOL JSM-6335F having a resolution of 10 µm at 2 kV. Figure 7, evidences the progressive change in the densification on the surface of porcelain samples after the sintering process was completed. The SEM micrographs 7a) and 7b) show densification of the porcelain sample P-1 and P-2 sintered at 1200^{0}C. The SEM micrographs 7c) and 7d) show the progressive change in densification on the surface of porcelain sample P-3 at the sintering temperature range 1200^{0}C to 1250^{0}C. The sintering process reduced the pores and promoted high dielectric and mechanical properties of the porcelain samples.

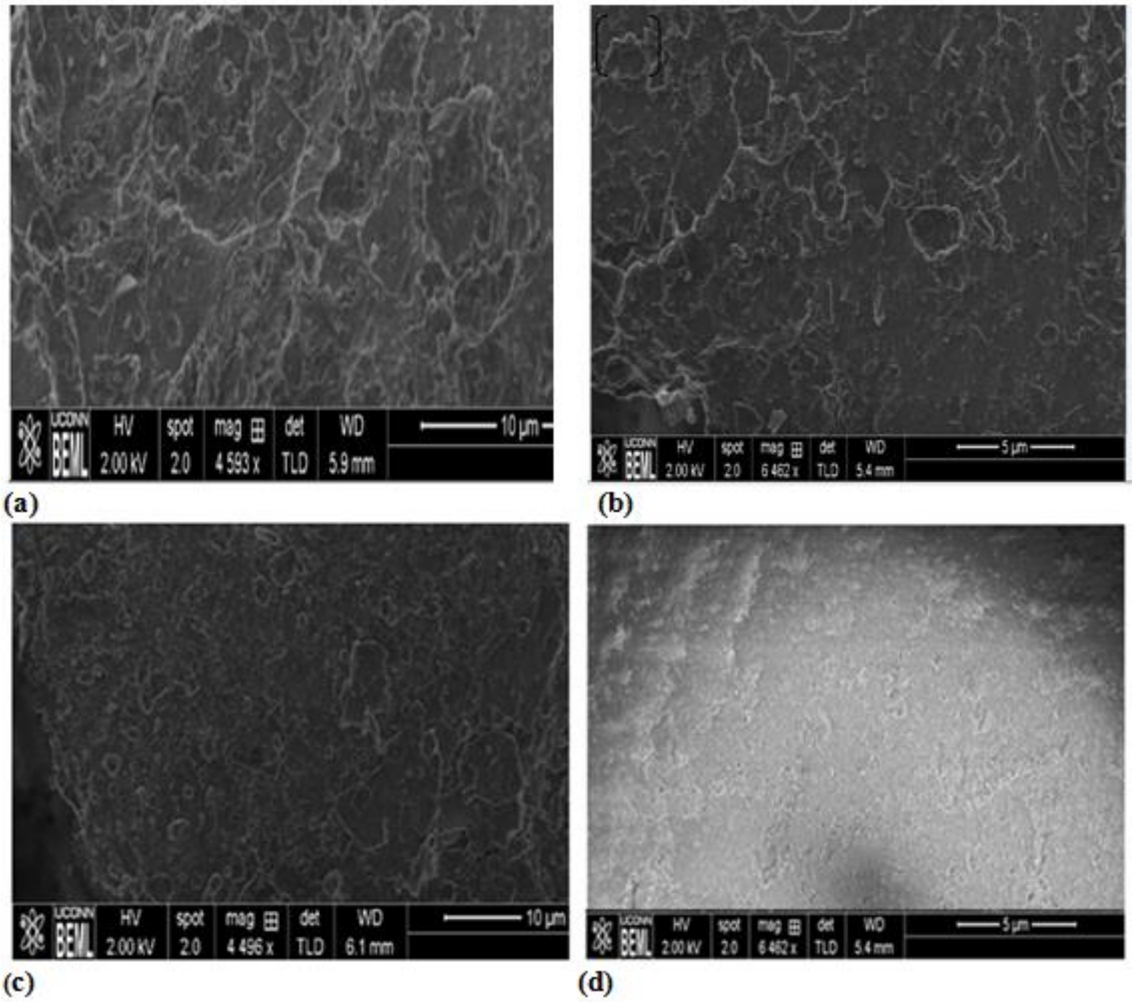


Figure **7:** SEM micrographs showing densification of a porcelain samples

4.4 Characterization of the Porcelain Samples

4.4.1 Physical Properties Analysis

The results for physical properties of porcelain samples are shown in Fig. 8. Water absorption and apparent porosity values were observed to decrease and bulk density to increase in porcelain samples P-1 and P-3 compared to their counterparts P-2 and P-4. This might be due to an increase of the firing temperature and high concentration of feldspar which promoted the formation of the liquid phase. The liquid phase formed during sintering fills the pores thus blocking the open porosity, decreases water absorption and increase the bulk density due to maximum vitrification range and densification of porcelain samples at 1250^0C. The trend was reported in the works Akwilapo and Wiik (2003), Kimambo (2014) and Matthew and Fatile (2014). Both authors reported that increase of firing temperature and high percentages of feldspar results to enough liquid phase or maximum vitrification which fills the open porosity, decrease water absorption and increases bulk density. However, lower feldspar content influences low liquid phase which results in high porosity increases water absorption and lowers bulk density due to low glassy phase. The porcelain samples P-1 and P-3 possess the lowest absorption values of about 0.31% to 0.38%, which are within Standard requirements for electrical porcelain insulators as International Standard Organization recommends water absorption to be less than 0.5%. However the bulk densities result for porcelain samples P-1, P-2 and P-4 are within established standards for porcelain body (1.71 to 2.1 g/cm^3) (Lugwisha, 2011). Yet the bulk density of porcelain sample P-2 is low regardless of having high percentages of feldspar. This might be caused by bloating effect which influences the development of pores within a porcelain sample structure which influenced low densification of the sample. The variation of water absorption, apparent porosity and bulk densities from the current study might have been caused by the method of production, chemical and mineralogical properties of the raw materials involved.

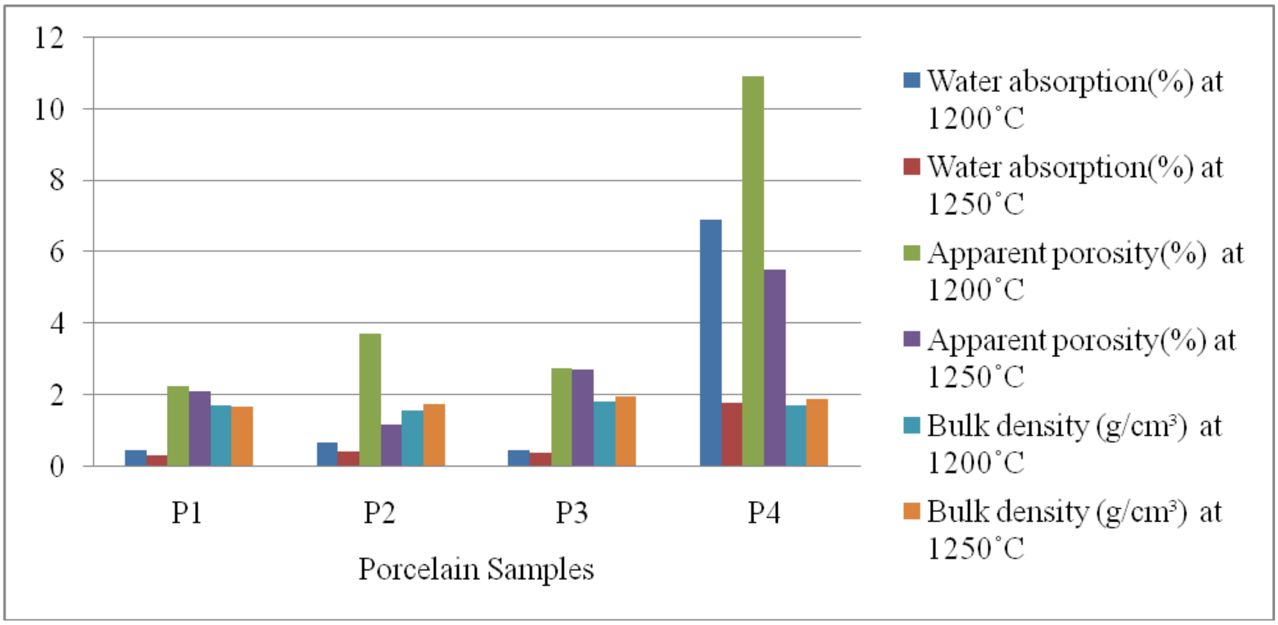


Figure 8: Effect of composition and firing temperature on water absorption, apparent porosity and bulk density of porcelain samples.

4.5 Mechanical Properties Analysis of Porcelain Samples

4.5.1 Linear Shrinkage Analysis

Figure 9, shows the changes in linear shrinkage when the electrical porcelain samples were fired at the temperature of 1200 to 1250^0C. Linear shrinkage was observed to be increasing during firing temperature at 1250^0C for porcelain samples P-3 and P-4. The trend might have been attributed to the high concentration of feldspar and firing temperature which promoted maximum vitrification and densification which trampled the porcelain samples to influence maximum linear shrinkage. Matthew and Fatile (2014) reported that feldspar plays the role of a fluxing agent in porcelain body thereby help to increase vitrification and shrinkage. Optimum vitrification is achieved in porcelain when there is maximum linear shrinkage (Márquez and Romero, 2008). The low linear shrinkage indicates the low vitrification range and densification achieved in porcelain structure. The samples with low shrinkage values are established to be accompanied by high strength comparing to those with high values of shrinkage. Higher shrinkage values may result in cracking of the porcelain structure which may cause the decrease in strength of the porcelain body.

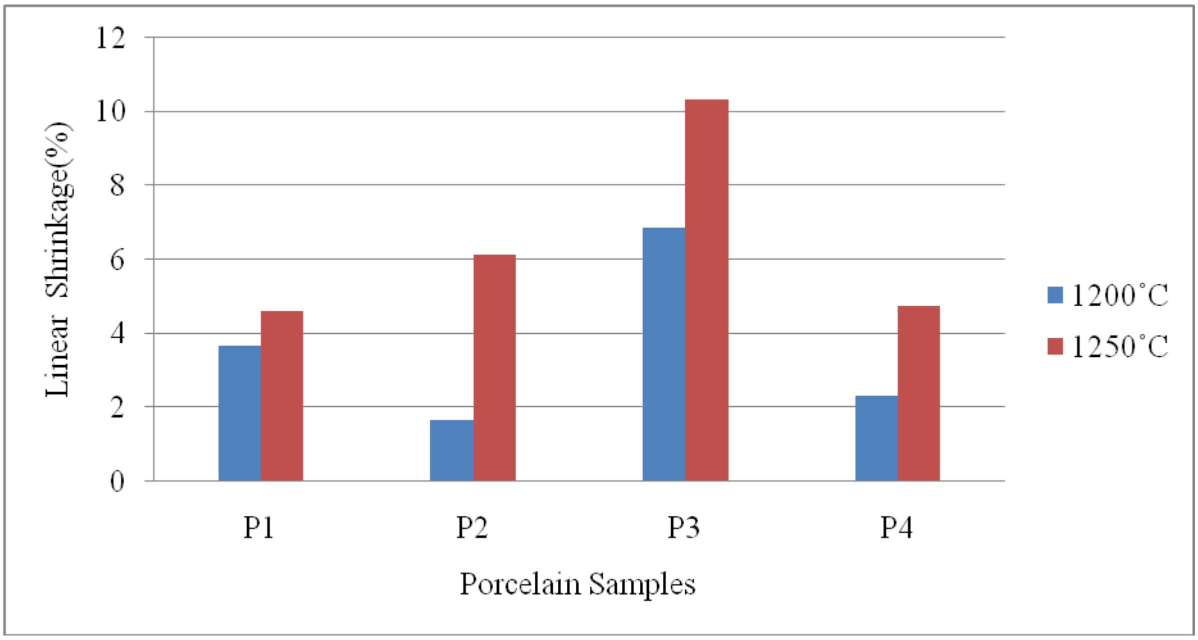


Figure 9: Effect of firing temperature on linear shrinkage on porcelain samples.

4.5.2 Bending and Compressive Strength Analysis

The results for bending and compressive strength are shown in Fig. 10. The porcelain samples P-1 and P-3 exhibited higher values than their counterparts P-2 and P-4. The trend may be due to high firing temperature and concentration of feldspar which promoted maximum vitrification and densification which trampled the porcelain samples to increase their strengths in absence of microcracks. Feldspar melts at a relatively low temperature which forms a molten phase which fills the pores and decreases the porosity. The increase of densification improves the bending and compressive strength of porcelain samples. However, porcelain samples P-2 and P-4 have low values for bending and compressive strength due to low feldspar content which inhibited maximum vitrification and densification of porcelain samples. The trend was reported in the works of Norris and Thorpe (1979), Akwilapo and Wiik (2003), Kimambo (2014) and Matthew and Fatile (2014). The authors reported that mechanical strength increased with the increase of firing temperature and high feldspar content in porcelain samples. High feldspar content influences formation of the liquid phase which fills the pores and eventually decreases porosity and increases mechanical strength. Theoretically, a maximum mechanical strength may be obtained when the apparent porosity decreased to zero (Kitouni and Harabi, 2011). The porcelain samples P-1 and P-3 possess the highest mechanical strength which is close to the Standard requirements for electrical porcelain of 35 N/mm^2 as recommended by International Standards of Organization (ISO).

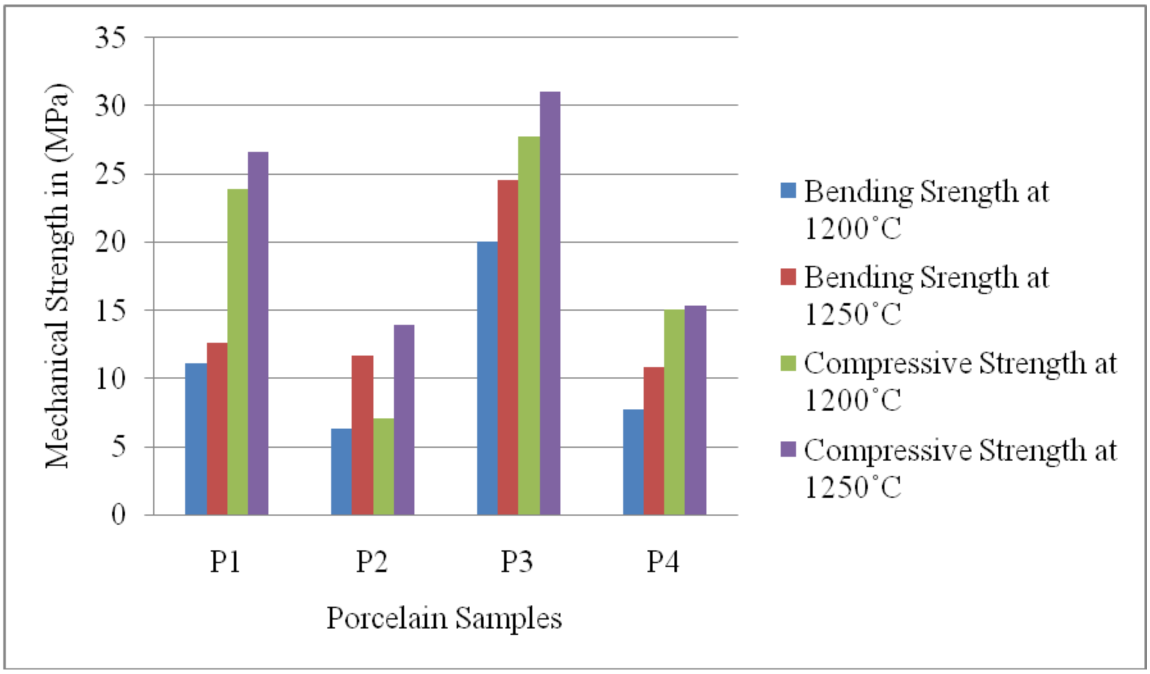


Figure 10: Effect of composition and firing temperature on the mechanical strength of porcelain samples.

4.6 Dielectric Strength Analysis

Figure 11, presents the results for dielectric strengths of porcelain samples at different firing temperature. The study shows that the best value for dielectric strength is exhibited by P-3. However, porcelain samples P-1, P-2 and P-3 have exceeded the dielectric strength value of 30 kV/mm for high tension electrical insulation. This might have been caused by maximum vitrification and densification achieved by the porcelain samples at the end of firing process. The liquid phase formed during sintering promoted proper filling of the pores and increased densification which has influenced the high dielectric strength of porcelain sample P-1, P-2, and P-3. However, their counterpart sample P-4 has low dielectric strength due to low vitrification exhibited by it. Low vitrification failed to suppress and reduce closed porosity after firing which caused low densification and later low dielectric strength due to low percentages of feldspar content. This was reported in the work of Okolo *et al.* (2014) that a porcelain insulators with 30% amount of feldspar gave the optimal dielectric strength while that with 15% of the amount of feldspar gave low dielectric strength. Low concentration of feldspar results in poor vitrification leading to cracking and disintegration of the porcelain product after firing. Olupot (2006) studied the effect of composition on porcelain bodies and the sintering temperature between 1175 °C and 1375 °C. The composition was very similar to the basic porcelain composition. The author found that a mixture consisting of 30% Mutaka kaolin, 15% Mukono ball clay, 30% Mutaka feldspar and 25% Lido beach flint yields a body with the highest dielectric strength of 19 kV/mm at 1250°C. Firing beyond 1250°C resulted in progressive deterioration of the properties of the samples due to less content of glassy phase. However, the current study has given the highest dielectric strength compared to previous studies.

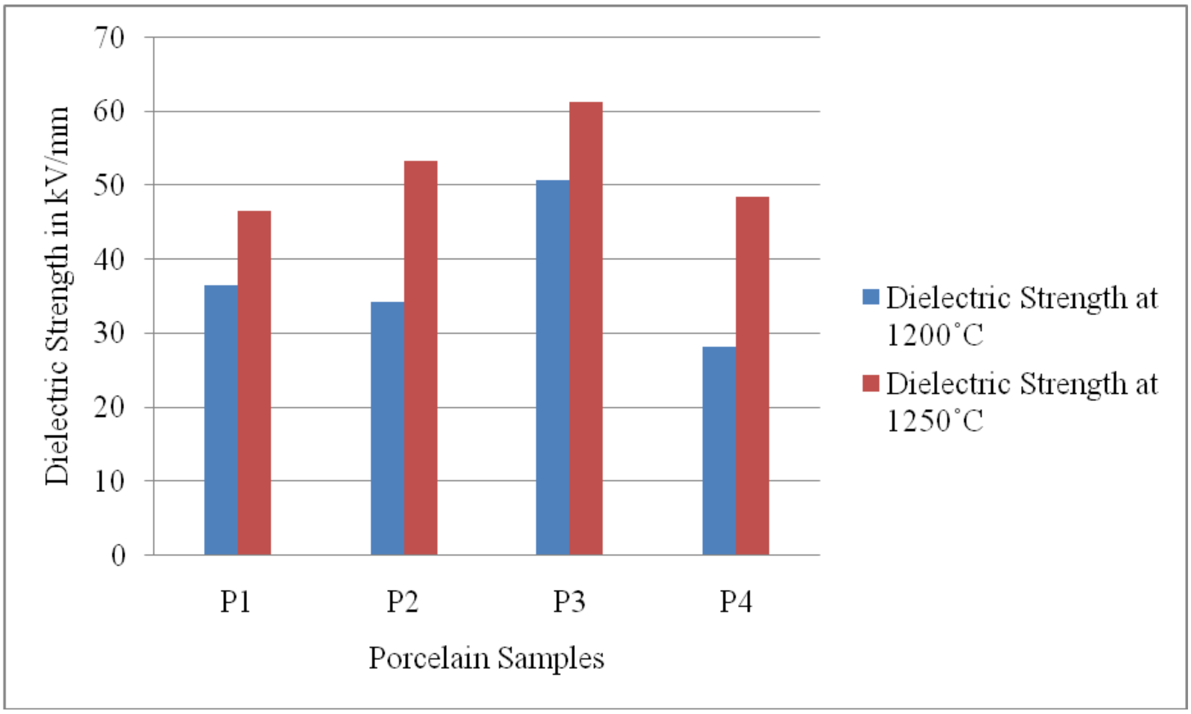


Figure 11: Effect of composition and firing temperature on the dielectric strength of porcelain samples.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Results from characterization studies show that the ceramic raw materials, Pugu kaolin and Same clay have the higher content of silica and alumina in their composition. Same clay and feldspar have considerable higher content of alkaline oxide K_2O than other deposits which promotes vitrification of a porcelain sample. However, vermiculite has a higher content of hematite (Fe_2O_3) compared to other deposits under study. Its use for the production of porcelain insulators may be ruled out unless the mineral clay is beneficiated. This is due to the reason that high concentration of hematite reduces glassy phase content at high firing temperature which may affect the dielectric properties of the porcelain body.

The X-ray diffraction patterns of Pugu kaolin and Same clay showed strong kaolinite which is a source of alumina (Al_2O_3). The raw materials except vermiculite were found to contain quartz and tridymite which are the source of silicon dioxide (SiO_2). Both alumina and silica form alumina-silicate compound known as mullite and glassy phase ($3Al_2O_3 \cdot 2SiO_2$) during sintering process which contributes to the increase of the mechanical and dielectric strength of the porcelain samples.

The results from the characterization of the porcelain samples presented in this work show that Tanzania ceramic raw materials are potential for production of high voltage porcelain insulators. It has been found that the porcelain sample (P-3) with composition 20 wt% of Pugu kaolin, 20 wt% of Same clay, 20 wt% of vermiculite and 40 wt% of feldspar gave the dielectric strength of 61.3 kV/mm, bending strength of 30.54 MPa and water absorption of 0.36% at 1250^0C. The examination of the surface morphology was done by Scanning Electron Microscope (SEM) evidenced the progressive change in densification on the surface of porcelain samples after the sintering process was completed at 1250^0C.

It is therefore, concluded that porcelain sample P-3 has the main requisite properties for the production of high voltage porcelain insulators provided the above-discussed composition specifications and recommendations are followed. The porcelain sample P-3 sintered at 1250^0C is highly recommended than its counterparts due to low water absorption and high dielectric strength which are within standards requirements for high voltage porcelain insulators. If a porcelain insulator is manufactured with high degree of porosity and water absorption rate. It will certainly absorb moisture and its insulation will decrease and leakage current will start to flow through the insulator which may result in catastrophic failure of an insulator in use. The dielectric strength of 61.3 kV/mm may be used for the manufacture of 11 kV and 33 kV power transmission and distribution porcelain bushings. This is to ensure that the working high voltage porcelain insulator withstands electrical stress which may result due to working voltage, lightning and temporary over-voltages that may result to flashover of insulators under abnormal environmental conditions.

5.2 Recommendations

There are factors to be taken into consideration in order to achieve the best high voltage porcelain insulators with low water absorption and high dielectric and mechanical strength. This includes proper selection of the raw materials, the firing temperature, and ramp rate, and the method of fabrication of porcelain samples. However, this dissertation focused on the evaluation of the dielectric and mechanical strength of the high voltage porcelain insulators made from Tanzania ceramic raw materials by varying the composition of the raw materials and the firing temperature.

From this study, the following are the recommendations**;**

(i) Fabrication method and the mechanism of strengthening of porcelains by glazing.

(ii) Determination of the optimum conditions of glazing in terms of the thickness of glaze, and firing temperature schedule for optimum mechanical properties.

(iii) Effects of fluxes on the dielectric and mechanical strength of the alumina silicate porcelain insulators

(iv) Investigation of the internal structure of the porcelain samples before and after firing to determine its effect on the physical, thermal and electrical properties of porcelain insulators.

REFERENCES

Acchar, W. and Dultra, E. J. (2015). *Ceramic Materials from Coffee Bagasse Ash Waste*: Springer.

Akwilapo, L. D. and Wiik, K. (2003). Ceramic properties of Pugu kaolin clays. Part I: Porosity and modulus of rupture. *Bulletin of the Chemical Society of Ethiopia*. **17**(2).

Alcântara, A., Beltrão, M. Oliveira, H. Gimenez, I. F. and Barreto, L. (2008). Characterization of ceramic tiles prepared from two clays from Sergipe-Brazil. *Applied Clay Science.* **39** (3): 160-165.

Anih, L. (2005). Indigenous manufacture and characterization of electrical porcelain insulator. *Nigerian Journal of Technology.* **24**(1): 44-50.

ASTM, C. (1999). 373-88. *Water absorption, bulk density, apparent porosity and apparent specific gravity of fired whiteware products*.

ASTM, D. (1988). C 326-82 (Reapproved 1988). *Standard test method for drying and firing shrinkage of ceramic white ware clays*.

Bragança, S. and Bergmann, C. (2003). A view of whitewares mechanical strength and microstructure. *Ceramics International.* **29**(7): 801-806.

Buchanan, R. C. (2004). *Ceramic materials for electronics* (Vol. 68): CRC press.

Callister Jr, W. D. and Rethwisch, D. G. (2012). *Fundamentals of materials science and engineering: an integrated approach*: John Wiley and Sons.

Carty, W. M. and Senapati, U. (1998). Porcelain-raw materials, processing, phase evolution, and mechanical behavior. *Journal of the American Ceramic Society.* **81**(1): 3-20.

Chaudhuri, S. (1974). Influence of Mineralizers on Constitution of hard Porcelain. 1. Mineralogical Compositions. *American Ceramic Society Bulletin.* **53**(2): 169-171.

Das, S. K. and Dana, K. (2003). Differences in densification behaviour of K-and Na-feldspar-containing porcelain bodies. *Thermochimica Acta*. **406**(1): 199-206.

Ekosse, G. I. E. (2010). Kaolin deposits and occurrences in Africa: Geology, mineralogy and utilization. *Applied Clay Science.* **50**(2): 212-236.

Esposito, L. Salem, A., Tucci, A., Gualtieri, A. and Jazayeri, S. (2005). The use of nepheline-syenite in a body mix for porcelain stoneware tiles. *Ceramics International.* **31**(2): 233-240.

Gorur, R. S., Cherney, E. A. and Burnham, J. T. (1999). *Outdoor insulators*: Ravi S. Gorur Phoenix, Ariz, USA.

Haertling, G. and Buchanan, R. (1991). Ceramic materials for electronics. *Buchanan, New York*. 12.

Hamano, K. Wu., Y. H., Nakazawa, Z. and Hasegawa, M. (1991). Effect of grain size of quartz on mechanical strength of porcelain body. *Journal of the Ceramic Society of Japan.* **99**(1146): 153-157.

Hamisi, H. Park, E., Choi, B., An, Y. and Lee, J. (2014). Influence of firing temperature on physical properties of same clay and pugu kaolin for ceramic tiles application. *International Journal of Materials Science and Applications.* **3**(5): 143-146.

Hasselman, D. and Fulrath, R. (1966). Proposed fracture theory of a dispersion-strengthened glass matrix. *Journal of the American Ceramic Society.* **49**(2): 68-72.

Islam, R. A., Chan, Y. and Islam, M. F. (2004). Structure–property relationship in high-tension ceramic insulator fired at high temperature. *Materials Science and Engineering.* **106**(2): 132-140.

Jawale, G., Kumar, N. and Majhi, M. (2016). Synthesis and characterization of zirconia doped electrical porcelain insulator.

Kasrani, S., Harabi, A., Barama, S. E., Foughali, L., Benhassine, M. and Aldhayan, D. (2016). *Sintering and dielectric properties of a technical porcelain prepared from economical natural raw materials*. Cerâmica.

Kimambo, V. (2014). Suitability of Tanzanian Kaolin, Quartz and Feldspar as Raw Materials for the Production of Porcelain Tiles. *International Journal of Science, Technology and Society.* **2**(6): 201. doi: 10.11648/j.ijsts.20140206.17

Kitouni, S. and Harabi, A. (2011). Sintering and mechanical properties of porcelains prepared from Algerian raw materials. *Cerâmica.* **57**(344): 453-460.

Kornmann, M. (2007). CTTB (Technical Centre for roof Tiles and Bricks in Paris), Clay Bricks and Roof Tiles, Manufacturing and Properties, Soc. *Industrie Minerale, Paris*.

Lobitzer, H. (1982). *Geology and utilization of the" Pugu Hills" kaolin deposit, Tanzania*: Ges. d. Geologie-u. Bergbaustudenten in Österreich, Inst. f. Geologie d. Univ. Wien.

Lugwisha, E. (2006). Properties of fired bodies made from Tanzanian talc-clay mixes for ceramic applications. *Tanzania Journal of Science.* **32(**2): 69-79.

Lugwisha, E. (2011). Identification of Clay Minerals of the Eastern Southern Region of Lake Victoria by Ethylene Glycol and Heat: Xray Diffraction and Infrared Spectroscopy Studies. *Tanzania Journal of Science.* **37**(1).

Maity, S. and Sarkar, B. K. (1996). Development of high-strength whiteware bodies. *Journal of the European Ceramic Society*. **16**(10): 1083-1088.

Martín-Márquez, J., Rincón, J. M. and Romero, M. (2008). Effect of firing temperature on sintering of porcelain stoneware tiles. *Ceramics International*. **34**(8): 1867-1873.

Matthew, G. and Fatile, B. (2014). Characterization of vitrified porcelain tiles using feldspar from three selected deposits in Nigeria. *Research Journal of Recent Sciences-ISSN, 2277*, 2502.

Morita, K., Suzuki, Y. and Nozaki, H. (1997). Study on electrical strength of suspension insulators in steep impulse voltage range. *IEEE transactions on power delivery*. **12**(2): 850-856.

Moulson, A. J. and Herbert, J. M. (2003). *Electroceramics: materials, properties, applications*: John Wiley and Sons.

Moyo, M. G. and Park, E. (2014). Ceramic Raw Materials in Tanzania – Structure and Properties for Electrical Insulation Application *International Journal of Engineering Research and Technology.* **3**(10): p 6.

Njau, H. G. and Park, E. (2015). Compressive Strength of Unfired Composite Bricks Made of Same Clay and Natural Fiber of Tanzania. *International Research Journal of Engineering and Technology* 2(9): p15.

Njau, H. G. and Park, E. (2015). Physical Properties of Unfired and Compressed Same Clay Brick Composites Reinforced with Natural Fiber from Tanzania. *International Journal of Innovative Research in Advanced Engineering.* (4).

Norris, A., Taylor, D. and Thorpe, I. (1979). Range curves: an experimental method for the study of vitreous pottery bodies. *Transactions and. Journal of the British Ceramic Society.* **78**(5): 102.

Ohya, Y., Takahashi, Y., Murata, M., Nakagawa, Z. and Hamano, K. (1999). Acoustic emission from a porcelain body during cooling. *Journal of the American Ceramic Society.* **82**(2): 445-448.

Okolo, C., Ezechukwu, O., Ifeagwu, E. and Unegbu, R. (2014). Development of Electrical Porcelain Insulators from Local Clays. *International Journal of Engineering Innovation and Research.* **3**(6): 877-881.

Oladiji, A., Borode, J., Adewuyi, B. and Ohijeagbon, I. (2010). Development of Porcelain insulators from locally sourced materials USEP. *Journal Research. Information Civil Engineering.* (7).

Olupot, P. W. (2006). *Assessment of ceramic raw materials in Uganda for electrical porcelain.* KTH.

Palatzky, A. and Werner, T. (1958). Increasing the mechanical strength of porcelain bodies. *Silikat Technology.* 9: 68-73.

Reed, J. S. (1995). Principles of ceramics processing.Wiley-interscience.,New York.215 pp.

Schwaighofer, B. and Muller, H. (1987). Mineralogy and genesis of the pugu hill kaolin deposit, Tanzania. *Clay Minerals, 22*(4): 401-409.

Sedghi, A., Hamidnezhad, N. and Noori, N. R. (2012). *The Effect of Fluxes on Alumina Silicate Porcelain Insulator Properties and Structure.* Paper presented at the International Conference on Ecological, Environmental and Biological Sciences (ICEEBS'2012) Jan.

Stathis, G., Ekonomakou, A., Stournaras, C. and Ftikos, C. (2004). Effect of firing conditions, filler grain size and quartz content on bending strength and physical properties of sanitaryware porcelain. *Journal of the European Ceramic Society*. **24**(8): 2357-2366.

Sutcu, M. (2015). Influence of expanded vermiculite on physical properties and thermal conductivity of clay bricks. *Ceramics International.* **41**(2): 2819-2827.

Tai, W. P., Kimura, K. and Jinnai, K. (2002). A new approach to anorthite porcelain bodies using nonplastic raw materials. *Journal of the European Ceramic Society,* **22**(4): 463-470.

Tomizaki, M. and Sugiyama, T. (1995). Study on high-silica porcelain bodies. effects of siliceous stone grain size. *Intercera.* **44**(4): 223-228.

Usman Jamo, H. (2015). *Mechanical properties of ceramics tiles by replacement of quartz by RHA and POFA.* Universiti Tun Hussein Onn Malaysia.

Valášková, M., Martynková, G. S., Smetana, B. and Študentová, S. (2009). Influence of vermiculite on the formation of porous cordierites. *Applied Clay Science.* **46**(2): 196-201.

Wiik, K. and Akwilapo, L. D. (2003); Ceramic properties of Pugu kaolin clays; Porosity and modulus of rupture 62. *Bulletin of the Chemical Society of Ethiopia.* **17**(2): 147-154.

Zoellner, A. (1908). *Zur Frage der chemischen und physikalischen Natur des Porzellans*: Friedrich-Wilhelms-Universität Berlin.

RESEARCH OUTPUTS

Journal Paper

építőanyag ▪ Journal of Silicate Based and Composite Materials

Effect of firing temperature on triaxial electrical porcelain properties made from Tanzania locally sourced ceramic raw materials

Blasius NGAYAKAMO
MSc Materials Scientist and Engineer at NM-AIST. Department of Materials Energy Science and Engineering. Fields of interest: ceramic raw materials, flux materials and high voltage porcelain insulators.

S. Eugene PARK
Associate Professor and chair, Materials and Energy Science and Engineering at NM-AIST Department of Materials Science and Engineering, Fields of interest: Ceramic and sustainable Energy Engineering.

Blasius NGAYAKAMO ▪ The Nelson Mandela African Institution of Science and Technology, Department of Materials Energy Science and Engineering ▪ henryblasius@gmail.com
S. Eugene PARK ▪ The Nelson Mandela African Institution of Science and Technology, Department of Materials Energy Science and Engineering

Érkezett: 2018. 02. 16. ▪ Received: 16. 02. 2018. ▪ https://doi.org/10.14382/epitoanyag-jsbcm.2018.19

Abstract
The study has investigated the effect of firing temperature during the production of technical triaxial electrical porcelain, for electrical insulation applications using Tanzania locally sourced ceramic raw materials. The green triaxial porcelain samples containing 50 wt% of Pugu kaolin, 35 wt% of Same clay and 15 wt% of feldspar were produced and fired at 1200 °C-1300 °C with a heating rate of 10 °C/min (dwell time of 1.5h) and cooled at 10°C/min to a room temperature. X-ray diffraction technique was used to investigate phases developed in the triaxial electrical porcelain after firing process. The main crystalline phases revealed were mullite and quartz. The technological properties of the triaxial electrical porcelain such as water absorption, apparent porosity, bulk density, bending and dielectric strength were determined for each porcelain sample fired at high temperature. The optimum physical-mechanical and electrical properties were found at 1250°C. However, the triaxial electrical porcelain properties were found to decrease with the increase in firing temperature.
Keywords: Firing temperature, triaxial electrical porcelain, physical-mechanical and dielectric properties
Kulcsszavak: Égetési hőmérséklet, triaxiális szigetelő porcelán, fiziko-kémiai és dielektromos jellemzők

1. Introduction

Triaxial electrical porcelain is composed of clay, feldspar which are locally sourced ceramic raw materials and other filler materials such as quartz and alumina. The raw materials play specific roles in influencing the properties and performance of the final products. Clay [$Al_2Si_2O_5(OH)_4$] provides plasticity, quartz (SiO_2) maintains the shape of the porcelain structure during firing, and feldspar [KxNa1-x ($AlSi_3$) O_8] promotes vitrification. The three ceramic raw materials place electrical porcelain in the phase system [$(K, Na)_2O$-Al_2O_3-SiO_2)] in terms of oxide hence referred as triaxial porcelain [1, 2]. Traditional ceramic raw materials are the potential candidate materials for the production of triaxial electrical porcelains. The use of traditional ceramics as raw materials instead of industrial chemicals is highly preferred due to the lower price of the raw materials [3].

The properties of triaxial electrical porcelain are contributed to the variations in the composition of the raw materials, the method of production, and the firing temperature adopted [1]. The sintered triaxial porcelain product contains mullite ($Al_6Si_2O_{13}$) and undissolved quartz (SiO_2) crystals embedded in glassy phase which result from the liquid phase formed by the melting of feldspar in the raw materials [4].

Therefore the desired properties of triaxial electrical porcelains are achieved particularly during the firing process since the technological properties of clay-based ceramics products depend on firing conditions such as temperature [5, 6]. However, other technological properties which are evaluated to determine the performance of the ceramic product after firing are water absorption, firing shrinkage and bending strength [6]. During the firing process, the triaxial porcelain body undergoes several phase transitions, during which both composition and structure change significantly which influence triaxial porcelain properties at the end of the firing process [5]. Hence, the properties of the triaxial porcelain are mainly influenced by sufficient development of mullite during firing process since the development of mullite in the porcelain is highly associated with firing temperature of the porcelain which should not be below 1150 to 1200 °C for the mullite forming processes to be completed [5, 7]. Therefore, the development of the physical-mechanical and dielectric properties of porcelain are contributed by each phase developed during firing which depends on the concentration and microstructural attributes which are influenced by temperature and the chemical composition of the raw materials which is an important factor because of its effects on porcelain properties [8-11]. Since the effect of firing temperature on the electrical porcelain properties made from Tanzania locally sourced ceramic raw materials is not reported. Therefore, the work intends to evaluate the effect of firing temperature on the triaxial electrical porcelains made from Tanzania locally sourced ceramic raw materials. However, the study focuses also on the phase changes, surface morphology development as well as the physical-mechanical and dielectric properties of the triaxial electrical porcelain sample due to change in firing temperature.

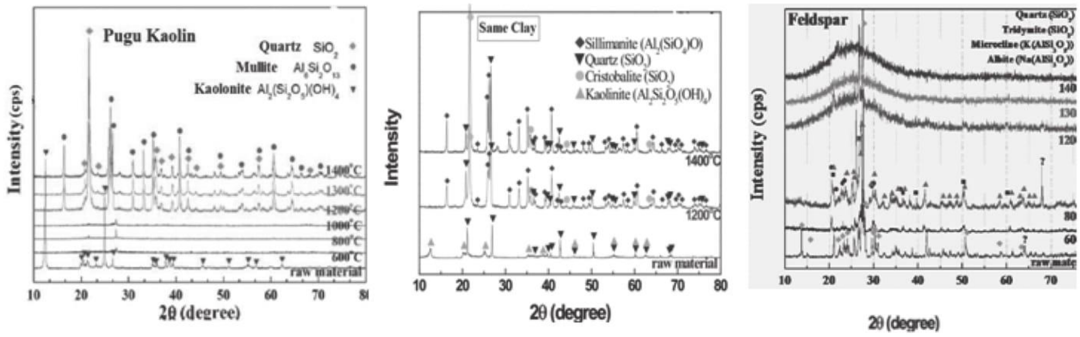


Fig. 1. X-ray diffraction patterns of Pugu kaolin, Same clay and feldspar [16]
1. ábra Pugu kaolin, Same agyag és földpát röntgendiffraktogramjai [16]

2. Experimental procedures

Pugu Kaolin was collected from the Pugu hills, 35 km west of Dar es Salaam, Same clay and feldspar from Same, Kilimanjaro region in the northern zone of Tanzania. The ceramic raw materials were crushed and ball milled to reduce their size. The particle size less than106 µm was achieved by using sieve shaker Model RX-29-10 digit. The chemical composition of the raw materials was analyzed by using X-Ray Fluorescence (XRF) PANalytical, Model: Minipal4 (PW4030)-Rh X-Ray Tube, 30kV, 0.002mA and the results are presented in *Table 1*. The examination of the surface morphology of the porcelain sample was carried out by Scanning Electron Microscope (SEM) Model: JEOL JSM-6335F having a resolution of 10µm at 2kV. The crystalline phase analysis of the porcelain insulator was analyzed by X-ray diffractometer Model: Bruker D2-PHASER-40Kv/44mA. Six triaxial porcelain samples were produced by varying the composition of the locally sourced materials by 50%wt of Pugu kaolin, 35%wt of same clay and 15%wt of feldspar. The powder mixtures were uniaxially compacted into rectangular shapes at 10 MPa. The porcelain green body samples were seasoned at a room temperature for 5 days and they were oven dried at the temperature of 110 °C for 24 hrs. The sintering of porcelain samples was done at 1200, 1250 and 1300 °C for 1.5 hrs at the ramp rate of 10 °C/min in each firing process. The sintered porcelain bodies were left to cool at 10 °C/min to room temperature and were subjected to physical-mechanical properties and dielectric strength analysis.

3. Results and discussion

3.1 Chemical composition of the raw materials

The chemical compositions of the raw materials in form of their oxides are presented in *Table 1*. The study results reveal that both clays have the higher content of silica and alumina. However, feldspar and Pugu kaolin have a higher content of Hematite (Fe_2O_3) compared to Same clay. The literature reports that small amount of coloring oxides such as Fe_2O_3 and TiO_2 less than 0.9% may be accepted for porcelain wares production [12]. However, a considerable high amount of Fe_2O_3 in Pugu kaolin and feldspar may not be accepted as they may impart yellowish and reddish color in porcelain wares unless beneficiated. Feldspar has considerable higher alkaline oxide K_2O than Pugu kaolin and Same clay. During the sintering process, the alkaline oxide K_2O melts and forms the liquid phase that contributes to densification at higher temperatures due to the formation of the glassy phase. Nevertheless, the quantities of the alkaline oxides depend on the mineralogical nature of the clays and their reactivity during melting of the clay minerals [13]. The alkaline oxides(K_2O and Na_2O) play a significant role towards vitrification, phase transformation and mullite grain growth [14, 15].

Oxides	Pugu kaolin	Same clay	Feldspar
SiO_2	60.0	60.4	57.1
Al_2O_3	30.3	13.9	14.0
Fe_2O_3	3.95	1.40	3.08
MnO	0.021	0.00	0.32
CaO	0.39	0.00	1.0
Na_2O	0.00	0.04	0.20
K_2O	2.14	2.6	12.09

Table 1. Chemical composition of raw materials
1. táblázat Alapanyagok kémiai összetétele

3.2 Mineralogical composition of the raw materials

The X-ray diffraction patterns of the ceramic raw materials before and after firing are presented in *Fig. 1* as reported by [16]. The result shows phase compositions of both Pugu kaolin and Same clay are kaolinite, however, Pugu kaolin showed the development of crystalline phases of mullite and quartz at a temperature of 1400 °C. In addition, Same clay was observed to form cristobalite and sillimanite above 1200 °C. Feldspar contains albite, and microcline, tridymite, and quartz. Since the major components of interests are potassium feldspar ($K_2O{\cdot}Al_2O_3{\cdot}O{\cdot}6SiO_2$) sodium feldspar ($Na_2O{\cdot}\ Al_2O_3{\cdot}O{\cdot}6SiO_2$); and lime feldspar ($CaO{\cdot}Al_2O_3{\cdot}O{\cdot}6SiO_2$). However, the results indicate that feldspar deposit contains a high content of potash feldspar compared to soda feldspar which is also supported by the chemical composition by XRF that is K_2O is 12.09% while

Na_2O is only 0.20%.So feldspar deposit is, therefore, a potash feldspar. Feldspar promotes vitrification of the porcelain insulator at the end of the sintering process.

3.2 Characterization of fired triaxial porcelain samples

Fig. 2 presents the results of water absorption, apparent porosity, and bulk density respectively for the porcelain samples versus firing temperature. The figure shows that the best values for physical properties for triaxial electrical porcelain are achieved at the firing temperature of 1250 °C. This might be due to the formation of the liquid phase and densification at this firing range. However, the values of water absorption, apparent porosity, and bulk density were observed to decrease at higher firing temperature. This might be due to the expansion of trapped water bubbles inside the porcelain matrix and change in the composition of the glassy phase [1, 3]. The results of the study are in agreement with the works of [1, 3, 13]. The authors reported that water absorption and bulk density increased due to vitrification and densification of the porcelain samples. However, the physical properties were observed to vary due to the decrease of vitrification range and an increase of firing temperature due to the expansion of trapped water bubbles inside the porcelain sample at high firing temperatures. Generally, the variation of the physical properties of the triaxial electrical porcelain might have been caused by the method of production, chemical and mineralogical properties of the raw materials.

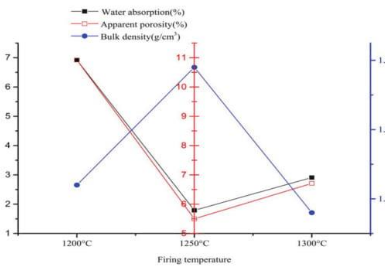


Fig. 2. Physical properties of triaxial electrical porcelain sample versus firing temperature
Fig. 2. Triaxiális szigetelő porcelán fizikai jellemzői az égetési hőmérséklet függvényében

Fig. 3 shows changes in the mechanical strength of triaxial electrical porcelain with firing temperature. The trend shows that the increase of mechanical strength of porcelain sample may be due to increased densification, vitrification and in absence of microcracks. The best mechanical strengths (both bending and compressive strengths) were obtained at 1250 °C. However, the mechanical strengths began to decrease above 1250 °C due to closed pores development and a considerable amount of cracks on the surface of the porcelain samples. The results of the current study are in agreement with the previous studies as reported in the works of Kitouni *et al.*,[13] and Olupot *et al.,* [1]. The authors have reported that the mechanical strength increases due to increased densification with temperature and tends to decrease due to development of pores at high firing temperature. However, the mechanical strength was found to decrease with the increase of the firing temperature due expansion of closed pores and microcracks [1]. Hence the mechanical strength of a porcelain sample is strongly dependent on the defects such as pores and cracks [13].

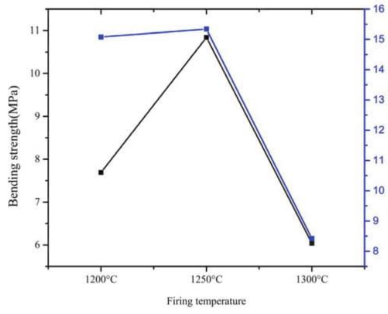


Fig. 3. Variation of mechanical strength of triaxial electrical porcelain sample versus firing temperature
Fig. 3. Triaxiális szigetelő porcelán mechanikai jellemzői az égetési hőmérséklet függvényében

Fig. 4 shows the variation of the dielectric strength of porcelain samples fired at 1200, 1250 and 1300 °C. The trend shows that the dielectric strength increases with an increase in firing temperature and began to decrease with further temperature rise at 1300 °C. The increase of the dielectric strength of electrical porcelains is due to increased vitrification range of the electrical porcelains samples. The results of the current study are also reported by Olupot *et al,* [1]. The authors evaluated ceramic raw materials from Uganda for electrical porcelain production. The authors obtained the highest dielectric strength of 19kV/mm at 1250 °C. However, above 1250 °C, the samples became more porous due to change in the composition of the glassy phase. The dielectric strength was found to decrease with the increase of firing temperature which affected vitrification range and the dielectric properties of the triaxial electrical porcelain.

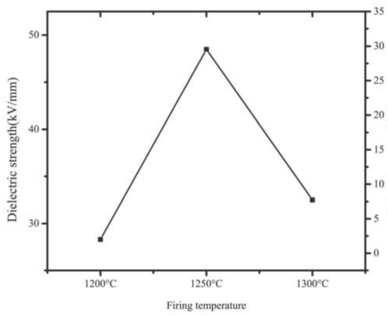


Fig. 4. Variation of dielectric strength of triaxial electrical porcelain sample versus the firing temperature
Fig. 4. Triaxiális szigetelő porcelán dielektromos jellemzői az égetési hőmérséklet függvényében

In *Fig. 5* the X-diffraction pattern of triaxial electrical porcelain is presented. The diffractogram confirms that the mullite and quartz phases are present in the porcelain insulator. Both phases promote the mechanical and dielectric properties of the porcelain insulator. However, high peaks of quartz may lead to high amount of glassy phase which may lower the dielectric strength of the porcelain insulators but not the mechanical strength of a porcelain insulator which is affected by microcracks. The high amount glassy phase provides free movement of mobile ions such as Na^+, K^+, and Al^{3+} which increases the conductivity [17].

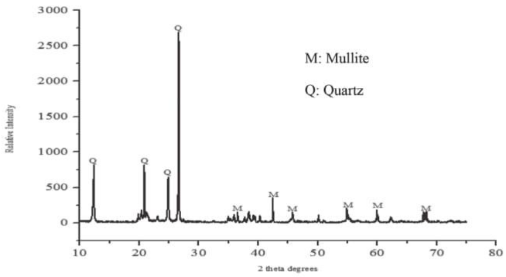


Fig. 5. X-ray diffraction pattern of a porcelain insulator fired at 1250 °C
Fig. 5. 1250 °C hőmérsékleten égetett szigetelő porcelán röntgendiffraktogramja

Fig. 6 shows the examination of the surface morphology using the Scanning Electron Microscope (SEM) Model: JEOL JSM-6335F having a resolution of 10nm at 2kV. It was evidenced the densification on the surface of the triaxial electrical porcelain sample after the firing process was completed.

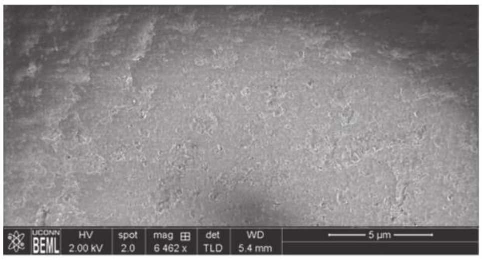


Fig. 6. SEM micrographs showing densification of triaxial electrical porcelain sample at 1250 °C
Fig. 6. 1250 °C hőmérsékleten égetett triaxiális szigetelő porcelán elektronmikroszkópos felvétele

4. Conclusions

In this research work, the effect of firing temperature on triaxial porcelain samples properties was investigated. At the optimum firing temperature of 1250 °C, the best physical-mechanical and dielectric properties were achieved. However, firing beyond 1250 °C resulted in progressive deterioration of the physical-mechanical and the dielectric properties of the electrical porcelain samples. This might have been caused by the development of microcracks and high content of glassy phase caused by high peaks of quartz. So it is imperative to be aware that, the actual firing temperature and its influence on the triaxial electrical porcelain properties depend on the chemical composition of the materials under study. Therefore, the locally sourced materials need to be evaluated from time to time in order to avoid deviation of the desired triaxial electrical porcelain properties during the firing process.

References

[1] Olupot, P. W. (2006): Assessment of ceramic raw materials in Uganda for electrical porcelain, *KTH*.

[2] Carty, W. M. – Senapati, U. (1998): Porcelain—raw materials, processing, phase evolution, and mechanical behavior. *Journal of the American Ceramic Society*, 1998. 81(1): p. 3-20. https://doi.org/10.1111/j.1151-2916.1998.tb02290.x

[3] Kasrani, S., et al., (2016): Sintering and dielectric properties of a technical porcelain prepared from economical natural raw materials, *Cerâmica*, 2016. p. 405-412. https://doi.org/10.1590/0366-69132016623641994

[4] Olupot, P. W. – Jonsson, S. – Byaruhanga, J. K. (2013): Effects of the Sintering Process on Properties of Triaxial Electrical Porcelain from Ugandan Ceramic Minerals. *World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, 2013. 7(5): p. 267-273. http://scholar.waset.org/1307-6892/11565

[5] Stubna, I. – Sin, P. – Viljus, M. – Trnik, A. (2014): The effect of the firing temperature on the hardness of alumina porcelain. *Materiali in tehnologije*, 2014. 48(3): p. 331-336. http://mit.imt.si/Revija/izvodi/mit143/stubna.pdf

[6] Njoya, D. – Tadjuidje, F. S. – Ndzana, E. J. A. – Pountouonchi, A. – Tessier-Doyen, N. – Lecomte-Nana, G. (2017): Effect of flux content and heating rate on the microstructure and technological properties of Mayouom (Western-Cameroon) kaolinite clay-based ceramics. *Journal of Asian Ceramic Societies*, 2017. 5(4): p. 422-426. https://doi.org/10.1016/j.jascer.2017.09.004

[7] Jang-Hoon Ha – Jongman Lee – In-Hyuck Song – Sang-Hyup Lee (2015): The effects of diatomite addition on the pore characteristics of a pyrophyllite support layer. *Ceramics International*, 2015. 41(8): p. 9542-9548.

[8] Olupot, P. W. – Jonsson, S. – Byaruhanga, J. K. (2008): Effects of mixing proportions and firing temperature on properties of electric porcelain from Ugandan minerals. *Industrial Ceramics*, 2008. 28(1): p. 1-10.

[9] Iqbal, Y. – Lee, W. E. (2000): Microstructural evolution in triaxial porcelain. *Journal of the American Ceramic Society*, 2000. 83(12): p. 3121-3127. https://doi.org/10.1111/j.1151-2916.2000.tb01692.x

[10] Lee, W. – Iqbal, Y. (2001): Influence of mixing on mullite formation in porcelain. *Journal of the European Ceramic Society*, 2001. 21(14): p. 2583-2586. https://doi.org/10.1016/S0955-2219(01)00274-6

[11] Chaudhuri, S. – Sarkar, P. – Chakraborty, A. (1999): The Electrical resistivity of porcelain in relation to the constitution. *Ceramics International*, 1999. 25(1): p. 91-99. https://doi.org/10.1016/S0272-8842(98)00006-6

[12] Acchar, W. – Dultra, E. J. (2015): Ceramic Materials from Coffee Bagasse Ash Waste. 2015: *Springer*.

[13] Kitouni, S. – Harabi, A. (2011): Sintering and mechanical properties of porcelains prepared from Algerian raw materials. *Cerâmica*, 2011. 57(344): p. 453-460. https://doi.org/10.1590/S0366-69132011000400013

[14] Chaudhuri, S., (1974): Influence of mineralizers on constitution of hard porcelain. 1. Mineralogical compositions. *American Ceramic Society Bulletin*, 1974. 53(2): p. 169-171.

[15] Das, S. K. – Dana, K. (2003): Differences in densification behavior of K-and Na-feldspar-containing porcelain bodies. *Thermochimica Acta*, 2003. 406(1): p. 199-206. https://doi.org/10.1016/S0040-6031(03)00257-0

[16] Hamisi, H., et al., (2014): Influence of firing temperature on physical properties of same clay and Pugu kaolin for ceramic tiles application. *International Journal of Materials Science and Applications*, 2014. 3(5): p. 143-146. https://doi.org/10.11648/j.ijmsa.20140305.12

[17] Islam, R. A. – Chan, Y. – Islam, M. F. (2004): Structure-property relationship in high-tension ceramic insulator fired at high temperature. *Materials Science and Engineering: B*, 2004. 106(2): p. 132-140. https://doi.org/10.1016/j.mseb.2003.09.005

Ref.:
Ngayakamo, Blasius – **Park**, S.Eugene: *Effect of firing temperature on triaxial electrical porcelain properties made from Tanzania locally sourced ceramic raw materials*
Építőanyag – Journal of Silicate Based and Composite Materials, Vol. 70, No. 4 (2018), 106–109. p.
https://doi.org/10.14382/epitoanyag-jsbcm.2018.19

Poster Presentation

Evaluation of Dielectric and Mechanical Strength of High Voltage Porcelain Insulators Made From Tanzania Ceramic Materials

Blasius Ngayakamo and Eugene S Park

Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania

Department of Materials, Energy Science and Engineering

Introduction

Background Information

❖Porcelain insulators prevent or regulate current flow in electrical power transmission system (Islam *et al.*,2004).High voltage transmission, porcelain insulators withstand electrical stress and should have dielectric strength greater than 30kV/mm(Moulson *et al.*,2003,Buchanan,1991).

❖Despite the availability of potential local ceramic materials, Tanzania is only manufacturing low voltage ceramic insulators which are restricted to the low voltage power supply .Therefore, the study, intended to evaluate the dielectric and mechanical strength of high voltage porcelain insulators data made from Tanzania ceramic raw materials to address the problem.

General Objective

❖To evaluate the dielectric and mechanical strength of high voltage porcelain samples made from Tanzania local materials.

Specific Objective

❖To determine the chemical composition of the ceramic materials.

❖To design formulations and fabricate porcelain samples.

❖To investigate the effect of firing parameters on the dielectric and mechanical strength of the prepared porcelain samples.

Materials Collection

❖Pugu Kaolin was collected from Dar es Salaam, Same clay and feldspar from Kilimanjaro and vermiculite from Tanga, and Mikese in Morogoro region.

Figure 1: Pictures of raw materials collected.

Research Methodology

❖Four compositions were formulated as shown in Table 1 and 20 porcelain samples were produced as indicated in fig 2.

Sample	Pugu kaolin	Same clay	Vermiculite	Feldspar
P1	30	0	30	40
P2	0	30	30	40
P3	20	20	20	40
P4	50	35	0	15

Table 1: Porcelain formulations(wt%)

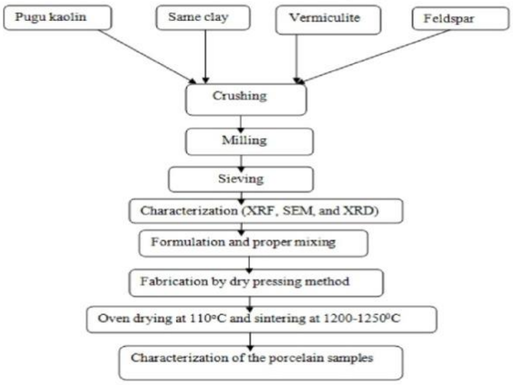


Figure 2: Flow diagram for production of porcelain samples.

Results and Discussion

The results showed significant change in physical-mechanical and dielectric strength properties as firing temperature was increased.

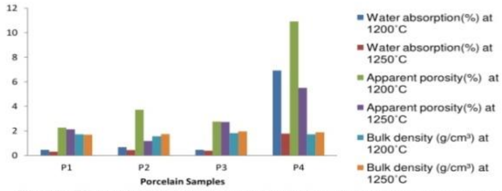


Figure 3: Effect of firing temperature on physical properties of porcelain samples

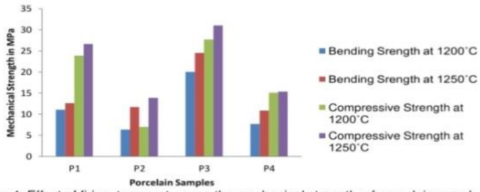


Figure 4: Effect of firing temperature on the mechanical strength of porcelain samples

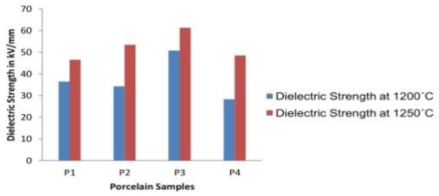


Figure 5: Effect of firing temperature on the dielectric strength of porcelain samples

The porcelain sample with composition, 20%wt Pugu kaolin, 20%wt Same clay, and 20%wt vermiculite and 40%wt feldspars sintered at 1250⁰C gave the highest dielectric strength of 61.3kV/mm, bending strength of 30.54MPa and low water absorption value of 0.36% which satisfies the main requisite properties for high voltage porcelain insulators production.

Conclusions

The study shows that a high-quality high voltage porcelain insulator can be achieved from locally sourced ceramic raw materials from Tanzania.

References

1.Islam, R.A., Y. Chan, and M.F. Islam, *Structure–property relationship in high-tension ceramic insulator fired at high temperature.* Materials Science and Engineering: B, 2004. **106**(2): p. 132-140.

2.Moulson, A.J. and J.M. Herbert, *Electroceramics:materials properties applications* 2003: John Wiley & Sons.

3.Haertling, G. and R. Buchanan, *Ceramic materials for electronics.* Buchanan, New York, 1991: p. 12.