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Technical Characterization of 33 kVA Porcelain Insulators Produced from Enohia and Nsu Clay

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ABSTRACT **Original Research Article**

Porcelain bodies were developed from mixtures of Nsu clay from Ehime Mbano Local Government Area of Imo state, Enohia clay from Enohia Itim Afikpo Local Government area of Ebonyi state, Ajaokuta feldspar from Kogi state and Otammiri river sand from Ihiagwa in Owerri west Local Government Area of Imo State. Batch A1 contained 50% of Nsu clay, 30% of feldspar and 20% of quartz. Batch A2 contained 45% of Nsu clay, 35 of feldspar, 19% of quartz, and 1% of talc. Batch A3 contained 55% of Nsu clay, 25% feldspar, 19% of quartz, and 1 % of talc. Batch B1 contained 50% of Enohia clay, 30 % of feldspar, and 20% of quartz. Batch B2 contained 45% Enohia clay, 35 of feldspar, 19% of quartz and 1 % of talc. Batch B3 contained 55 of Enohia clay, 25 of feldspar, 19 % of quartz, and 1 % of talc. Batch C1 contained 25% of Nsu clay, 25% of Enohia clay, 30 of feldspar, and 20% of quartz. Batch C2 contained 22.5 % of Nsu clay, 22.5 % of Enohia clay, 35 % of feldspar, 19 % of quartz, and 1 % of talc. Batch C3 contained 27.5% of Nsu clay, 27.5 % of Enohia clay, 25 % of feldspar, 19 % of quartz, and 1 % of talc. The raw clays were analyzed by x-ray diffraction and x-ray fluorescence spectroscopy to determine their mineralogical content and chemical composition. Insulator prototypes as well as test pieces were produced from each batch. The test pieces and prototypes were fired in a kiln up to 1200°C and later subjected to mechanical and electrical parameter tests. Batch C samples which were formulated from equal mixtures of Nsu clay and Enohia clay exhibited a superior mechanical and electrical performance than when each clay sample was used alone. It is recommended to further improve the quality of the starting raw materials by stringent beneficiation procedures, especially to lower the iron oxide content of the raw materials and improve dielectric characteristics of the porcelain products.

Keywords: Porcelain, Casting Slip, X-Ray Fluorescence, Cold Compressive Strength, Flexural Strength, Dielectric, Leakage Current.

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Introduction

Electrical insulators are nonconductive device used for transmission and distribution of electricity from one place to another. They play the crucial role of providing insulation between the bare conductors and the metal support towers and reinforced concrete pillars during the transmission and distribution of electricity. According to Sakoda et al (2025), their development dates back to the late 19th century, when advancements in ceramic technology enabled the production of high-performance insulating materials. They are typically made of triaxial porcelain bodies, comprising a mix of kaolinitic clay, feldspar and quarts, Olupot et al (2010).

The clay gives plasticity to the ceramic mixtures while flint or quartz maintain the shape of the formed article during firing and feldspar serves as flux, which is added to decrease firing temperature and thus to reduce cost by saving fuel (energy). Ovri (2015) The particular composition of the body as well as processing routes affects the technical composition of the final product. Important technical properties for a good electrical porcelain insulator include high dielectric strength,

high mechanical strength and low thermal expansion coefficient among others.

A good insulator should be able to withstand high voltages and electric field intensity, without breaking down or allowing current leakages. Insulators should also be able to withstand high tensile, bending and compressive loads from the overhead cables they bear. Water absorption should also be very minimal, implying quite low values of porosity, (Ologunwa et al 2021).

For distribution porcelain insulators, typically operating between 11Kv and 33KV, normal and safe leakage current range is about < 1 mA to 5 m and 5 mA to 50mA indicates impaired dielectric properties. (Waluyo et al 2021). Porcelain insulators are expected to have compressive strength above 4000 to 6800 MPa, as well as flexural strength in the range of 100 to 200 MPa and tensile strength in the range of 30 to 50 MPa, (Csanyi 2013).

The microstructure of a material plays a critical role in determining its properties and performance in various applications. By carefully controlling and engineering the microstructure, materials can be tailored to meet specific requirements and achieve desired performance characteristics in a wide range of industries.

For instance, the development of strength in porcelain has been attributed to the formation of a new mullite phase at high temperatures with the needlelike crystals interlocking with the glassy phase as well as unreacted alumina and silica to greatly improve the strength characteristics of the product, Yahya et al (2016). Adherence to standardized specifications for porosity, crushing strength, flashover voltage, and dielectric properties is essential for the reliable performance of porcelain insulators.

According to (Ani 2005), most of the porcelain insulators used in electricity transmission and distribution in Nigeria are imported from overseas, despite the abundance of potential local raw materials for their local development. This research effort aims to develop suitable high voltage porcelain insulators, from local Nigerian raw materials.

Description of Study Area

Raw material beneficiation was done at the Ceramic Workshop of Akanu Ibiam Federal Polytechnic Unwana, Ebonyi State Nigeria. Batching of raw materials, production of test pieces and prototypes, sintering of test pieces and mechanical tests were handled in the Ceramic Workshop.

Dielectric characteristics of the batches were tested in the High Voltage laboratory of the department of Electrical Engineering in Akanu Ibiam federal polytechnic. Mineralogical characterization of the raw materials used, were carried out at the Geological Research institute Kaduna, Nigeria.

Materials and Methodology

The materials used for this research work include Nsu clay from Ehime Mbano local government area of Imo state, Enohia clay, from Uro beach road Enohia Itim in Afikpo North Local Government Area of Ebonyi state, Otammiri River sand and Potash feldspar sourced from Kogi state. Analytical grade talc was sourced from a technical materials store in Enugu state. Other materials used include a ball mill with alumina grinding balls, laboratory jaw crusher, plastic buckets, various sizes of sieve screen, electronic weigh balance, platform scale, optical digital microscope.

The clay samples were soaked separately in ample water and allowed to dissolve completely in the water. The clay was stirred vigorously with a stirrer and some organic matter and other insoluble impurities floated to the top of the water, and were decanted with the excess water. This process was repeated three times, until no more impurities floated to the top of the water. Afterwards, the excess water was decanted. The residue clay was then poured on a dry nylon spread on the floor and allowed to dry for several days.

The dried clay lumps were then put in a jaw crusher and reduced to smaller fragments. Afterwards they were separately ground in a ball mill for eight hours and sieved using a mesh 80 sieve screen. The feldspar sample and quartz sample were also processed by crushing in the jaw crusher and grinding using the ball mill and alumina grinding media. They were also sieved using mesh 80 sieve screens.

Batching and Test Piece Production

The sieved raw materials were carefully weighed out, using an electronic weighing balance and combined in various proportions to form nine different batches, as shown in table 3.1 below. The weighed out raw materials were thoroughly mixed together into a homogeneous mixture. Suitable amounts of water were then added to the dry mass of each batch, to produce casting slips.

The slips were deflocculated with suitable amounts of sodium silicate solution as reported in Osonwa et al (2018). Suitable molds for porcelain insulator prototypes were produced from plaster of paris. Prototype insulators were cast from each batch and allowed to dry for several days. Cubic test pieces measuring 150mm x 150mm x 150mm were prepared for determination of the cold compressive strength of samples from each batch.

Table 3.1. Composition of the various batches

Raw Material	Percentage Composition in Batch (%)								
	A1	A2	A3	B1	B2	B3	C1	C2	C3
Nsu Clay	50	45	55	0	0	0	25	22.5	27.5
Enohia Clay	0	0	0	50	45	55	25	22.5	27.5
Feldspar	30	35	25	30	35	25	30	35	25
Quartz	20	19	19	20	19	19	20	19	19
Talc	0	1	1	0	1	1	0	1	1

A small quantity of the processed powdered sample from each of the raw materials was analyzed on Malvern Panalytical Empyrean II diffractometer, employing CuKα radiation and a graphite monochromator (λ=1.5418Å). The clay samples were meticulously ground into a powder with a particle size of 0.15 microns, as recommended for XRD analysis. These samples were used to determine the mineralogical composition of the clay samples as well as the chemical composition, by x-ray diffraction and x-ray fluorescence spectroscopy respectively.

The air dried test pieces and prototypes were then put in an electric oven and dried for six hours at 110°C. They were then transferred into a gas kiln and fired slowly up to 1200°C. After cooling overnight, the samples were brought out and inspected. The prototypes that passed virtual inspection (Sample A2, B2 and C1) were then further tested to determine their dielectric characteristic. Progressively higher impulse voltages were applied to the samples and the leakage currents during the peak impulse were automatically recorded. Lower values of leakage currents at a given voltage indicate a better dielectric behavior as reported by Khan et al (2013).

The cubic test pieces were used to determine the cold compressive strength of the samples. The test pieces were then successively mounted on a hydraulic compressive strength test machine and a uniaxial hydraulic load was applied to each specimen until failure occurred. Cold compressive strength was determined from the relation:-

$$CCS = \frac{maximum\ load\ at\ failure\ (KN)}{average\ area\ of\ breaking\ face\ (mm2)} \quad \text{……..equation 1}$$

(Osaremwinda et al 2014).

Results and Discussion

The x-ray diffraction results of Nsu clay and Enohia clay are shown in figures 4.1a, 4.1b, and 4.2a and 4.2b respectively.

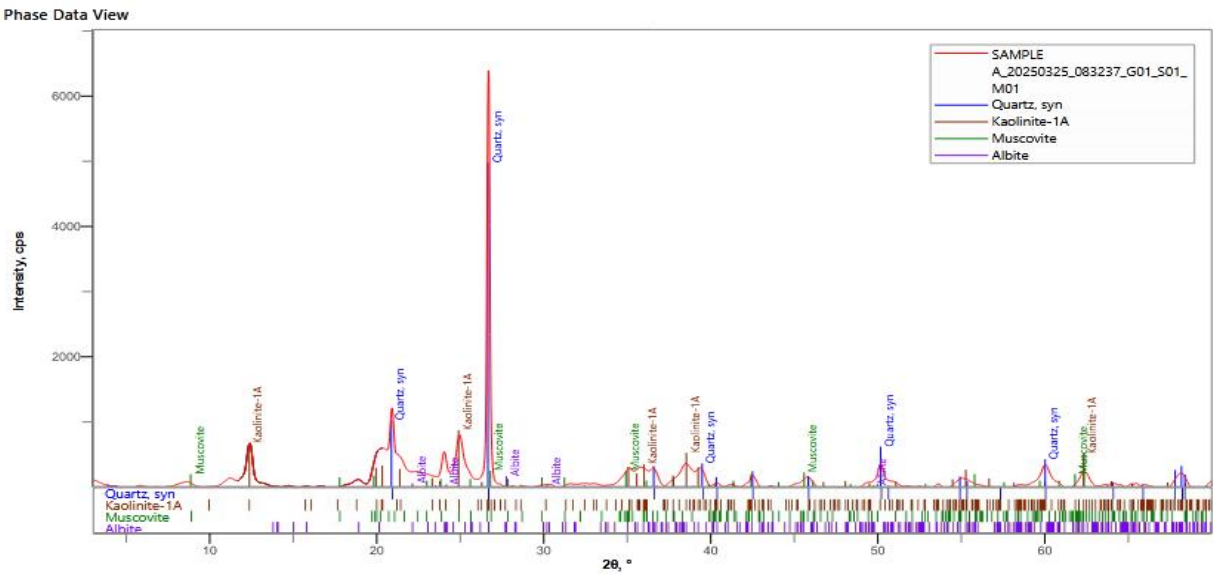


Figure 4.1a. X-ray diffraction result of Nsu clay showing the x-ray diffraction pattern generated.

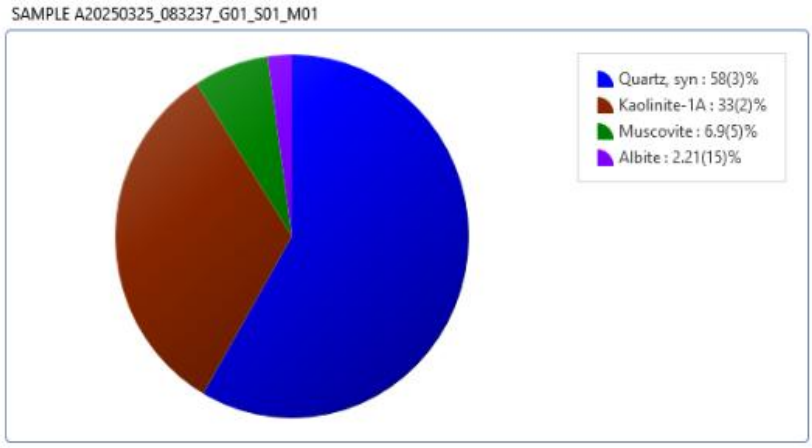


Table of results

Dataset / Weight Fraction, wt%	Value, Unit	Quartz, syn	Kaolinite-1A	Muscovite	Albite
SAMPLE A_20250325_083237_G01_S0...	0	58(3)	33(2)	6.9(5)	2.21(15)

Figure 4.1b. Plot of quantitative xrd result of Nsu clay.

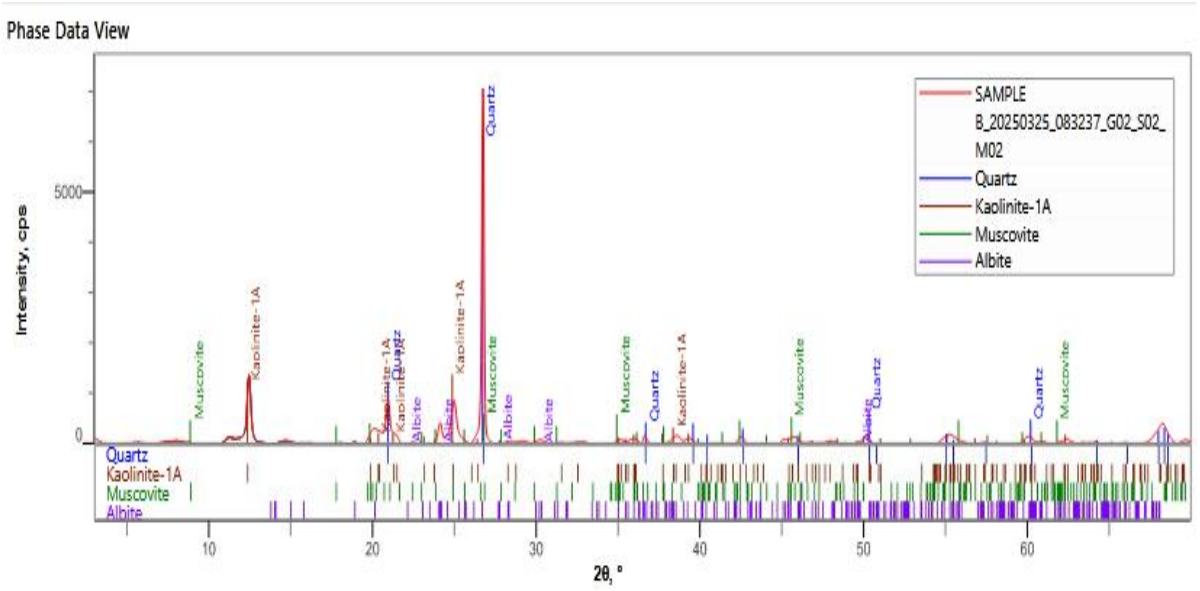
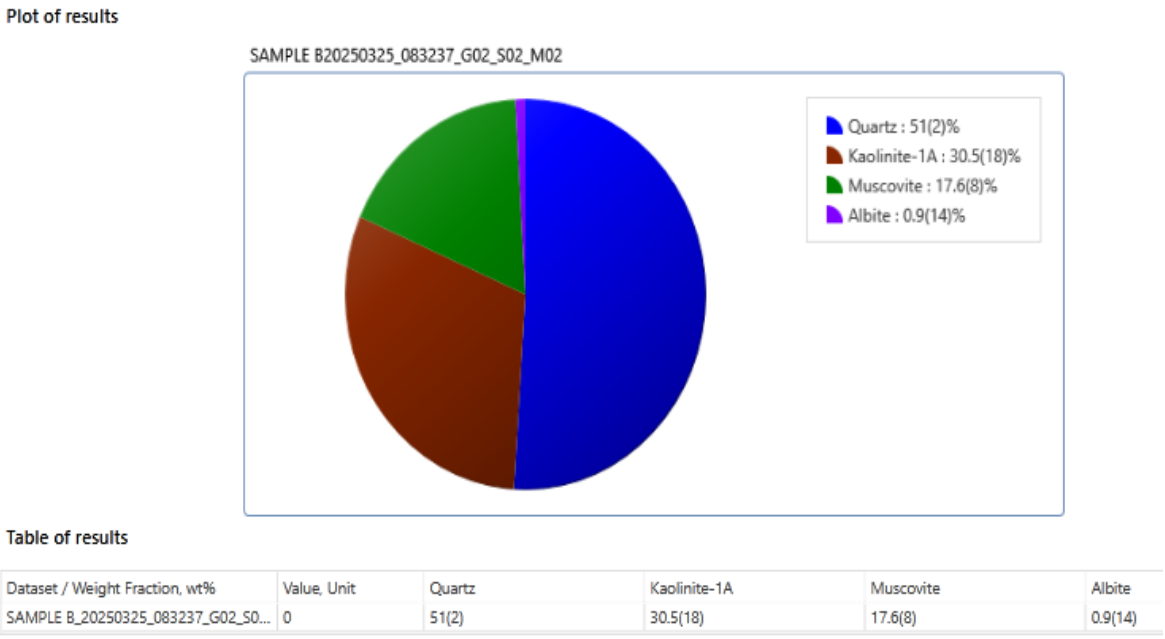


Figure 4.2a. X-ray diffraction result of Enohia clay showing the x-ray diffraction pattern generated.



Dataset / Weight Fraction, wt%	Value, Unit	Quartz	Kaolinite-1A	Muscovite	Albite
SAMPLE B_20250325_083237_G02_S0...	0	51(2)	30.5(18)	17.6(8)	0.9(14)

Figure 4.2b. Plot of quantitative xrd result of Enohia clay

Table 4.1 below summarizes the results of the chemical analyses of Nsu clay and Enohia clay, obtained by x-ray fluorescence spectroscopy. Table 4.2 shows the cold crushing strength of the samples, while table 4.3 shows the results of the impulse voltage test of the samples.

From the results of the cold compressive strength, it can be seen that the samples all fell short of the range stated in literature for high voltage porcelain insulators. However this could be because of the production procedure used to produce the test pieces, rather than compositional shortcomings. The test pieces were made by hand pressing into the mold. This method would produce poorly compacted profiles that are characterized by presence of voids which can impair mechanical strength.

The impulse voltage test of the samples shows that the tested samples produced leakage currents values between 14 to 40 milliamps, when tested with impulse voltages between 10KV to 30KV. This range of impulse voltages indicate impaired dielectric properties. However the values also show that these compositions hold promises of improved performance, if production methods are improved. The shortcomings observed in the dielectric performance could rather be due to technical challenges with production procedure and equipment, rather than composition.

Another observation that can be seen from the impulse voltage tests is that the combination of Nsu and Enohia clays, in equal proportions, produced better dielectric performance, compared to each clay use alone. The presence of iron oxide is usually deleterious to dielectric properties of an insulator, especially when it exceeds a certain threshold, typically greater than 3%, (Piva et al 2016). The presences of a distinct hematite crystalline phase at concentration above this threshold are thought to be responsible for this deleterious effect.

From the chemical analysis results of the clay samples presented in table 4.1, it can be seen that Nsu clay has 2.79% of Fe_2O_3, while Enohia clay has 9.012% of Fe_2O_3. It can therefore be expected that combining the two clays in equal proportions will result in a batch with an overall lower concentrations of iron oxide, and therefore the improved dielectric performance.

Conclusion and Recommendations

From the results discussed above, it can be concluded that Nsu clay and Enohia clay can be successfully utilized with other local ingredients, for the production of high voltage porcelain insulators. It can also be concluded that improved beneficiation procedures and production methods would produce better results with these local raw materials. The results of the impulse voltage tests on the samples also indicate that the combination of Nsu clay and Enohia clay in equal proportions would produce better technical performance, compared to when each clay is used alone. It is recommended to carry out elaborate beneficiation operations on the raw materials, to reduce the amounts of any deleterious impurities that can impair technical performance of the final product.

Table 4.1. x-Ray fluorescence results of Nsu clay and Enohia clay.

Oxide	**Sample A (Nsu Clay)**	**Sample B (Enohia Clay)**
SiO_2	66.6	55.384
V_2O_5	0.211	0.159
Cr_2O_3	0.080	0.040
MnO	0.054	0.021
Fe_2O_3	2.79	9.012
Co_3O_4	0.010	0.022
NiO	0.006	0.002
CuO	0.133	0.042
Nb_2O_3	0.029	0.017
WO_3	0.000	0.000
P_2O_5	0.159	0.094
SO_3	0.183	0.498
CaO	0.181	0.263
MgO	0.523	0.000
K_2O	0.722	1.387
BaO	0.148	0.000
Al_2O_3	24.314	29.356
Ta_2O_5	0.054	0.009
TiO_2	2.864	2.600
ZnO	0.005	0.028
Ag_2O	0.034	0.024
Cl	0.776	0.901
ZrO_2	0.121	0.142
SnO_2	0.000	0.000

Table 4.2. Cold crushing Strength Results of samples.

Sample No.	Length (cm)	Breath (cm)	Area of breaking face (cm^2)	Breaking Load (KN)	Average Cold Crushing Strength for 3 Trials.(MPa)
A1	5.1	5.1	26.01	174.325	72.33
A2	4.8	4.6	22.08	169.485	75.36
A3	5.4	4.8	25.92	174.325	56.44
B1	5.3	4.8	25.44	200.050	81.60
B2	5.1	5.0	25.50	180.550	71.29
B3	5.3	5.0	26.50	174.325	69.65
C1	5.4	5.2	28.08	269.450	99.40
C2	4.8	4.9	23.52	277.650	112.27
C3	5.0	4.9	24.50	255.443	101.66

Table 4.3. Results of impulse voltage test of samples A2, B2 and C1.

Impulse Voltage (KV)	Leakage Current (Milli-Amps)		
	Sample A2	Sample B2	Sample C1
5	8	8	7
10	14	15	14
15	22	22	21
20	28	29	27
25	35	34	33
30	40	40	38
35	45	46	44
40	50	50	48

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