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Effect Of Variations in Percentage Composition of $Al_2O_3.2sio_2.2H_2O$, $Kalsi_3o_8$ AND Sio_2 ON THE Properties of Locally Produced 33KVA Porcelain Insulator

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Abstract
Development of 33 KVA porcelain insulator using Nsu clay was carried out to determine the suitability of local raw materials for production of standard porcelain insulators. The clay, with other materials after characterizations were used to compose seven samples (A to G) and shaped using jigger jollying machine. The physical properties investigated after sintering at 1400 °C shows that samples A to G had percentage linear shrinkage ranging from 3.9 % to 8.9 % with cold crushing strength ranging from 20.13 MPa to 29.18 MPa respectively. The investigation revealed that samples A to G as stated above had percentage water absorption ranging from 0.71 % to 0.41 % with corresponding values of 0.023 % to 0 % after glazing respectively. The apparent porosity indicated that samples A – G had 1.94 % to 0.36 % with corresponding values of 0.25 % to 0 % after glazing, while bulk density result revealed that samples A - G had 1.80 g/cm^3 to 2.57 g/cm^3. The flash over voltage test results indicated that samples A – G had 33 KVA to 36 KVA with corresponding 14 to 9 numbers of cycles for thermal stress resistance test recorded respectively. However, samples F and G gave the most favourable result when comparing the properties stated above with international standard. Therefore samples F and G are recommended for mass production of 33 KVA porcelain insulators. The study therefore suggests that good quality 33KVA porcelain insulator of international standard can be produced locally with 100% local content. Mass production of this porcelain insulator from local raw materials will boost immensely, the economic profile of the country both locally and internationally considering that the product under study is an essential component challenging the power sector.

Keywords*: Porcelain, Nsu clay, Insulator, Flash over Voltage*

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I. Introduction

In recent times the demand for electricity distribution is quite enlarged due to population upsurge. To satisfy this demand, local production and distribution facilities must be improved and encouraged. The efficiency of any system is mainly based on the continuity of the service, avoiding faults. To maintain continuity, the performance and characteristics of insulators should be of good quality [1,2]. In power transmission and distribution systems, ceramic insulators have been in wide use from a long time. Nowadays, composite insulators are widely used because of low cost, high mechanical strength, light weight, superior insulation performance, and good dielectric strength compared with conventional type of insulators [3,4]. However, porcelain insulator still offers additional advantage of higher environmental stability. It was observed that, out of all the materials used for insulator production, porcelain is the most suitable and reliable material [5]. This is because porcelain has high electrical resistance, high mechanical strength and high dielectric constant. Clay, a natural available ceramic raw material is widely used for the production of electrical porcelain insulator and other equipments such as, circuit breaker, cut out switch component for power bushing weather shed and suspension high voltage insulator [6].

However, most electrical insulators are made of porcelain which is a blend of three silicate minerals of, kaolin, quartz and feldspar each of which react upon one another to produce a very strong bond upon subjection to heat treatment at appropriate high temperatures [7]. Porcelain is a ceramic material made by heating raw materials, generally including clay in the form of kaolin, in a kiln to temperatures between1200 °C (2192 °F) and 1400 °C (2,552 °F). The toughness, strength, and translucence of porcelain arise mainly from the formation of glass and the mineral mullite within the fired body at these high temperatures [8]. Porcelain had been found to be veritable stoneware due to its very high density, industrial fast firing cycles, tangible mechanical strength and wear resistance. Unquestionably porcelain insulators have a wide range of application in the safe transmission of electricity. It is primarily composed of clay, feldspar and filler material, usually quartz or alumina. The clay [($Al_2Si_2O_5(OH)_4$] gives plasticity to the ceramic mixture, flint or quartz [SiO_2] maintains the shape of the formed article during firing and feldspar [$K_xNa_{i-x}(AlSi_3)O_8$] serves as flux [9]. These three constituents place electrical porcelain in the phase system in term of oxide constituents, hence the term tri-axial porcelain [10].

A perfect insulator does not exist, because even insulators contain small numbers of mobile charges (charge carriers) which can carry current. In addition, all insulators become electrically conductive when a sufficiently large voltage is applied that the electric field tears electrons away from the atoms. This is known as the breakdown voltage of an insulator. Some materials such as glass, paper and Teflon, which have high resistivity, are very good electrical insulators. A much larger class of materials, even though they may have lower bulk resistivity, are still good enough to prevent significant current from flowing at normally used voltages, and thus are employed as insulation for electrical wiring and cables. Examples include rubber-like polymers and most plastics [11].

This research is focused on production and characterization of 33KVA porcelain insulator using Nsu clay. This study is done to ascertain the suitability or otherwise of our local silicate minerals for the production of this important component needed for electrical power transmission.

II. Materials And Methods

Nsu clay ($Al_2O_3.2SiO_2.2H_2O$) is a large deposit of secondary (sedimentary) clay found in Eleme Mbano Local Government Area of Imo State. In its raw (mined) form, it is dull cream in colour with some pinkish to light purple patches. It is very refractory compared with other secondary clays around the South-East region of Nigeria. When sintered up to about 1000^{o}C, it appears creamy-white in colour. Other materials used together with the clay i.e $KAlSi_3O_8$, SiO_2 (feldspar, quartz) and talc were sourced in processed form (locally) in Ceramic and Glass Technology Department of Akanu Ibiam Federal Polytechnic Unwana, Nigeria.

2.1 Chemical Analysis

The chemical analysis of the Nsu clay, feldspar and quartz ($Al_2O_3.2SiO_2.2H_2O$, $KAlSi_3O_8$, and SiO_2) were determined using minipal4 EDS-XRF machine. The result in concentration of weight percent oxide was obtained.

2.2 Preparation of Raw the Materials

The Nsu clay used was sourced and air-dried for 5 days and oven dried at 110^{o}C for 24 hrs so as to remove excess moisture from the materials. The clay was crushed using Pascal engineer machine Edge mill and sieved with mesh 100. The raw materials were weighed as shown in table 1 below.

Table 1: Table of composition

	Samples (%)						
Materials	A	B	C	D	E	F	G
$Al_2O_3.2SiO_2.2H_2O$ (Nsu Clay)	53	51	49	47	45	43	41
SiO_2 (Quartz)	28	29	30	31	32	33	34
$KAlSi_3O_8$ (Feldsper)	16	17	18	19	20	21	22
Talc	3	3	3	3	3	3	3

2.3 Body Preparation and Production Processes

Sample A was weighed out using chemical weighing balance Metra TL 3000 model and poured into the R69 model of blunger with 50% water. The clay body was properly blungered till homogenous mixture was obtained. The wet mix was passed through a magnetic sieve (locally fabricated) for demagnetization of iron content in the composition and sieved with mesh 60 to remove unwanted lumps. The mixture was dewatered using J W Ratchliff filter press and the filter cake was subjected to pug milling processes (R25A model of pug mill) to de-air and consolidate the clay body. The consolidated clay body was collected covered with a nylon and left to age for 48hours. The aged clay body was shaped into 33kva porcelain insulator using jigger jollying machine. This process was repeated for other samples. The samples ware air dried at room temperature for 72hours and one week in drying cabinet at 110^{o}C. The dried samples were sintered (biscuit fired) at 1100^{O}C and glazed with an already made porcelain glaze body composition using spraying method. All the glazed porcelain samples were sintered at 1400^{O}C using front loading electric, J W Ratchliff, P U 131 type of kiln.

2.4 DETERMINATION OF PROPERTIES OF THE PRODUCTS

2.4.1 **Water Absorption Test**

This was performed 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°C until they attained constant mass. They were then cooled to room temperature and weighed to note the initial weight (w_1). 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 (w_2) noted. The percentage water absorption i.e. the relative weight gain was calculated.

2.4.2 **Linear Shrinkage Test**

Seven test pieces from each sample were given mark (line) with sharp object measured 10cm length at the center point of the top side of the test pieces at wet stage. The changes in length of the marks (line) were determined after drying and firing to give linear drying shrinkage, firing shrinkage and total shrinkage of the pieces.

% drying shrinkage = $\frac{WL(cm)-DL(cm)}{WL(cm)} \times 100$……………………………………(1)

% firing shrinkage = $\frac{DL(cm)-FL(cm)}{DL(cm)} \times 100$ …………………………………...(2)

% Total shrinkage = $\frac{WL(cm)-FL(cm)}{WL(cm)} \times 100$ ……………………………………(3)

Where DL = Dry length, WL = Wet length, FL = Fired length.

2.4.3 Determination of Apparent Porosity and Bulk Density before and after Glazing.

These tests were carried out on seven test pieces from each sample. The pieces were weighted (w_1) after through drying. The pieces were evacuated in a vacuum vessel. Water was introduced and covered the specimens completely under pressure. 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 deduce the volume since density of water is $1g/cm^3$. The value also represents volume of the open pores in cubic centimeters. The total volume of a specimen is (w_3-w_1).

The % Apparent porosity $= \left[\frac{w_2-w_1}{w_2-w_3}\right] X\,100$ ……………………………………(4)

Bulk density $= \frac{w_1}{w_2 - w_3}$ ………………………………………………………(5)

2.4.4 Compressive Strength Test

Seven test pieces from each sample were crushed using compressive strength tester (Buehler hydraulic press). The load (force) applied before the specimens fractured were recorded. Samples were mounted in turn on the compressive strength tester and load was applied axially at a uniform rate by operating the pump handles in an up and down movement till it failed. Compressive strength in MPa was taken as the maximum pressure shown by the gauge dial which were read off from the machine tester (Buehler hydraulic press).

Crushing Pressure (Stress) = F/A ……………………………………..(6)

2.4.5 Flash Over Voltage Test

The test was carried out in a high-tension laboratory of Belack Ceramic Ltd Obowo Imo State. The porcelain insulator samples were arranged/connected properly to the frequency flashover voltage system, the voltage of the transformer was increased until the flashover is observed and recorded in the peak voltmeter (kVA).

2.4.6 Thermal Stress Resistance Test

The porcelain insulator samples were boiled in water at temperature of 100°C and immersed in water of 0°C. This process was repeated until the samples cracked and the number of cycles for each sample was noted.

III. Results

3.1 Result of chemical analysis of the raw materials

Table.2 Result of chemical analysis of the raw materials

Parameters	% OXIDES COMPOSITION		
	$Al_2O_3.2SiO_2.2H_2O$ (Nsu clay)	$KAlSi_3O_8$ (Feldspar)	SiO_2 (Quartz)
SiO_2	46.56	70.7	94.56
Al_2O_3	35.60	16.42	0.64
CaO	0.85	0.40	0.001
TiO_2	0.69	1.00	0.03
Fe_2O_3	0.05	0.03	0.45
MgO	0.65	0.06	0.06
K_2O	0.70	0.30	0.30
Na_2O	0.08	0.07	3.90
Loss on Ignition	10.90	0.22	0.02
Other oxides	3.92	10.8	0.039

3.2 Result of Physical Properties of the Product

NOTE: The physical properties of the produced porcelain insulators are stated at legend with different colours of lines indicting them in the graphs as indicated below:

Linear Shrinkage (%) = LS (%)
Crushing Strength (Mpa) = CS (Mpa)
Water absorption (%) = WA (%)
Water absorption after glazing (%) = WAG (%)
Apparent Porosity (%) = AP (%)
Apparent Porosity after glazing (%) =APG (%)
Bulk Density (g/cm^3) = BD (g/cm^3)
Flash Over Voltage (KVA) = FOV (KVA)
Thermal Stress Resistance (No. of cycle) = TSR (No. of cycle)

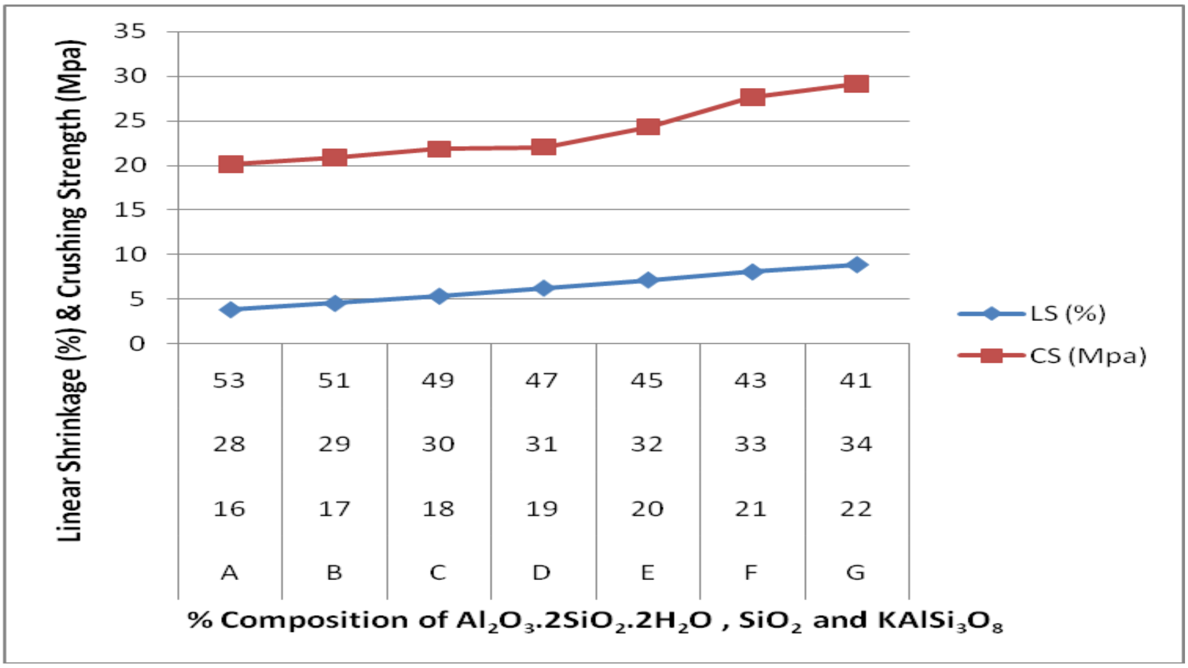

Fig. 1: Effects of % composition of $Al_2O_3.2SiO_2.2H_2O$, $KAlSi_3O_8$ and SiO_2 on Linear Shrinkage and Crushing Strength of the porcelain insulators

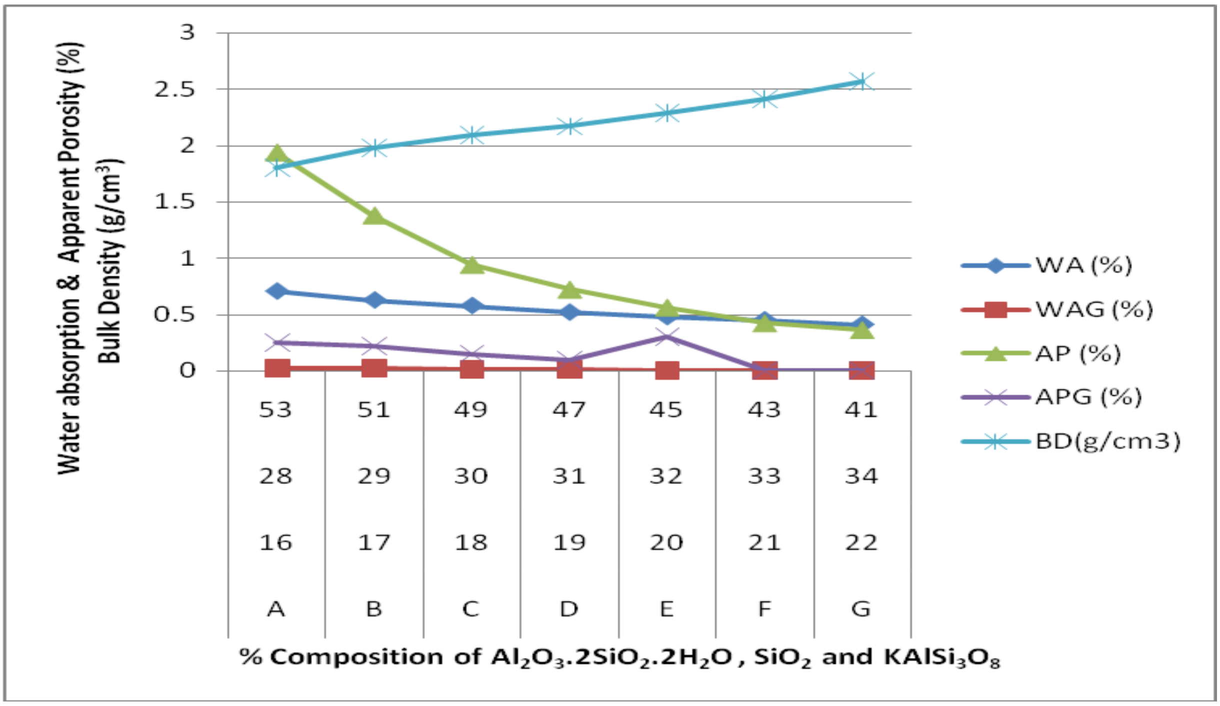

Fig. 2: Effects of % composition of $Al_2O_3.2SiO_2.2H_2O$, $KAlSi_3O_8$ and SiO_2 on Water absorption, Apparent Porosity and Bulk Density of the porcelain insulators

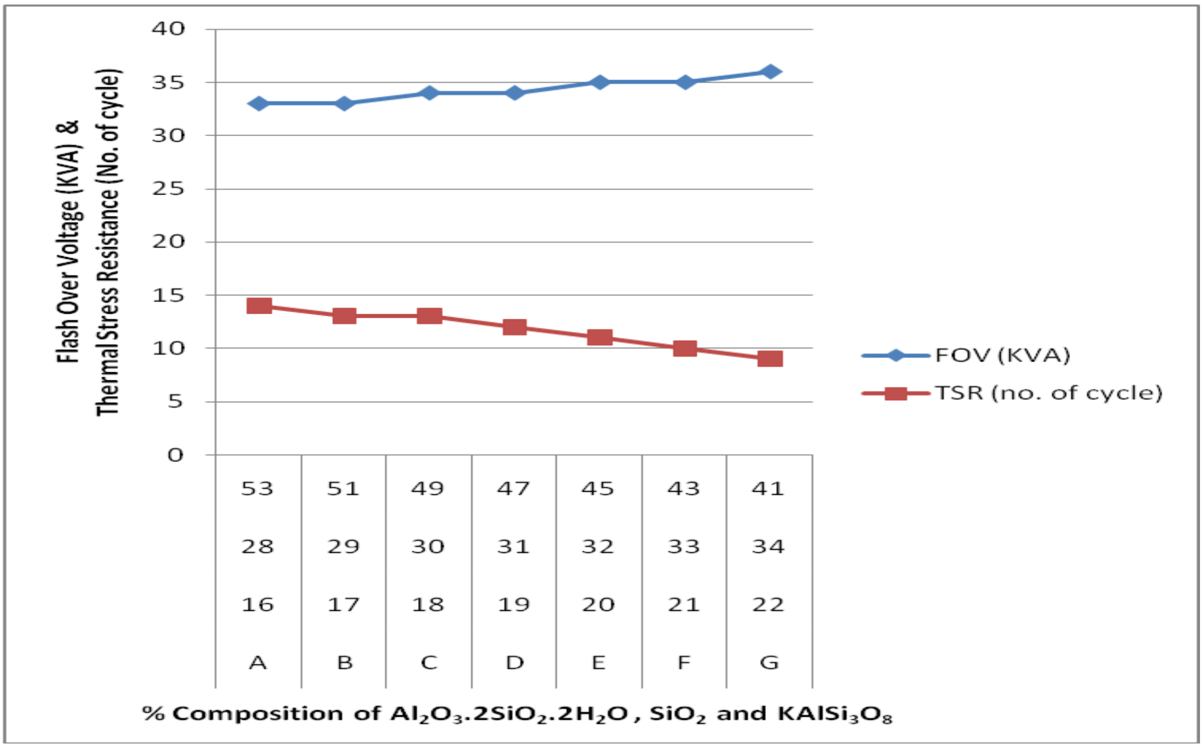

Fig. 3: Effects of % composition of $Al_2O_3.2SiO_2.2H_2O$, $KAlSi_3O_8$ and SiO_2 on Flash Over Voltage and Thermal Stress Resistance (No. of cycle) of the porcelain insulators

IV. Discussion

The result of chemical composition of the raw materials as presented in table.2 indicated that the content of SiO_2 and Al_2O_3 in $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) sample is 46.56% and 35.60% respectively. This indicates that the % SiO_2 content of the clay is within the acceptable range of 40% and above for typical clay useful for porcelain insulator and refractory production as reported by Eke [7] in 2006 and Ossai [12] in 2005. Also, the Al_2O_3 content is within the percentage required for typical clay used for insulator i.e it should contain

23-36% alumina [7]. It was revealed that $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) is a kaolinitic clay deposit based on its chemical characterization.

The results of physical properties of the produced porcelain insulators (A-G) after sintering at 1400^{o}C indicated that the insulator had % linear shrinkage of 3.9%, 4.6%, 5.4%, 6.3%, 7.2%, 8.1% and 8.9% (fig. 1). The higher the percentage of $KAlSi_3O_8$ and SiO_2 (feldspar and quartz), the higher the linear shrinkage (fig. 1), while increase in percentages of $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) led to decrease in shrinkage (fig. 1). This is may occur due to the expansion that accompanied the low quartz to high quartz and the high quartz to high critobalite polymorphic transformations that took place during sintering between 573°C and 1400°C. The more the insulator shrinks, the less porous it is, hence the denser it becomes [13]. The result therefore shows that, the value obtained are within the recommended range (2 -10%) for porcelain insulator [14,15].

The cold crushing strength result revealed that Samples A -G had 20.13MPa, 20.89MPa, 21.86MPa, 22.07MPa, 24.32MPa, 27.66MPa and 29.18MPa (fig. 1). It was observed that as the percentage composition of $Al_2O_3.2SiO_2.2H_2O$ reduces which led to the increase in percentage of $KAlSi_3O_8$ and SiO_2 brings about increase in the crushing strength of the product (fig. 1), whereas, decrease in the percentage of $KAlSi_3O_8$ and SiO_2 with increase in the percentage of $Al_2O_3.2SiO_2.2H_2O$ reduces the crushing strength of the insulators (fig. 1). Also, the high compressive strength value may be due to the formation of the glassy phase which brings about the bonding strength of the porcelain insulator. Moreover, the presence of CaO, Na_2O and K_2O in the chemical composition (Table. 2) of the materials is sufficient to enhance the process of glassy phase formation. Also, the nearer to the sintering point a material is fired, the more pronounced becomes the sintering at the temperature [13], thereby reducing porosity, increasing density and linear shrinkage with increase in crushing strength values of the porcelain (fig. 1 and 2). The crushing strength values obtained were acceptable when compared with the minimum value of 10MPa as stated by IS 1445 [16] in 1977 and international recommended minimum value of 15MPa for porcelain insulators and refractory materials [9,14].

The result of the water absorption test shows that samples A – G had 0.71%, 0.63%, 0.58%, 0.52%, 0.48%, 0.45% and 0.41% with corresponding values of 0.023%, 0.019%, 0.013%, 0.008%, 0.002%, 0% and 0% after glazing respectively (fig. 2). The increase in the percentage of $KAlSi_3O_8$ and SiO_2 in the body composition led to reduction in the rate of water absorption, while increase in percentages of $Al_2O_3.2SiO_2.2H_2O$ increases the rate of water absorption of the porcelain (fig. 2). The low values of water absorption may be attributed to the formation of the vitreous phase which brings about the blockage of the pores in the porcelain insulator. Moreover, the closer the sintering temperature of a material is fired, the more pronounced becomes the sintering at the temperature, which led to reduction in porosity (cellurity), increasing bulk density with linear shrinkage and brings about low water absorption as shown in fig. 1 and 2. The water absorption values obtained from samples were within the range of values recommended by Power Holding Company of Nigeria (PHCN) porcelain insulator standard [17]. However, for electrical application, porcelain insulator should have zero or very low water absorption capacity because the presence of water reduces the electrical resistance of the product.

The apparent porosity values recorded indicated that samples A – G had 1.94%, 1.38%, 0.94%, 0.72%, 0.56%, 0.42% and 0.36% with corresponding values of 0.25%, 0.22%, 0.15%, 0.09%, 0.3%, 0% and 0% after glazing respectively (fig. 2). It was discovered that as the percentage composition of $Al_2O_3.2SiO_2.2H_2O$ increases which brought about the decrease in percentage of $KAlSi_3O_8$ and SiO_2 led to increase in the apparent porosity values of the porcelain insulators (fig. 2), whereas, increase in the percentage of $KAlSi_3O_8$ and SiO_2 with decrease in the percentage of $Al_2O_3.2SiO_2.2H_2O$ reduces the apparent porosity and water absorption value of the insulators (fig. 2). This implies that at higher sintering temperature, thermally activated material transport into the pores causes' reduction in porosity. The low values of apparent porosity may be due to the formation of the glass phase which introduced the blockage of the pores in the porcelain insulator after sintering. Furthermore, when the sintering temperature of a material reached, the more pronounced becomes the density, which will bring about reduction in porosity and rate of water absorption as shown in fig. 2. The apparent porosity values obtained from samples were within the range of values recommended by Power Holding Company of Nigeria (PHCN) porcelain insulator standard [17]. In other to obtain the needed porosity for optimum electrical resistance with little or no water absorption capacity, electrical porcelain insulators are usually glazed.

The bulk density result revealed that Samples A - G had 1.80g/cm^3, 1.98 g/cm^3, 2.09 g/cm^3, 2.17 g/cm^3, 2.29 g/cm^3, 2.41 g/cm^3 and 2.57 g/cm^3 values (fig. 2). It was observed that, the higher the percentage of $KAlSi_3O_8$ and SiO_2 the higher the bulk density, while increase in percentages of $Al_2O_3.2SiO_2.2H_2O$ led to decrease in bulk density (fig. 2). Furthermore, the absolute value of bulk density increases with increasing $KAlSi_3O_8$ and SiO_2 content, this implies that at higher temperature densification occurs that resulting in the reduction of porosity and increase in bulk density as shown in fig. 2. This may be due to high percentage of loss on ignition of $Al_2O_3.2SiO_2.2H_2O$ (10.90%) as against $KAlSi_3O_8$ (0.22%) and SiO_2 (0.02%) as shown on table.2.

The above results fell within the recommended (minimum of $2g/cm^3$) for porcelain body [7], except samples A and B that fell out of the range.

The flash over voltage test results indicated that samples A – G had 33KVA, 33KVA, 34KVA, 34KVA, 35KVA, 35KVA and 36KVA (fig. 3). It was discovered that as the percentage content of $KAlSi_3O_8$ and SiO_2 increases which brought about the decrease in percentage of $Al_2O_3.2SiO_2.2H_2O$, led to increase in the flash over voltage values of the porcelain insulators (fig. 3), whereas, increase in the percentage composition of $Al_2O_3.2SiO_2.2H_2O$, with decrease in the percentage of $KAlSi_3O_8$ and SiO_2 reduces the flash over voltage value of the insulators (fig. 3). The products were found to be possessing adequate flash over voltage compared with international standard specification of 33KVA to 36KVA [16-18].

The thermal stress resistance test (numbers of cycles) result recorded indicated that samples A – G had 14, 13. 13, 12, 11, 10 and 9 numbers of cycles respectively (fig. 3). It was noticed that as the percentage composition of $Al_2O_3.2SiO_2.2H_2O$, increases which led to the decrease in percentage of $KAlSi_3O_8$ and SiO_2, shows increase in the thermal stress resistance values of the porcelain insulators (fig. 3), whereas, increase in the percentage of $KAlSi_3O_8$ and SiO_2 with decrease in the percentage of $Al_2O_3.2SiO_2.2H_2O$ reduces the thermal stress resistance value of the insulators (fig. 3). This implies that at higher sintering temperature, thermally activated material migrated into the pores causes' reduction in porosity which led to reduction in thermal resistance porcelain insulators (fig. 3). The design of an insulator shells shall be such that stresses due to expansion and contraction in any part of the insulator shall not lead to deterioration. Shells with cracks shall be eliminated by temperature cycle test. These values fell above minimum of 5cycles as stated by IS 1445 [16] in 1977 and is within the 8 – 20 numbers of cycles recommended for porcelain insulators [14,19].

It was discovered that as the percentage content of $KAlSi_3O_8$ and SiO_2 increases which brought about the decrease in percentage of $Al_2O_3.2SiO_2.2H_2O$ in the porcelain body, led to increase in the linear shrinkage, bulk density, crushing strength and flash over voltage of the porcelain insulators (fig. 1-3). Furthermore, increase in the percentage composition of $Al_2O_3.2SiO_2.2H_2O$ in the porcelain body with decrease in the percentage of $KAlSi_3O_8$ and SiO_2 increases the thermal stress resistance (numbers of cycles), apparent porosity and water absorption of the porcelain insulators (fig. 2 and 3) . However, samples F and G gave the most favourable result when considering the properties stated above. Therefore samples F and G are recommended for mass production of 33KVA porcelain insulator.

V. Conclusion

It was shown in this research that $Al_2O_3.2SiO_2.2H_2O$ (Nsu clay) is a kaolinitic clay deposit based on its chemical characterization. $Al_2O_3.2SiO_2.2H_2O$ can be successfully used together with $KAlSi_3O_8$, SiO_2 and talc for production of porcelain insulators such as 33KVA, 11KVA etc as revealed by the properties investigated above. It was also discovered that variation in percentage composition of the stated materials had effects on the properties of the products as indicated in discussion. This indicated that good quality of 33KVA porcelain insulator of international standard can be produced locally with 100% local content. Mass production of this porcelain insulator from local raw materials will not only save cost of importation of this material which is an essential component that is challenging the power sector, but it will also boost and expands the economy of the country.

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