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Exploitation of Ekoli Edda clay for 33KVA porcelain insulator production

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Abstract

Exploitation of Ekoli Edda clay to devise 33KVA porcelain insulator was done to ascertain the appropriateness of available local raw materials for porcelain insulators production. Ekoli Edda clay was used to formulate eleven samples (A to K) with other materials after characterization and formed using jigger jolleying machine. The properties scrutinized after sintering at 1400^{0}C signified that samples A - K had linear shrinkage ranging 7.5% to 2.5% with compressive strength ranging 21.14MPa to 30.84MPa respectively. The study uncovered that samples A - K as declared above had water absorption ranging from 3.06% - 1.21% with matching values of 1.092% - 0.011% succeeding glazing respectively. The apparent porosity indicated that samples A - K had 3.10% - 1.29% with resultant values of 1.331% - 0.031% after glazing, while bulk density result confirmed that samples A - K had 1.94g/cm^3 - 3.03g/cm^3. Flash over voltage results exposed that samples A - K had 30 KVA - 37 KVA with matching thermal stress resistance result ranging from 20 - 8 numbers of cycles correspondingly. It was discovered that the higher the percentage of Ekoli Edda clay in the recipe of the porcelain insulators, the higher the linear shrinkage, porosity, thermal stress resistance and water absorption while the lower the compressive strength, bulk density and flash over voltage of the porcelain insulators. On the other hand, sample K endow with the most encouraging result when reflecting on the properties affirmed above. Consequently, sample K is recommended for mass production of 33KVA porcelain insulator. It was noted that with 100% local raw materials, 33KVA porcelain insulator of global standard can be produced locally. Hence, exploitation of the local content for mass production of the porcelain insulators will not only lessen the cost or stop their importation, but it will also create employment opportunity, enhance and broaden the wealth of the nation.

Keywords: 33KVA; Ekoli Edda clay; Insulator; Porcelain; Electrical resistance

1. Introduction

Porcelain is a broad range of sintered ceramic artifact that has high vitreous state with qualities of luminousness and stumpy porosity [1]. Electricity supplies have fully fledged to become a vital part of human lives which required power transmission and distributions with the aid of porcelain insulators of various kind and standard. The energy demand globally is expanding substantially as a result of the spiraling up of industries and development in the human standards of living in the world [2]. The demand of electric power is relatively blown up. Local production and delivery services must be improved and buoyant in order to meet up with the demand. The efficiency of any system is mainly based on the stability of the service, keep away from slip-up. The schedule and uniqueness of insulators should be exceptional in order to sustain permanence [3,4,5].

In power transmission and supply systems, porcelain insulators have been in use for a long time. However, introduction of composite insulators indicated that they also have high mechanical strength, light weight, better insulation concert and excellent dielectric strength when compared with some conventional group of insulators. [6,7,8]. Numerous

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electrical insulators are produced of porcelain which is a mixture of three silicate minerals (feldspar, kaolin and quartz) each of which intermingle with one another to convey an exceptionally tough bond upon heating at appropriate elevated temperatures. Moreover, porcelain is the most appropriate and reliable material out of all the materials being employed for insulator production. The main reason is that porcelain has high dielectric constant, high electrical resistance and high mechanical strength [6,9].

Clay is a naturally available ceramic raw material mostly used for the production of electrical porcelain insulator and a lot of other items (e.g circuit breaker, cut out switch component for power bushing weather shed, suspension high voltage insulator etc) [1]. Usually, porcelain is being produced by sintering ceramic raw materials such as clay in the range of kaolin and others in a kiln or furnace at elevated temperatures ranging between 1200 °C and 1400 °C or more depending on the composition. The stiffness, strength, and translucence possessed by porcelain insulators occur majorly as a result of the formation of vitreous phase and the mineral mullite inside the sintered body at elevated temperatures [10]. It had been ascertain that porcelain is unconditional stoneware due to its extremely soaring density, manufacturing speedy sintering cycles, substantial mechanical strength and unswerving wear resistance.

Porcelain is predominantly made of clay, feldspar and filler material, typically quartz or alumina. Moreover, the clay [($Al_2Si_2O_5(OH)_4$] proffers suppleness to the ceramic blend, flint or quartz [SiO_2] conserves the shape of the fashioned ware during sintering while feldspar [$K_xNa_{1-x}(AlSi_3)O_8$] perform as flux [11,12,13]. Nevertheless, these three components position electrical porcelain insulators in the segment formation in expression of oxide constituents, thus the term tri-axial porcelain [14]. On the other hand, a flawless insulator does not exist, all insulators turn out to be electrically conductive when agreeably huge voltage is supplied that the electric field tears electrons away from the atoms. This is called breakdown voltage of an insulator. Some group of materials (rubber-like polymers and most plastics), regardless of the fact that they may possess lower bulk resistivity, they are still okay to prevent significant current from flowing in general utilized voltages. Hence, they are utilized as insulation for electrical wiring and cables [15].

This research is primarily on utilization of Ekoli Edda clay and other locally sourced raw materials for development of 33KVA porcelain insulator. This is done in order to encourage the utilization of local raw materials in the manufacturing of electrical porcelain insulator. It is acknowledged that numerous raw materials are available for the manufacture of electrical porcelain insulators and other ceramic products in Nigeria, but the detailed technological properties of some of the local raw materials are not readily available [16]. Therefore, locally developed technology is conscientiously an essential guide for exploring and advancing underutilized resources to improve on industrialization processes of a nation.

2. Materials and methods

The Ekoli Edda clay used in this research was sourced from Ekoli Edda community in Afikpo south Local Government Area of Ebonyi State. In its raw (mined) form, it is mottled white in colour with some blackish to light gray patches. It is moderately refractory compared with other secondary clays around the South-East region of Nigeria. When sintered up to about 1000^oC, it appears light creamy in colour. Other materials used together with the clay were feldspar, quartz and talc. They were sourced in processed form (locally) in Ceramic and Glass Technology Department of Akanu Ibiam Federal Polytechnic Unwana, all in Nigeria.

2.1. Chemical and Mineralogical Analysis

The chemical analysis of the Ekoli Edda clay, feldspar and quartz were determined using minipal4 EDS-XRF machine. The result in concentration of weight percent oxide was achieved. Also, mineralogical analysis of the Ekoli Edda clay sample was analysed using X-ray diffraction patterns (XRD) to establish the oxide mineral present in the clay.

2.2. Preparation of Raw the Materials

The sourced Ekoli Edda clay was air-dried for 168 hours and dried in oven at 110^OC for 36hours to get rid of surplus moisture from the materials. The clay was crushed using Pascal engineer machine Edge mill and sieved with mesh 100. The raw materials were used to compose eleven samples (A-K) as indicated in table 1 below.

Table 1 Table of composition Materials

MATERIALS	Samples (%)										
	A	B	C	D	E	F	G	H	I	J	K
Ekoli Edda clay	62	60	58	56	54	52	50	48	46	44	42
Quartz	19	21	23	25	27	29	31	33	35	37	39
Feldsper	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5
Talc	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5

2.3. Preparation of Body and Production Processes

The sample A was weighed out using Metra TL 3000 model electronic weighing balance, conveyed into R69 model of blunger and mixed together comprehensively with 50% of water to form a slip. The slip was properly blungered till homogenous blend was accomplished. It was filtered with a locally fabricated magnetic sieve for demagnetization of iron content from the slip composition and passed through mesh 60 to get rid of unwanted lumps. The slurry was dewatered via J W Ratchliff model of filter press and the filter paste was pug milled with the aid of R25A model of pug mill to de-air and consolidate the clay body into a firm column. The consolidated clay body was enveloped with nylon and allowed to age for 48hours. The aged clay body was shaped into 33KVA porcelain insulator via jigger jolley machine. These steps were repeated for other samples. The shaped samples ware air dried at room temperature for 120hours and 168hours in drying cabinet at 110^oC. The dried samples were first sintered at 1150^oC (biscuit fired) and the biscuit sintered ware samples were glazed with an already made (locally) glaze body by means of spraying method. The glazed porcelain insulator samples were sintered at 1400^OC via front loading, J W Ratchliff, P U 131 brand of electric kiln.

2.4. Determination of properties of the products

2.4.1. Water Absorption Test

This was carried out by a 24hrs immersion in cold water as specified by Standard Organization of Nigeria (SON). Seven pieces from each sample were pre-conditioned by drying in a ventilated oven at 110^OC until they maintain constant mass. They were then cooled to ambient temperature and weighed to note the initial weight (w1). The specimens were immersed in cold water at room temperature for 24hrs and thereafter removed. All trace of water was wiped off and the weight of the test pieces (w2) noted. The percentage water absorption was then calculated using the equation:

$$\%\, water\ absorption = \frac{saturated\ weight - dry\ weight}{dry\ weight} x\ 100\%$$

2.4.2. Linear Shrinkage

A mark (line) with sharp object were given to seven test pieces from each samples at the centre point of the top side of the test pieces at wet stage (a measured length). The changes in length of the marks (line) were considered after drying and firing to provide drying shrinkage, firing shrinkage and Linear shrinkage of the pieces.

$$\%\, drying\ shrinkage = \frac{wet\ length - dry\ length}{wet\ length} x\ 100$$

$$\%\, firing\ shrinkage = \frac{dry\ length - fired\ length}{dry\ length} x\ 100$$

$$\%\, Linear\ shrinkage = \frac{wet\ length - fired\ length}{wet\ length} x\ 100$$

2.5. Apparent Porosity and Bulk Density Before and After Glazing.

Seven test pieces from each sample were used to carry out this test. The pieces were weighed (W_1) after proper drying in oven. The pieces were removed and the specimens were soaked in water. Saturated specimens were weighed in air (W_2) and in water (W_3). The weight of the absorbed liquid (W_2 – W_1) was used to realize the volume since density of water is 1g/cm^3. The value also stands for volume of the open pores in cubic centimetres. The total volume of a specimen is (W_3 – W_1). The apparent porosity and bulk density was calculated with the equation below.

$$\% \, Apparent\ porosity = \frac{W_2 - W_1}{W_2 - W_3} \ X \ 100$$

$$Bulk\ density = \frac{W_1}{W_2 - W_3} \ x \ 100$$

2.6. Compressive Strength Test

Seven test pieces from each samples of the porcelain insulator were subjected to compressive strength tester machine (Buehler hydraulic press). The applied loads (or forces) prior to the specimens broken were recorded. Specimens were mounted one after the other on the compressive strength tester machine and load was applied axially at a steady rate by operating the pump handles in an up and down movement till fracture takes place. The force at this breaking point was recorded.

It can be calculated as thus:

$$Compressive\ Strength = \frac{Load\ applied}{Cross\ Sectional\ area}$$

2.7. Flash Over Voltage Test

The test was carried out using seven test pieces from each sample at high-tension laboratory of Belack Ceramic Ltd Obowo, Imo State, Nigeria. The porcelain insulator samples were connected correctly to the frequency flashover voltage system, the voltage of the transformer was amplified pending the flashover is observed and was recorded in the peak in KVA.

2.8. Thermal Stress Resistance Test

Seven test pieces from each porcelain insulator samples were boiled in water at temperature of 100^{0}Cand swiftly engrossed in water of O^{0}C. This procedure was repeated pending the samples got cracked and the number of cycles for each sample was recorded.

3. Results and discussion

Table2 Result of chemical analysis of the raw materials

Parameters	Ekoli Edda clay % Oxides	Feldspar % Oxides	Quartz % Oxides
SiO_2	54.90	70.7	94.56
Al_2O_3	33.99	16.42	0.64
CaO	0.51	0.40	0.001
TiO_2	0.69	1.00	0.03
Fe_2O_3	2.96	0.03	0.45
MgO	0.57	0.06	0.06
K_2O	1.00	0.30	0.30
Na_2O	0.19	0.07	3.90
Loss on Ignition	10.86	0.22	0.02
Other oxides	5.19	10.8	0.039

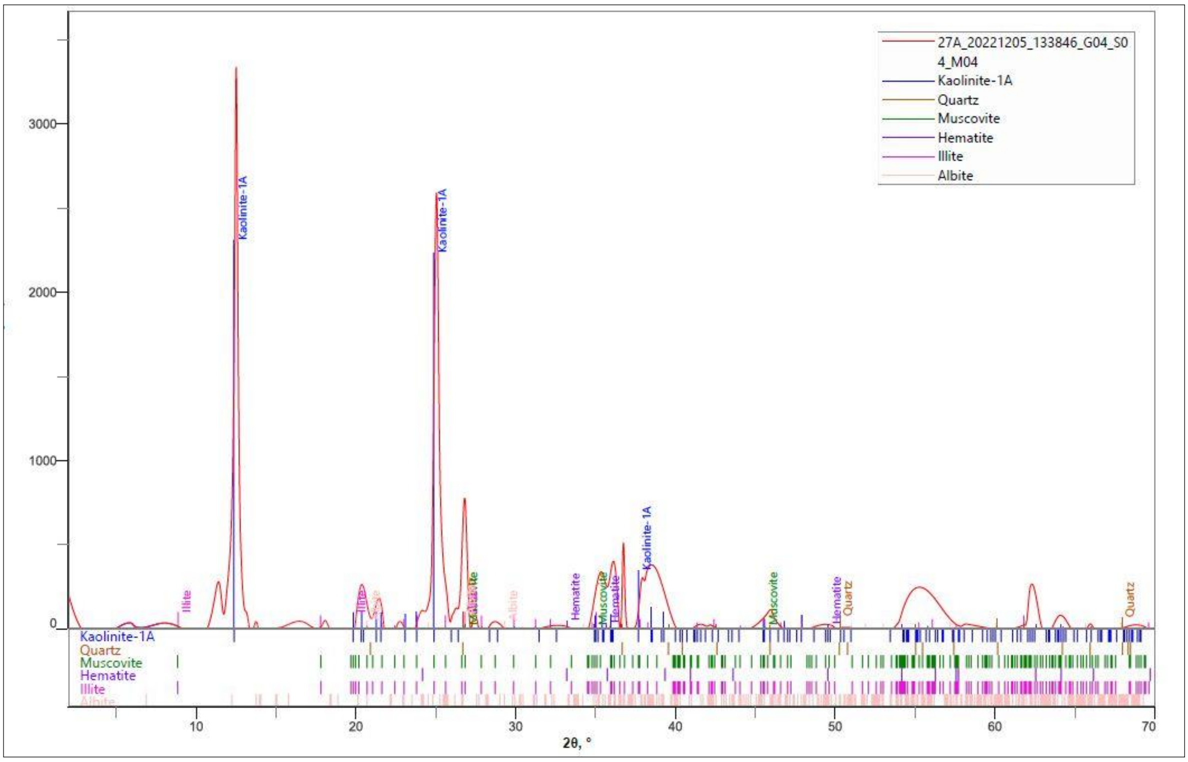

Figure 1 X-ray diffraction patterns (XRD) pattern of Ekoli Edda clay.

The result of chemical analysis of the raw clay as offered in Table. 2 revealed that the content of SiO_2 and Al_2O_3 in Ekoli Edda clay sample is 54.90% and 33.99% respectively. This signifies that the % SiO_2 in the clay is within the satisfactory range of 40% and above for typical clay valuable for porcelain insulator and refractory production [6,17,18]. In addition, the Al_2O_3 content is in line with Odewale et al., [3], Chesti study in Jack *et al* [19] and Eke [6] which reported that typical clay to be utilized for insulator production should contain 23-36% Alumina content. The mineralogical composition of Ekoli Edda clay sample consists mainly of kaolinite and quartz with others (Muscovite, illite, haematite and Albite) in small quantities (Fig.1). It was indicated that Ekoli Edda clay is a kaolinitic clay deposit based on its chemical and mineralogical compositions (Table.2 and Fig. 1). The clay mineral and other raw materials were utilized for development eleven samples (A - K) of 33KVA porcelain insulators body as declared in body composition (Table.1) shaped using jigger jolley machine.

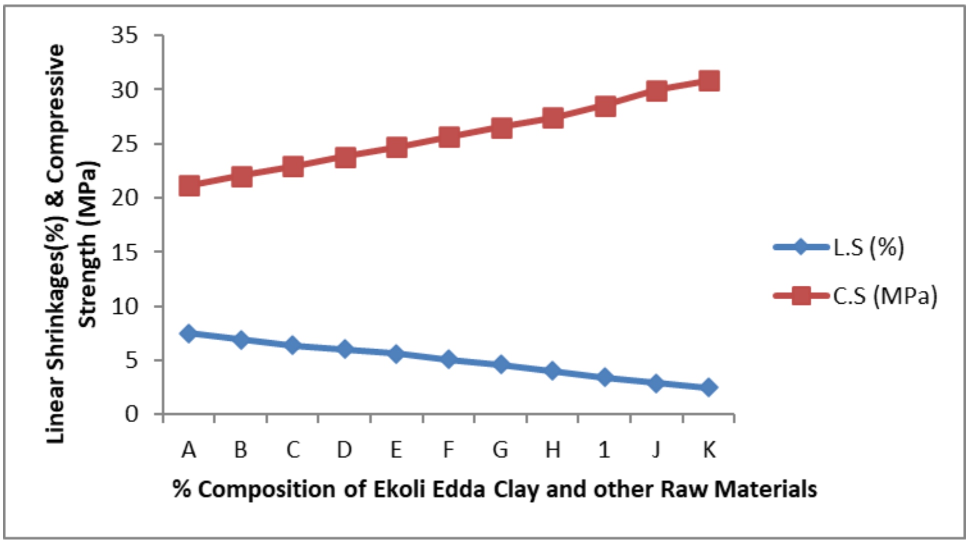

Figure 2 Effects of Percentage Composition of Ekoli Edda Clay and other Raw Materials on Linear Shrinkage and Compressive Strength of the Porcelain Insulators.

The results of the physical properties examination of the produced porcelain insulators (A-K) subsequent to sintering at 1400^{o}C indicated that the samples had % linear shrinkage of 7.5%, 6.9%, 6.4%, 6.0%, 5.6%, 5.1%, 4.6%, 4.0%, 3.4%, 2.9% and 2.5% (Fig. 2). It was revealed that the higher the percentage of Ekoli Edda clay in the body composition, the higher the linear shrinkage. While raise in the percentages of Quartz leads to decrease in the linear shrinkage (Fig. 2 & Table. 1). This may occur possibly as a result of the expansion that travels along with the low quartz to high quartz and the high quartz to high critobalite polymorphic modifications that occurred during sintering between 573°C and 1400°C [20]. Also, it may occur due to high loss on ignition (15.34%) of Ekoli Edda clays compared to that of other raw materials (Table. 2). The more the porcelain insulator bonds together during sintering, the less porous it is and the denser it develops into [21]. The values of the result obtained fell within the recommended range of 2-10% for porcelain insulator [3,22,23]. The higher shrinkage values frequently result to warping and cracking of the porcelain wares which generally bring about failure or diminution in the products strength.

Compressive strength result of the samples A - K signified that they had 21.14MPa, 22.02MPa, 22.92MPa, 23.83MPa, 24.71MPa, 25.62MPa, 26.54MPa, 27.45MPa, 28.56MPa, 29.97MPa and 30.84MPa (Fig.2). It was noticed that increase in the percentage composition of Ekoli Edda clay which brought about reduction in percentage of composition quartz (Table. 1) led to decrease in the compressive strength of the products. While increase in the percentages composition of Quartz leads to increase in the compressive strength of the insulators (Fig. 2). The soaring compressive strength values may be as a result of growth of the vitreous phase which gives the bonding strength of the porcelain insulator. Also, the availability of CaO, K_2O and Na_2O in the chemical composition (Table. 2) of the raw materials is sufficient to enhance the succession of vitreous segment growth [2]. Furthermore, the nearer to the sintering point a particular material is sintered, the more precise developed the sintering at the temperature[21], consequently decreasing porosity and linear shrinkage, increasing bulk density with increase in compressive strength values of the porcelain (Fig. 2 & 3). The obtained compressive strength recorded were within the satisfactory range when weighed against the international recommended minimum value of10MPa as stated by IS 1445 [24] and 15MPa for porcelain insulators [11,13,22,25].

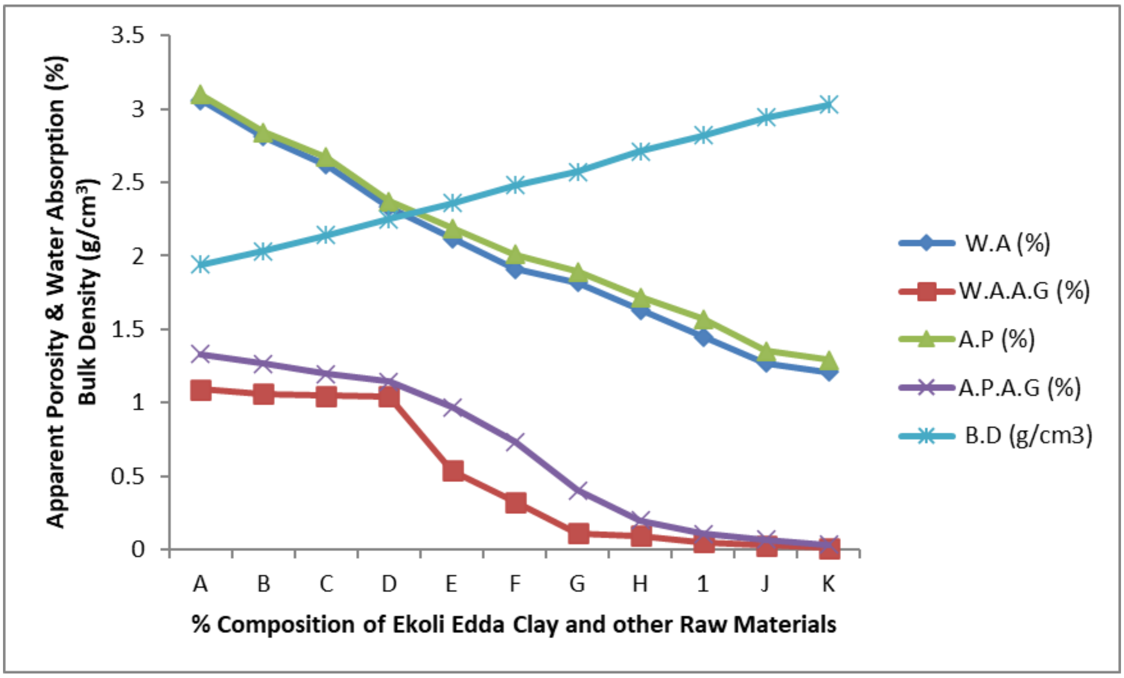

Figure 3 Effects of Percentage Composition of **Ekoli Edda** Clay and other Raw Materials on Apparent Porosity and Water Absorption of the Porcelain Insulators.

The water absorption test result revealed that samples A – K had 3.06%, 2.81%, 2.62%, 2.33%, 2.12%, 1.91%, 1.82%, 1.63%, 1.45%, 1.27% and 1.21% with equivalent values of 1.092%, 1.061%, 1.049%, 1.041%, 0.537%, 0.324%, 0.111%, 0.092%, 0.051%, 0.027% and 0.011% after glazing (Fig. 3). The raise in the percentage composition of Ekoli Edda clay in the porcelain recipe (Table. 1) brings about increase in the rate of water absorption, while raise in percentages of quartz decreases the rate of water absorption of the porcelain insulators (Fig. 3). The growth of the vitreous phase that leads to the blockage of the pores in the porcelain insulators may be attributed to their stumpy values of water absorption. Furthermore, the closer the maturing temperature of a substance is sintered; the palpable becomes the sintering at the temperature [3,21] which led to decline in cellurity, rising bulk density and leads to low water absorption before and after glazing (Fig. 3). The accomplished water absorption values of the insulator samples were within the range of values recommended by Power Holding Company of Nigeria (PHCN) [26]. Equally, for electrical application, porcelain insulator should have zero or extraordinarily low water absorption capacity since the presence of water weakens the electrical resistance of the product.

The apparent porosity values obtained indicated that samples A – K had 3.10%, 2.84%, 2.67%, 2.37%, 2.19%, 2.01%, 1.89%, 1.72%, 1.57%, 1.35% and 1.29% with parallel values of 1.331%, 1.263%, 1.196%, 1.143%, 0.968%, 0.735%, 0.402%, 0.197%, 0.108%, 0.068% and 0.031% after glazing (Fig. 3). The increase in the percentage composition of Ekoli Edda clay in the porcelain recipe which brought about the decrease in percentage of quartz (Table. 1) led to increase in the apparent porosity values of the porcelain insulators. While the higher the percentages of quartz the lower the apparent porosity of the porcelain samples were noticed (Fig. 3). This revealed that at elevated sintering temperature, thermally stimulated material travels into the pores leads to attenuation in cellurity (porosity). The apparent porosity abridged values may most likely be as a result of the formation of the glassy phase which initiates the stalemate of the minute-opening in the porcelain insulators after sintering and glazing [3,21]. The apparent porosity ranges of values achieved were in conformity with the values recommended by the power holding company of Nigeria (PHCN) for porcelain insulators [26]. Nevertheless, electrical porcelain insulators are regularly glazed for the intention of accomplishing the preferred porosity that complimentary electrical resistance with minuscule or zero water absorption capability.

The result of bulk density signified that samples A - K had 1.94g/cm^3, 2.03 g/cm^3, 2.14 g/cm^3, 2.25 g/cm^3, 2.36 g/cm^3, 2.48 g/cm^3, 2.57 g/cm^3, 2.71 g/cm^3, 2.82 g/cm^3, 2.94 g/cm^{3}and 3.03 g/cm^3 values. It was noticed that, increase in percentages composition of Ekoli Edda clay in the porcelain body leads to reduction in the bulk density of the insulators, whereas increase in the percentage composition of quartz led to increase in bulk density of the samples (Fig. 3 & Table 1). Additionally, it was obviously specified that at elevated temperature, densification came up which was significant in the attenuation of porosity and increase in bulk density. It may likely be as a result of the development of the glassy phase which instigates the impasse of the minute-opening in the porcelain insulators and increasing the bonding strength [3,21]. The results fell within the suggested (minimum of 2g/cm^3) for porcelain body except sample A that fell below it [6,11,20].

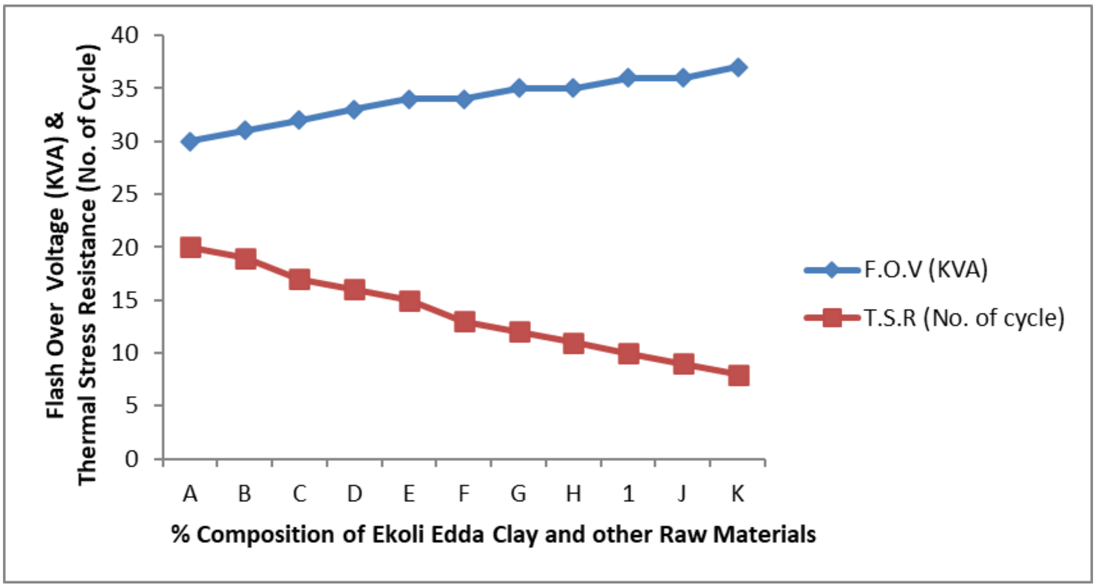

Figure 4 Effects of Percentage Composition of **Ekoli Edda** Clay and other Raw Materials on Flash Over Voltage and Thermal Stress Resistance of the Porcelain Insulators**.**

The result of flash over voltage test investigated specified that samples A – K had 30KVA, 31KVA, 32KVA, 33KVA, 34KVA, 34KVA, 35KVA, 35KVA, 36KVA, 36KVA and 37KVA (Fig. 4). It was noticed that increase the percentage of Ekoli Edda clay in the porcelain body composition which brought about the reduction in percentage of quartz brought about decrease in the flash over voltage values of the porcelain insulators. Whereas, the higher the percentage of quartz in the porcelain body recipe, the higher the flash over voltage values of the porcelain insulators (Fig. 4 & Table 1). The insulators were found to exhibit adequate flash over voltage matched up with international standard (33KVA to 37.5KVA) precondition of 33KVA porcelain insulators except samples A to C that fell below it [3,11,16,24,25,26].

The thermal stress resistance result indicated that samples A – K had 20, 19, 17, 16, 15, 13, 12, 11, 10, 9 and 8 numbers of cycles respectively. It was exposed that the higher the percentage of Ekoli Edda clay in the porcelain insulators body composition which brought about the reduction in percentage of quartz, led to increase in the thermal stress resistance values of the porcelain insulators (Fig. 4 & Table 1). Whereas, the higher the percentage of quartz which brought about the reduction in the percentage of Ekoli Edda clay in the porcelain recipe lowers the thermal stress resistance value of the insulators (Fig. 4 & Table 1). This illustrated that at high sintering temperature, thermally stimulated material motivated into the pores which brought about reduction in porosity that led to decline in thermal resistance of the porcelain insulators. Design of the shells of an insulator should be prepared in a way that expansion and contraction stresses should not have any deterioration effect on the insulator [3,21]. The obtained rates of thermal stress resistance values are higher than the minimum of 5 cycles as affirmed by Indian Standard IS 1445 [24]. Moreover, the values are within the assortment of 8 - 20 numbers of cycles recommended for porcelain insulators [3,22,27].

Furthermore, It was discovered that the higher the percentage of Ekoli Edda clay in the body composition of the porcelain insulators, the higher the linear shrinkage, porosity, thermal stress resistance and water absorption while the lower the compressive strength, bulk density and flash over voltage of the porcelain insulators. Also, decrease in the percentage of Ekoli Edda clay composition with increase in percentage of the quartz in the recipe, leads to higher compressive strength, bulk density and flash over voltage with lower linear shrinkage, porosity, thermal stress resistance and water absorption of the porcelain insulators. On the other hand, sample K endow with the most encouraging result when reflecting on the properties affirmed above. Consequently, sample K is recommended for mass production of 33KVA porcelain insulator.

4. Conclusion

The research indicated that Ekoli Edda clay is a deposit of kaolinitic clay based on its chemical description. Utilization of the clay in addition with other local raw materials for manufacturing of porcelain insulators (e.g 11KVA, 33KVA) can be profitably achieved as signified by the properties investigated above. It was discovered that with 100% local raw materials, 33KVA porcelain insulator of global standard can be produced locally. Therefore, exploitation of the local content for mass production of the porcelain insulators will not only save / lessen the cost or stop their importation, but it will also create employment opportunity, enhance and broaden the wealth of the nation.

Compliance with ethical standards

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Statement of ethical approval

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved with declaration of no conflict of interest.

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