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Chapter

Production of Electrical Porcelain Insulators from Local Raw Materials: A Review

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Abstract

This paper reviewed the production of electric porcelain insulators utilizing from local raw materials from developing countries. The raw materials used were feldspar, quartz/silica and kaolin. The chemical composition, mineralogy, and thermal properties of the raw materials were characterized using AAS, XRD, and TGA respectively. Different weight percentage combinations of the individual raw materials were investigated by the authors. Most of the results showed relatively acceptable porcelain insulators properties such as low water absorption, porosity, high insulation resistance, dielectric strength and bulk density. The paper showed that electric porcelain insulators with good properties can be produced from available local raw materials in some developing countries using appropriate formulations. However, for production of improved porcelain insulators properties, suggestions were made on the areas for future research.

Keywords: porcelain insulator, feldspar, quartz, kaolin, electrical insulation, water absorption

1. Introduction

Since the origin of electricity generation at the Edison direct current pearl street power station, electricity industries have grown to become an essential part of human lives. The energy demand in Africa is increasing significantly due the springing up of industries and advancement in the human standards of living in the continent [1]. These have place a continuous strain on the power sectors to meet up with the consumers' demand which are increasing on daily basis. For instance, in Ethiopia the energy sector have been growing in the past two decades and reached currently electric power of 2360 MW, this would be expected to reach 10,000 MW in the next 10 years [2].

It has been estimated that more than 20% of the total outlay for a typical transmission and distribution system of electrical energy is spent on insulation alone

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[3]. Nigerian electrical power holding company (PHCN) spends a lot of resources maintaining and replacing aged insulators on electric transmission lines. It imports 99% of the total insulators it uses, notably from Asian countries, of which ceramic insulators occupies a central position [3]. The high degree dependency on importation has led to the high cost of maintenance and replacement of insulators used for the transmission of the electricity. Since majority of these insulators are imported, their standard has posed a big challenge to consumers. This is due to the different environmental conditions of the countries involved in manufacturing and consumption. These varied environmental conditions affect the efficiency of insulators.

Electrical insulators help to prevent the passage of current to other areas where it is not wanted or where it can cause harm or death to the living things that come in contact with it [4]. Among the insulator materials utilized in electric power transmission and distribution systems, porcelain ceramic insulators is the most commonly used material for overhead insulators [5]. The use of ceramic porcelain as electrical insulator is unrivalled by any other materials currently. Porcelain insulators are characterized with excellent properties such as high mechanical strength, high electrical stability and corrosion resistance even in harsh environments [6]. These properties have made these insulators dominant in electrical power industries over the years, despite the emergence of new insulators made from plastics and polymer composites.

The word "porcelain" has it origin in the Italian "porcella" literally meaning "little pig", a Mediterranean sea-snail whose shell is white and translucent [7]. The first ceramic porcelain was first manufactured in China, followed by Europe during the period of industrial revolution [8]. In 1849, Werner Von Siemens adopted the traditional porcelain to produce one of the first electric insulators to insulate the telegraph cable from Frankfurt to Berlin [9]. Porcelain was believed to be the first material to be made artificially by humans, the majority of the early Chinese porcelain was called "hard paste" porcelain which was composed of: 50% Kaolinite ($Al_2O_3SiO_22H_2O$), 25% Feldspar ($K_2OAl_2O_36SiO_2$) and 25% Quartz (SiO_2) [8]. These three constituents place ceramic porcelain in the phase system in terms of oxide constituent, hence termed "Triaxial porcelain" [10]. The kaolin clay content of this porcelain gives plasticity to the ceramic mixture while quartz maintains the shape of the formed article during firing and feldspar serves as flux, which is added to decrease the required firing temperature and thus to reduce cost by saving Energy [11]. They are vitrified and fine-grained ceramic white wares, used either glazed or unglazed, baked at high temperatures to achieve vitreous, or glassy, qualities such as low porosity and translucence [5]. They are widely used in household, laboratory and industrial applications. Ceramic Porcelains are suitable for electrical, chemical, mechanical, structural and thermal wares. The versatility of porcelain makes them applicable for both low and high tension insulation in electrical transmissions. Although in electrical insulation applications, porcelains are expected to meet minimum specification of the latter two, dielectric (high resistivity, low dielectric loss) and mechanical properties [12]. They should also have low atomic mass, low defect concentration, high lattice stiffness, high purity with a minimum disorder, resistivity between $10^{12}\ \Omega$–$10^{14}\ \Omega$ and covalent [13]. Electrical porcelains have been technologically evolved regarding the design topics, manufacturing process and raw materials in order to fulfill highly demanded market requirements [14].

Over the years porcelain insulators have demonstrated numerous advantages over many insulators such as good mechanical strength, good environmental aging performance, and excellent resistance to material degradation caused by electrical stress and discharge activities [15]. Porcelain allows high surface leakage current to flow on their wetted surfaces, due to their low hydrophobic surface characteristics which permits water to form a continuous conductive film along the creepage path [16].

There is constant vandalization of ceramic porcelain insulators due to its high cost. These challenges gave rise to the introduction of polymeric insulators at distribution voltage levels, as alternative to ceramic porcelain insulators due to its low cost.

Non ceramic or polymeric insulators have good hydrophobic surface characteristics, high mechanical strength to weight ratio, resistance against vandalism and reduced maintenance costs [17]. On the other hand, polymeric insulators are easily affected by UV rays, stress due to high voltages and they also contribute to environmental pollutions [14].

1.1 Origin and functions of triaxial constituents of ceramic porcelain insulator

1.1.1 Kaolin

The major mineral constituent of the clay used in porcelain is kaolinite; rocks rich in this mineral are typically referred to as either 'china clay' of 'kaolin'. Kaolin is a soft white mineral that has a large array of uses, which, under the electronic microscope it is seen to consist of roughly hexagonal, platy crystals ranging in size from about 0.1micrometer to 10 micrometer or even larger [18, 19]. Kaolin are found in combination with other minerals such as muscovite, quartz, feldspar and anatase in nature [20]. It has always been used with other materials so as to increase it workability, and also to lower the klin temperature necessary to produce a firm product. This china clay has found extensive usage in making pharmaceuticals, paint, paper and composite materials. It is the major constituent used in manufacturing electrical porcelain. Kaolin gives the fired porcelain a soft plastic base, shape and opacity [21]. It has melting point of 1800°C, with a molecular formula $(Al_2O_3.2Si)_2\ 2H_2O$, with a highly refractory acumen [22]. Kaolinite is the main constituent of kaolin with 39.8% alumina, 46.3% Silica, 13.9% water. **Figure 1** shows the chemicals structure of kaolinite as designed by Brindley and Nakahira [23].

1.2 Quartz

Quartz or silica is a ubiquitous mineral with molecular formula SiO_2 in its purest form. It occurs in many diverse modes in nature. The name 'quartz' is an old German word of uncertain origin, first used by George Agricola in 1530 [24]. Quartz contains 99–100% silica (SiO_2) and about 0.1% impurities such as Fe_2O_3, Na_2O, CaO, MgO, Al_2O_3 and K_2O depending on its percentage purity [25]. They occur as primary and essential constituent of igneous rocks of acidic composition, such as Granite, Porphyry and Rhyolite [26]. **Figure 2** shows the schematic quartz structure showing the most intrinsic and extrinsic lattice [27].

Figure 1.
Structure of kaolinite designed by Brindley and Nakahira viewed from the a-axis direction [23].

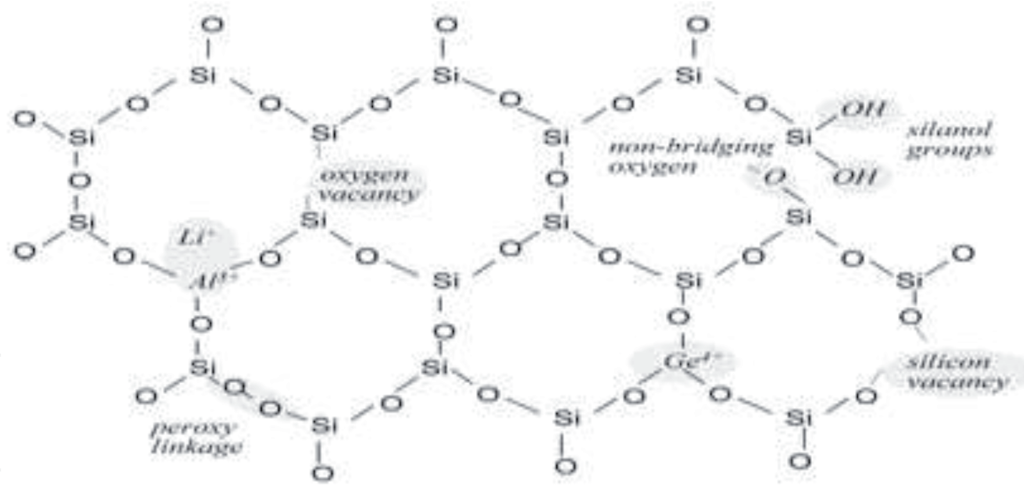


Figure 2.
Schematic structure of quartz [27].

Quartz plays a very important role in the formulation of ceramic porcelain. The fired porcelain microstructures consist mainly of glass phase, mullite and quartz as major crystalline phases. Quartz helps to maintain the shape of the ceramic porcelain during firing. Evidence have shown that under optimized conditions of firing and for particle of size of 10–30 μm, quartz has a beneficial effect on the strength of porcelain, in conformity with the matrix reinforcement and dispersion strengthening hypotheses [28]. It's evident that quartz particle size plays a vital role in controlling the mechanical strength of ceramic porcelain insulators. They also provide the refractory crystalline phase or skeleton contributing to the mechanical strength of the body.

1.3 Feldspar

The compositional and structural properties of Feldspar envisage the rich information that can be tied to their genesis. They are among the most vital minerals found in the earth crust with extensive solid solutions at temperatures higher than about 700°C and large immiscibility gaps at lower temperatures [29]. They are aluminosilicate minerals with the general molecular formula AT_4O_8 in which A = potassium, sodium, or calcium; and T = silicon and aluminum, with a Si:Al ratio ranging from 3:1 to1:1. Feldspar comes in three major formulations $NaAlSi_3O_8$, $KAlSi_3O_8$ and $CaAlSi_3O_8$ respectively [30].

The structure of feldspars is a three-diamentional framework of linked SiO_4 and AlO_4 tetrahedra, with sufficient opening in the framework to accommodate K, Na, Ca, or Ba to maintain electroneutrality as shown in **Figure 3**. In **Figure 3**, the small black circles are Si and Al, the large circles is O (oxygen) [31]. Feldspar rocks are used in the fine ceramic industry as a fluxing agent to form a glassy phase for accelerating of sintering process and, also as sources of alkalis and alumina in glazes [32]. They are the fluxing agent for the ceramic porcelains. Its selection significantly affects the properties of the fired ceramic porcelain body and optimal firing temperature or soaking time [33]. The densification of the green body and the stain resistance of polished ceramic porcelain are determined by the distribution of the particle size of feldspar [34].

Electrical ceramic porcelains are considered to be one of the most complex ceramic systems. A variation on the triaxial constituent (kaolin, feldspar and quartz) of porcelain can affect the thermal, dielectric or mechanical properties of the porcelain [5]. The effectiveness of porcelain ceramic insulator on low or high voltage transmission line is determined by its chemical constituents.

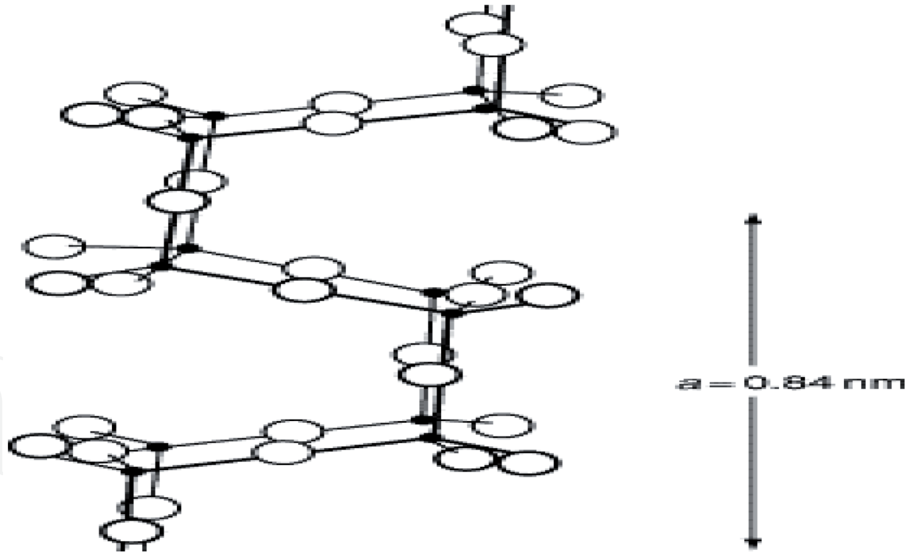


Figure 3.
The essential structural features of all feldspar projected on a plane [31].

There has been tremendous progress on the enhancement of porcelain, but challenges still remain in understanding the properties relating to the selection and investigation of its raw materials, processing, microstructure and phase evolution, all which are critical determinants for its use as electric insulation materials [35]. This research reviews the physical and chemical properties of the electrical ceramic porcelain insulators as an indication for their electrical applications.

2. Review on different materials with their percentage compositions used to produce electrical ceramic porcelain insulators (ECPI)

ECPI are made up of two major types of materials: the plastic materials and the non-plastic materials.

The plastic materials are essentially the clay materials or kaolinites, they serve as the shape makers. Plastic materials essentially give the ECPI the required shape without rupturing during forming and they also help them to retain the required shape after forming. The non-plastic materials include the quartz, feldspar and many other similar materials. These materials help to reduce the plastic nature of the ECPI so as to ameliorate cracks during drying, and also help to lower the firing temperature of ECPI [36].

Ovri and Onuoha sourced kaolin clay from Awo-omama in Oru East Local Government area of Imo state, Nigeria [5]. The clays used for the studies were called Awo-omama clay and Ibere clay located in Ikwuano Local Government Area, Abia State, while feldspar and quartz were bought locally from Umuahia in Abia State, Nigeria. The Awo-omama clay, Ibere clay, feldspar and quartz from their report showed a high level of SiO_2 and the lowest content of K_2O, with no K_2O present in quartz.

In 2018, locally sourced materials, that is, Feldspar (Kagara), Quartz (kadna) and Talc (kagara) were used for the production of ECPI by Nwachukwu and Lawal. This was to investigate their insulation strength [37]. The compositions used in the production were kaolin 28%; ball clay 10%; feldspar 35% and quartz 25% for the most potent sample as reported, the percentage composition of Talc was kept constant at 2%.

Ball clay sourced from Ise, Ikere-Ekiti, Ekiti state, Nigeria was reported as a binder in the formations of ECPI [7]. Kaolin which was the major constituent in the

ECPI was gotten from Ijapo, Akure, Ondo State, Nigeria while feldspar and quartz were sourced from Ogun state, Nigeria. In southern part of Ghana, raw kaolin, feldspar and quartz materials deposited in Assin-Fosu and Kumasi, located in central region and Ashanti region respectively were used for the manufacture of two different ECPI. Assin-fosu sample analysis showed a high level of kaolin compare to Kumasi sample, while that of Kumasi contains higher level of feldspar and quartz respectively [38].

Bamboo leaf ash was partially substituted in production of ECPI by Marimuthu in south Indian state. The combination of bamboo leaf ash gathered from the campus of Annamalai University in Chidambaram, Tamil Nadu, with clay, feldspar and quartz purchased from M/s Oriental Ceramic Industry, Viruthachalam, Tamil Nadu were employed [39].

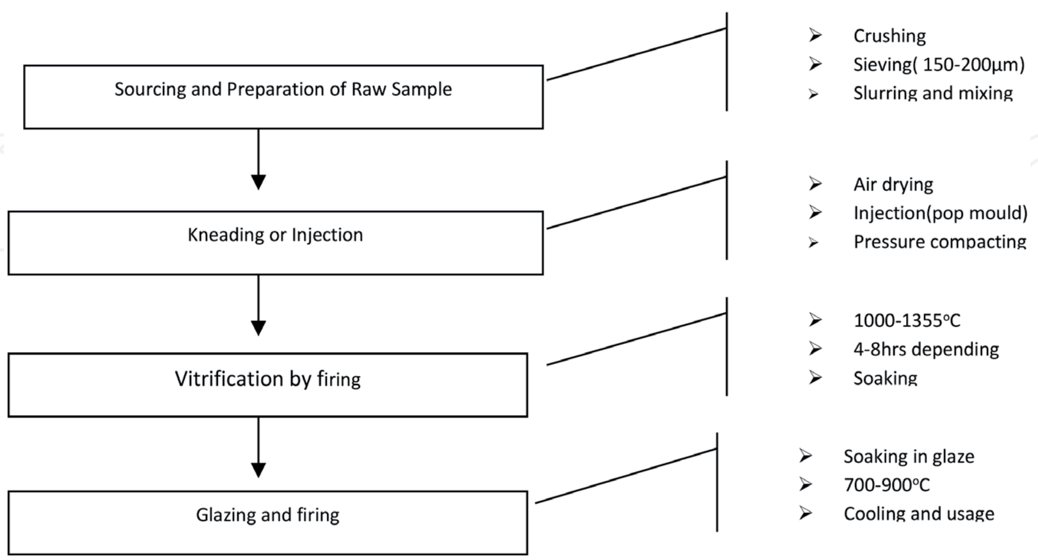
In 2014, Olupot used ball clay from Mukono, kaolin and feldspar from Mutaka and sand from Lido beach on the shores of Lake Victoria in Entebbe, Uganda to produce ECPI [25].

The development of ECPI from local clays gotten from Ekwulobia, Iva Valley and Nawfija in Anambra state, Nigeria, were studied [40]. The study compares the physical, chemical and mechanical characteristic of these clays to obtain the unique properties that make ECPI suitable for electrical insulation in varied conditions.

Four porcelain composite comprising of kaolin (27–37%), beach sand (20–24), ball clay (13–18%) and feldspar (25–40%) were used to formulate ECPI to investigate the triaxial properties of ceramic composite [41].

2.1 Method of producing ECPI

The methods for production of ECPI are generally similar just a little alterations according the producers demand. Budnikov recommended kaolin 30%, ball clay 10%, feldspar 22% and quartz 38% as the percentage composition of the mixture used in manufacturing ECPI [42]. Although ECPI with a mixture composition of 27% kaolin, 13% ball clay, 40% feldspar and 20% sand have also been studies [39]. The basic process of production of ECPI is described in the diagram below:



The chemical and physical properties of kaolin, feldspar and quartz were determined before the production is carried out in most of the reported previous studies [3, 7, 43]. Oladiji also used Atomic Absorption Spectroscopy (AAS) to determine the chemical composition of quartz and feldspar after the materials have been crushed and sieved properly [7]. Another study determined the physical properties of ECPI such as bulk density, moisture content, linear shrinkage and porosity using Archimedes method with water as the liquid medium as for ASTM 378–88 and universal tester (UTM) was used to determine the mechanical strength of the ECPI [39]. The morphological structure of the clay, quartz and feldspar were also determined using XRD and field emission gun scanning electron microscope (FEG-SEM) [39, 43]. The particle size and the dielectric measurements of ECPI constituents were determined using particle size distribution analyzer (Analysette 22) and a high voltage breaking voltage test machine (Terco HV-9133) [41].

3. The effect of different methods of manufacturing ECPI on its electrical, physical and mechanical properties

The chemical composition of ECPI plays an important role on the ECPI reactions to the change in environmental conditions. It's evident that the change in environmental condition such temperature and pressure can affect the life span of most chemically bonded compounds. These compounds tend to change their mode of bonding and cleavages with slight change in these environmental conditions. These changes play major roles on the physical and mechanical properties of ECPI especially on their insulation abilities.

ECPI manufactured using a dry process technique was reported [3]. The best sample of insulator produced by this method contains kaolin 30%, ball clay 10%, feldspar 22% and quartz 38%. The sample exhibited zero water absorption after immersion in water for 24 hours. This shows that the sample has very little pores or spaces which might be noticeable if the sample was allowed to stay longer in the water. Little or no water causes the ECPI to have high bulk density, high failing load and a very good resistance when use for high voltages. The breakdown voltage, dielectric constant and the two resistivity where reported as 26 kV/mm, 10.8, 7.14×10^7 Ω-m and 1.97×10^7 Ω-m respectively. The breakdown voltage suggested that the sample has high mechanical strength to withstand high voltage stress, while the dielectric constant suggests that it is a good insulating material. The dielectric constant for good insulating material should fall below 12 [44] and a breaking voltage of ≥25 kV/mm. The two resistivities were high and greater than the recommended value for a good insulator (1×10^6) confirming the insulation claims of the porcelain [43].

Ovri and Onuoha analyzed a locally sourced materials using AAS as shown in **Table 1** [5]. The result of **Table 1** is in agreement with previous studies [45, 46]. The two samples (Awo-omama and Ibere) with percentage composition 20–30%

Composition	Awo-omama	Ibere	Feldspar	Quartz
SiO_2	53.54	43.94	63.40	97.42
Al_2O_3	27.75	26.54	17.32	0.15
Fe_2O_3	0.92	0.48	0.83	0.46
MgO	0.93	1.61	0.24	—
CaO	1.35	3.37	0.42	—
Na_2O	0.16	0.28	1.75	—
K_2O	0.57	0.77	14.86	—
LOI (H_2O)	11.20	16.00	0.51	0.42

Table 1.
The Chemical composition of the raw materials used for the study [5].

Feldspar, 50–70% clay and 10–20% quartz exhibited high linear shrinkage of 7.27–9.24% and 8.33–9.68% when compared with other results [45]. This was suggested by Ovri and Onuoha to be due to high content of the plastic materials (clay) compared to the non-plastic content (quartz and feldspar) in the samples. ECPI showed an apparent porosity of 16.81–20.80% and 14.00–17.30% which is in agreement with the value (16.82%) obtained by Power Holding Company of Nigeria (PHCN) while the water absorptions for both clay are also high (8.9–12.15%; 8.33–10.84%). The high value of porosity and water absorption are as a result of non-plastic materials used in the production of the ECPI. These non-plastic materials create more pore or spaces which allow the trapping of moisture in ECPI. High water absorption and porosity are not beneficial for the performance ECPI, because the presence of moisture reduces the electrical resistance of the electrical porcelain. To remedy this issue, good porcelain should have high plastic content and should be glazed properly. Awo-omama and Ibere samples exhibit electrical resistivity ($0.61–1.05x10^7\Omega$-m and $0.79–1.39x10^7\Omega$-m) that is also in agreement with the recommended PHCN resistivity ($0.45x10^7\Omega$-m). Electrical resistivity is the ability of the insulator to resist current flow.

A report on the use of Bamboo leaves ash (BLA) as a substitute for quartz in production of porcelain has provided a very important waste management strategies, and it is also a cheap readily available raw materials for ECPI production [39]. The study compares the substitution of quartz with BLA at different concentrations respectively. The properties of the specimens were compared with that of standard porcelain (SP) prepared using procedure ASTM C373, an industrial standard ceramic material. The chemical composition showed that BLA also contain high content of SiO_2 just like quartz, feldspar and kaolin. Since BLA is a product of oxidation, it contains more oxide than any of the three constituent as shown in **Table 2**. The porosity and water absorption of the BLA specimen were reported to be decreasing with increase in BLA, they were also higher than the porosity of SP. This is attributed to the fine nature of the BLA, making it easy for them to fill up the pores, therefore reducing the level of water absorption by the porcelain. Similar result have been reported [25, 47].

Low water absorption is a good quality of ECPI since high water absorption reduces the insulating abilities. The bulk density of BLA was reported to be higher than that of the SP due to the filling in of pores by BLA, thereby resulting into denser ECPI. When the bulk density is high while the porosity is low, the mechanical strength of the electrical porcelain (BLA) will be expected to be high too. The

Composition	Clay	Feldspar	Quartz	BLA
SiO_2	63.45	64.20	97.55	79.90
Al_2O_3	29.33	14.02	0.97	2.78
Fe_2O_3	3.17	0.38	0.27	0.86
K_2O	1.15	16.83	0.41	3.98
CaO	0.33	0.65	0.23	7.84
MgO	0.39	0.28	0.08	1.97
Na_2O	0.28	2.90	0.35	0.20
TiO_2	1.57	0.35	0.04	0.38
Others	0.66	0.26	0.10	2.09

Table 2.
The chemical composition of the raw materials (wt%) used [25].

linear shrinkage was also reported to increase as the BLA concentration increased. This is because significant particle occupied the inter-particle spacing as a result of the volume reduction [48]. The mechanical strength of the blended BLA insulator (3.12 MPa) was higher than the reference SP insulator (2.48 MPa). This was attributed to the pozzolanic reaction activity of the BLA insulator, the reduction of cracks and flaw. BLA exhibited higher electrical insulation resistance (21.0 GΩ) and higher flashover voltage (9.92 kV/mm) compared to standard sample (SP) (12.5 GΩ; 8.65 kV/mm) at maximum injection of 5000 DC voltage and alternative current voltage of 50 Hz frequency. The improvements in the electrical properties of BLA sample were attributed to the enhanced physical properties, the presence of fine particles and the presence of high silica content [49].

The triaxial electrical properties of ECPI were investigated by Dowuona et al. using powder XRD, SEM and particle size distribution analysis in order to determine their insulating capacity [41]. Two samples of ECPI produced comprises kaolin (27–40%), beach sand (20–24%), ball clay (13–18%) and feldspar (25–40%). SEM analysis of the materials suggested small uniform particle sizes and radial distribution for kaolin and ball clay, while sand and feldspar are relatively bigger and non-uniform in sizes. The characterization of the powder materials using XRD identified quartz as having the highest peak intensity between kaolin, sand, feldspar and ball clay. Other peaks identified are muscovite, vermiculite and mica in Kaolin; calcite and albite in sand; vermiculite and mica in ball clay; microcline and albite in feldspar. As the particle size increases the percentage shrinkages increment were reported for the different samples, this was due to a drop in the plasticity of the porcelain materials. This suggested that radial distribution of particles was the principal cause for plasticity of clay materials [50]. Larger particles have been reported previously to cause crack in vitreous phase of ECPI compare to fine particles which can easily melt and blend to the mixture [51]. The smaller the particles sizes the greater the loss on ignition (LOI). The two (A&B) samples were milled with different quantity of zirconium oxide (155.85 g and 500 g). Sample A showed bending strength less than 50% of the value of sample B. The presence of ZrO_2 helps the mechanical strength of the sample because of the fine nature of the ZrO_2 particles. The sample with the higher quantity of kaolin (37%), ball clay (18%) and ZrO_2 but low in feldspar (25%) showed highest breakage voltage of 53.4 kV with breakdown strength of 10.45 kV/mm at room temperature. It also showed a high bending strength of 71 MPa which is higher than the standard value for pin type ECPI. The same sample also portrayed very high dielectric strength when compared to the others. The report suggested that it is very important to use fine particle size distribution in order to achieve the desired result in manufacturing electrical porcelain.

Nwachukwu and Lawal used talcum powder in the preparation of ECPI to study its electrical and physical properties [37]. The talc was constant in all the samples while altering the other constituents such as kaolin, ball clay, feldspar and quartz. The constituent composition for each material used in the sample production is shown in the **Table 3**. The chemical compositions of the different materials were determined by X-ray fluorescence spectrometer. The result showed that the quartz contains 95.4% silica, the clay contains 58.75 and 27.6% of silica and alumina, while the Talc was the only constituent that contains Ta_2O_5 and NiO. **Table 4**, presents that shrinkage test, failing voltage, bulk density and water absorption. The samples with little feldspar and quartz less than 5% warped in the mold while those with less clay came out with cracks. This emphasizes the importance of the plastic (clay) and non-plastic materials (feldspar and quartz) in porcelain production. Feldspar functions as a fluxing agent allowing flow of mixtures and the formation of slags by impurities which help to reduce cracks.

Specimen	Feldspar	Quartz	Clay(Kaolin)	Plastic clay	Talc
	%	%	%	%	%
1	0	0	72.21	25.79	2
2	5	5	64.84	23.16	2
3	10	10	57.47	20.53	2
4	15	15	50.10	17.90	2
5	20	20	42.74	15.26	2
6	25	25	35.37	12.63	2
7	30	30	28.00	10.00	2
8	35	35	20.63	7.37	2
9	40	40	13.26	4.73	2
10	35	25	28.00	10.00	2

Table 3.
The percentage composition of the porcelain samples [37].

Properties	3	4	5	6	7	8	9	10
Total shrinkage (%)	8.70	4.19	3.20	3.16	3.01	2.97	5.76	2.60
Fired shrinkage (%)	0.6	0.98	1.06	0.8	0.37	0.32	1.84	0.60
Dry shrinkage (%)	8.1	3.21	2.14	2.36	2.64	2.65	3.92	2.00
Water absorption	3.72	2.89	2.82	2.63	2.60	2.59	3.46	2.52
(%)								
Bulk density	2.14	2.16	2.29	2.37	2.42	2.49	2.74	2.52
(g/cm^3)								
Failing load (kN)	1.97	2.55	2.57	2.67	2.69	2.73	1.92	3.01

Table 4.
The physical properties of produced porcelain Insulator [37].

The total shrinkage and water absorption were found to decrease as the plastic materials increases. This is because the clay helps to fill in the pore spaces in the porcelain insulator, but the samples average values are still within the accepted values for the both parameters. The increase in kaolin caused slight decrease on the bulk density even though the feldspar content was increasing. This was attributed to the different value of loss on ignition of kaolin (7.49) as against feldspar (0.73) give by the X-ray analysis [37]. The failing loads were found to be directly proportional to the kaolin content, showing that the strength of ECPI is mainly derived from the plastic materials.

The di-electric constant of the samples (8.7–11.4) showed that they will make good insulator because they fall to the recommended value for good di-electric insulator (below 12.0) [52, 53]. This suggests that the possibility of electric shock is low since the insulator has a good charge storage capacity. The samples exhibit electrical resistance that are above the recommended range 1.0x10^6 which is a quality of a good insulator [3, 54]. Generally, this suggests that the fine nature of the talc powder helped to amplify the qualities of the other constituents in the porcelain insulators. The sample with the composition 20.63% kaolin, 7.37% plastic clay, 35.0% feldspar, 35.0% quartz and 2% talc possesses the best insulation properties for the ECPI.

The properties of ECPI fired at different temperatures (1000°C, 1100°C, 1200°C, 1300°C) with a heating and cooling rate of 6°C/min and 1-hour socking were studied [1]. The study focused on the effect of different firing temperature on the physical and mechanical properties of ECPI. **Table 5** showed the chemical composition while **Figure 1** showed the effect of temperature on the physical and mechanical properties of different ECPI samples [1].

This clay contains least quantity of SiO_2, this is uncommon for kaolin clays. The clay also has highest LOI, this was due to the loss on structural hydroxide occurred during transformation of kaolinite clay to metakaolinite phase formation around 500°C [1]. **Figure 4** shows the effect different firing temperature on the water absorption, bulk density, apparent porosity and dielectric strength. The water of absorption and apparent porosity decreased with increase in firing temperature and reaching to zero at temperature of 1300°C. This was due to the filling of spaces or pores by molten feldspar as the temperature increases. Reports have shown that the lower the absorption and apparent porosity, the better the insulation strength of ECPI [25]. The dielectric strengths of the samples were reported to reach a maximum of 13 kV/mm as the firing temperature increases. This is attributed to the increased vitrification range of the ECPI samples at the optimized firing temperature [54]. The XRD showed only feldspar and quartz peaks at 1000°C with no peak for the clay. At 1100°C a new peak appeared showing the formation of primary mullite [55]. As the firing temperatures increases beyond 1100°C, the peak for feldspar gradually disappears while that of mullite intensifies and the SEM images showed the formation of glassy phase. This variation on the XRD peaks can

Materials	Oxides (Wt %)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	TiO_2	LOI
Clay	46.86	36.74	0.86	0.02	0.08	0.01	1.34	0.04	0.01	13.85
Feldspar	72.50	14.55	2.40	0.52	1.00	2.95	3.68	0.09	0.16	2.08
Quartz	96.66	0.87	0.68	0.16	0.10	0.01	0.85	0.04	0.01	0.36

Table 5.
The chemical composition analysis of clay, feldspar and quartz minerals in wt% [1].

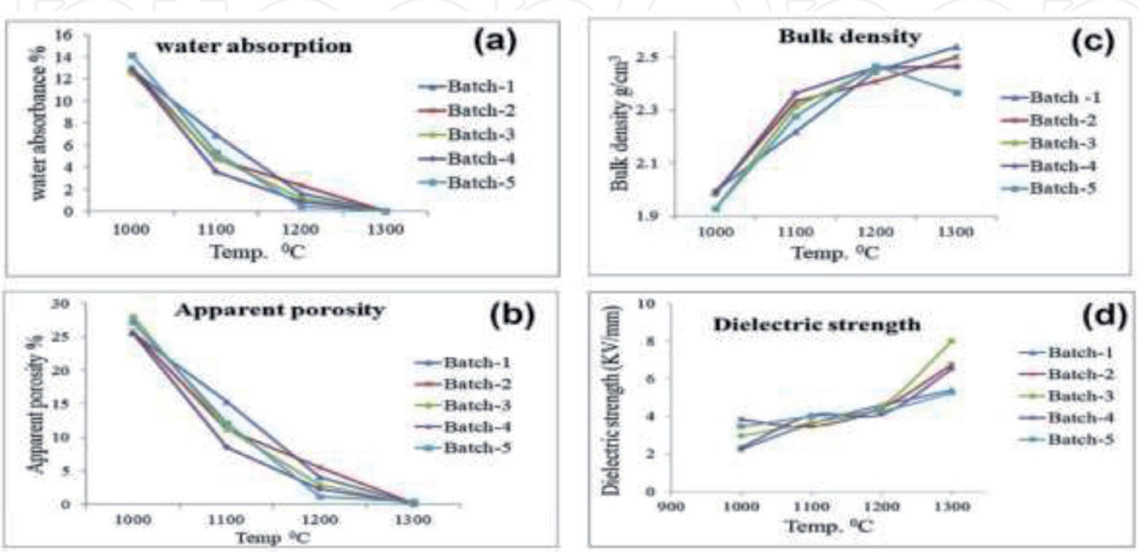


Figure 4.
Variation in (a) water absorption, (b) apparent porosity, (c) bulk density and (d) dielectric strength, of samples with temperature.

be attributed to the melting of feldspar at 1100°C and the formation of glassy phase (mullite) by the melted feldspar.

Stephy et al. reported the production of ECPI made from china clay mixed with kaolin, feldspar and quartz for use on voltage lines of 20 kV, 70 kV, and 150 kV [56]. The ECPI showed a relative permittivity (ε) of 6, with low thermal conductivity, significant heat capacity, good mechanical strength, high stability and strong resistant to corrosion. Maximum and minimum electric field of 142178 kV/cm and 30554 kV/cm respectively were obtained for the 150 kV lines. For the 70 kV lines the maximum and minimum electric field observed were 65743.3 kV/cm and 11720 kV/cm respectively, while 20000 kV/cm to 3061 kV/cm were obtained for 20 kV. Contaminants that accumulated on the porcelain insulator surface affected the distribution of the voltage and magnetic field. Voltage distribution pattern were uniform throughout the creepage distance [56].

Noori et al. monitored the effects of some design materials on properties of electrical porcelain insulators. Wet method was used to prepare the porcelain insulators with feldspar, kaolin and ball clay as the consistent raw materials [57]. The composition of quartz (silica) was varied with alumina as alumina gradually replaced silica in the mixture feed. The result indicated that the bending strength of the produced ECPI increased as the alumina content displaces the quartz in the mixture. Furthermore, the alumina content also increased the bulk density of the ECPI leading low porosity and water absorption. High voltage insulators are expected to have water absorption very close to zero to avoid current conduction. Change in dielectric loss tangent was relatively insignificant while the study on the thermal shock resistance showed that a cycle of 30 was needed before a crack was observed on the ECPI. The sintering temperature (varied between 1250°C and 1350°C) was reported to have appreciable effect on the properties of the produced ECPI. Therefore, the imperfections of quartz-based ECPI can be reduced by using alumina-based ECPI instead.

Moses and Eugene investigated the suitability of Tanzanian raw materials in ceramic porcelain insulator using Pugu kaolin, Kilimanjaro quartz and feldspar [58]. The characterization of the raw materials showed that they have the required properties for effective blending. Sintering temperature of 1300°C was utilized with one hour soaking time. Maximum bending strength of 53.525 MPa was obtained for porcelain insulator with kaolin, feldspar and quartz in the weight percentage of 48 wt%, 46 wt%, and 6.0 wt% respectively. Increase in kaolin weight content with decrease in the quartz content of the mixture significantly increased the bending strength of the ECPI. Low bending strength usually results from development of cracks. Highest ECPI insulation resistance of 42750MΩ at injection of 1000 volts was observed for a mixture of 22 wt% quartz, 64 wt% feldspar and 14 wt% kaolin. The water absorption decreased with reduction in the weight of feldspar content while increasing in the kaolin content. Furthermore, decrease in the relative weight content of feldspar led to a decrease in the bulk density of the ECPI. Linear shrinkages of the ECPI were found to decrease with increase in the kaolin content with simultaneous decrease in feldspar and quartz contents. Moses and Eugene recommended that a quality porcelain insulator should have kaolin, quartz and feldspar in the weight percentage of 48 wt%, 6 wt% and 46 wt%.

Locally sourced raw materials (kaolin, quartz, ball clay and feldspar) from Ondo and Ekiti states of Nigeria with varying compositions were used to produce and characterize porcelain insulators according to Oladiji and his research team [7]. Slip casting method was employed in producing the ECPI with sodium silicate as the deflocculant. The raw materials were separately milled and sieved at 200 μm and mixed. The mixture consists of weight percent of ball clay and quartz while kaolin and feldspar were varied. The result showed that the porcelain strength (in terms of failing load) relatively increased as the weight percent composition of kaolin increased and that of feldspar decreased. There was an insignificant reduction in bulk density of the produced ECPI as the weight of feldspar was decreased (and kaolin increased). This is as a result of high loss on ignition of kaolin compare to feldspar. Water absorption decreased from 4.58% to as low as 0.27% as the weight content of kaolin increased while feldspar decreased. This is because feldspar permits better mixture flow which subsequently increases porosity resulting to higher water absorption. Total linear shrinkage of the porcelain insulator constantly increased from 12.20% to 16.20% with increase in weight content of kaolin coupled with decrease in feldspar. This is as a result of the plastic/clay nature of kaolin. At injection of 1000 volts, the porcelain insulation resistance was relatively constant at about 50,000 MΩ. The insulation resistance gradually decreased at higher injection volts. Material mixture with composition 33 wt% kaolin, 15 wt% ball clay, 32 wt feldspar and 20 wt% quartz was recommended for best ECPI.

Okolo et al. reported on the use of Nigerian clays from different clay deposits in Anambra State in producing ECPI with major objective of determining the insulation resistance of the insulator. Mixtures of the clay, feldspar and quartz of varying composition were used to produce the porcelain insulator [40]. The mixed samples were fired at 900°C after glazing, before sintering at 1250°C. The porcelain insulation resistance was found to increase up to 1.13 GΩ ohms as the clay content reduced at injection of 5000 volts. The best porcelain insulators was found to consist of a combination of 50 wt% clay, 30 wt% feldspar and 20 wt% quartz for Nwafija clay mixture and 60 wt% clay, 25 wt% feldspar and 15 wt% wt% clay for Ekwulobia and Iva valley clays. The work concluded that very low content of non-plastic material led to distortion and high firing shrinkage while very high content resulted to disintegration of the porcelain insulators and vitrification leading to cracking.

Andualem et al. investigated the suitability of local raw materials available in Ethiopia for ECPI production [1]. The quantity of quartz was kept at constant weight of 10 wt% while the weight of feldspar and clay were varied. XRD, AAS, and TGA were used to characterize the individual materials. The materials were mixed, ground and sieved at about 45 to 75 micro meters. Different firing temperatures of 1000°C, 1100°C, 1200°C and 1300°C were utilized. The result indicated that water absorption (and consequently corrosion) decreased as firing temperature increased reaching almost zero at 1300°C. This was as a result of the melting of feldspar at higher temperature. Expectedly, increase in temperature resulted to an increase in the bulk density of the ECPI since water absorption has an inverse relation with bulk density. However, increase in feldspar to clay ratio led to a decrease in the bulk density due to the large amount of viscous liquid phase from the melted feldspar. The dielectric strength of the porcelain insulator increased with increasing firing temperature with maximum of 8 kV/mm attained at 1300°C. This was due to increased vitrification range at higher temperature. The mixture analysis showed that relatively equal proportion of feldspar and kaolin/clay showed better dielectric strength.

4. Indication for use

Low voltages (500 V to 2000 V): Electrical ceramic porcelain insulator with percentage composition ranges of kaolin 30–50%, feldspar 20–30% and quartz 25–35% at firing temperature of up to 1300°C can be suggested for low voltages.

High voltages (˃2000 V): Electrical ceramic porcelain insulator with the percentage composition ranges kaolin 20–25%, plastic clay 7–10%, feldspar 30–35%, quartz 30–35% and talc 2% at a firing temperature of up to 1250°C can be suggested for high voltages.

Humid geographical locations: The porcelain with percentage composition of kaolin 30%, ball clay 10%, feldspar 22% and quartz 38% with firing temperature of 1300°C. This porcelain will have the least moisture absorption in a humid environment.

5. Conclusion and recommendation

The present paper reviewed the production and characterization of electric porcelain insulators reported by authors using local raw materials. The three major factors for good electrical ceramic porcelain insulators are the percentage composition of the raw materials, the fine nature of the raw materials and the firing temperature. The best percentage composition of porcelain is that which allows minimal water absorption and apparent porosity (kaolin 30%; feldspar 22%; quartz 38%). The fine nature of the porcelain plays a major role in improving the bulk density, total shrinkage, mechanical strength and electrical resistance. The firing temperature of up 1300°C is very good for the vitirification of electrical porcelain. It is important to note the chemical composition of the raw materials differs, so the need to access it is vital to obtaining a quality product. The study concludes that standard and acceptable electric porcelain insulators can be produced from the local raw materials.

Future research suggestions for improved standard porcelain insulators,

- The use of local materials for the production of high voltage ECPI should be investigated.

- Further research should be channeled towards possible full/partial substitution of feldspar by recyclable and economic material with high alkaline content which may increase the glassy phase at reduced firing temperature.

- The potentials of replacing silica with alumina in the feed mixture should be investigated for better quality porcelain insulator.

- The chemical structure of the mixtures before and after firing should be investigated to provide more insight into their effect on the properties/thermal properties of the produced porcelain insulators.

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Abbreviations

AAS	Atomic Adsorption spectroscopy
ECPI	Electrical ceramic porcelain insulator
FEG-SEM	Field emission gun scanning electron microscope
PHCN	Power holding company of Nigeria
MW	Megawatts
SEM	Scanning electron microscope

TGA	Thermogravimetric Analysis
UTM	Universal testing machine
UV-Ray	Ultra violet ray
XRD	X-ray diffraction

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