IOP Conference Series: Materials Science and Engineering

Investigating the Production Quality of Electrical Porcelain Insulators from Local Materials

To cite this article: V.C. Nwachukwu and S.A. Lawal 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **413** 012076

IOP Conf. Series: Materials Science and Engineering **413** (2018) 012076 doi:10.1088/1757-899X/413/1/012076

Investigating the Production Quality of Electrical Porcelain Insulators from Local Materials

V.C. Nwachukwu and S.A. Lawal*

Department of Mechanical Engineering, School of Infrastructure, Process and Engineering Technology, Federal University of Technology, Minna Nigeria
Corresponding author email: lawalsunday@futminna.edu.ng

Abstract- Electrical porcelain insulators were manufactured from Agai and Kutigi Clay and other locally available raw material i.e. Feldspar (Kagara), Quartz (Kadna) and Talc (Kagara). Compositions were formulated using a universal triaxial porcelain composition (kaolin, 28%; ball clay, 10%; feldspar, 35% and quartz, 25%) to produce test pieces. The pulverized and mixed compositions were molded and fired at a temperature of 1250°C. The physical and electrical properties were investigated. The results show that the samples have electrical resistance between $3.52 \times 10^8\ \Omega$ and $2.05 \times 10^9\ \Omega$, and dielectric constant between 8.7 and 11.4, with respect to the frequency considered. The results of the physical tests i.e. linear shrinkage, bulk density, water absorption and failing load were also in agreement with the standard for porcelain insulators.

Keywords: Porcelain; Shrinkage; Bulk density; Water absorption.

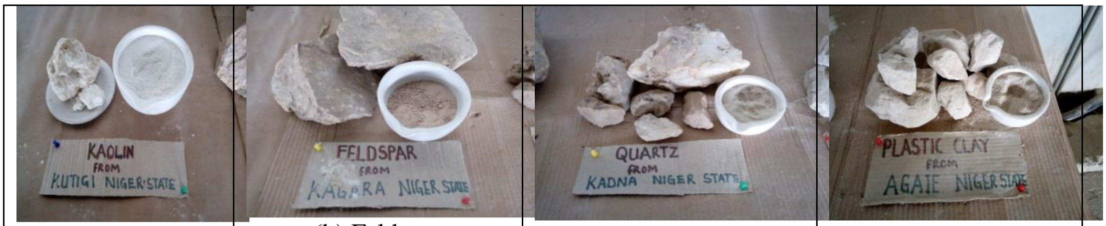
1. Introduction

Locally developed technology is considered an essential index for exploring and promoting underutilized resources, technological and economical potential of a nation's industrialization processes. It has been established that abundant raw materials are available for the manufacture of electrical porcelain insulators as well as heated ceramic wares in Nigeria. Insulators are extensively used for high and low voltage applications in generation, transmission and distribution of electrical power. The need for insulation is essentially to prevent passage of electricity to some other device or area, so that the electricity does not cause harm or cause death to those who touch areas or devices connected to the electrical insulators. Despite the enormous wide range of application and availability of raw materials, most used insulators are still being imported to Nigeria. It is hereby imperative to facilitate manufacturing of locally produced electrical insulators to meet increasing demand. Hence, the development of techniques to produce high quality porcelain units that are commercially viable and meet required standards cannot be overemphasized. Porcelain is a ceramic material made by heating raw materials, generally including clay in the form of kaolin, in a kiln to temperatures between 1,200 °C (2,192 °F) and 1,400 °C (2,552 °F). Porcelain 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 [$KxNai\text{-}x(AlSi_3)\ O_8$] serves as flux. These three constituents place electrical porcelain in the phase system in terms of oxide constituents, hence the term triaxial porcelain. Most existing literature on body compositions and processing conditions for porcelains of all kinds such as Norton [1] applies mainly to foreign raw materials, which can be quite different from the local ones in terms of chemical, mineralogical and physical characteristics. Therefore, more efforts should be channeled to establish data and procedures on the development of electrical porcelain with local raw materials. Attempts was made by Onaji and Usman [2] to develop a slip casting technique for the electrical porcelain body using ball clay materials and the result was fruitful. According to Biffi [3], the compression pressure to produce porcelain tiles must be between 350 and 450 kg/cm^2 because the density of particles must allow oxidation of organic substances and removal of gases that are generated during firing. Therefore, this study aimed at producing and characterizing porcelain insulators utilizing kaolin, plastic clay, quartz and feldspar.

2. Materials and Methods

2.1 Materials

The raw materials used in this research include Plastic Clay, Quartz. Feldspar, Kaolin and Talc as shown in Fig. 1. Other equipments used are Glost kiln (for firing the product), Electric dryer (for drying), Universal weighing machine, Crusher, Mesh (300µm), Mixer, Mould ball mill and Blunger.



(a) Kaolin (b) Feldspar (c) Quartz (d) Plastic Clay

Fig. 1. Production materials

2.2 Methods

2.2.1 Processing of kaolin, quartz, feldspar, talc and plastic clay

The raw materials were sourced from the respective location and then purified by washing and drying to remove deleterious material. This was followed by crushing operation to reduce the materials into a smaller lump. According to the percentage composition presented in Table 1, batch weighing of each materials was carried out, some quantity of water was then added to the paste and then charged into the ball mill for wet milling. Each of the ten batches were milled for 5hrs, 6hrs, 8hrs, 9hrs, 10hrs, 11hrs, 12hrs, 13hrs, 14hrs and 15hrs respectively. Thereafter, the resulting slip was made to undergo blunging for two hours to produce a liquid slurry having the tendency to flow. Blunging operation promotes balance plastic charge and better integration. The slip from the blunger was emptied into a sieve of about 300µm size to determine the particle and then passed through a classifier to ascertain appropriate particle size. After classifying the slip, it which was satisfied okay was then magnetized by passing it through a magnetic sieve to remove the iron content. The resulting material was then kept for 24hrs for efficient ageing and degassing. Other material percentage composition was varied except for talc that was kept constant throughout the whole process.

2.2.2 Casting process

Solid state casting was the method employed in this process. A mould made of Plaster of Paris (POP), was used in each of the batch casting. The suspension was poured into porous plaster moulds where capillary forces sucked the water into the moulds - from the slip leading to a steady dispersion of clay particles in dense face to face packing on the inside surface of the moulds in a process called hollow casting process. It is called a hollow casting process because draining of water from the slip is required. After draining, the resulting mixture could stay in the mould for 3hrs before pulling it out from the plaster mould. The resulting casted samples were arranged in iron trays and allowed to air dry for three days and then - sent into a ceramic electric dryer to further drying for six hours. The mould used in the casting process is shown in Fig 2.

Fig. 2: Casting mould made of POP

2.2.3 Fettling of porcelain insulators

Fettling is a post casting operation carried out to remove rough edges and contours from the casted ceramic (Fig. 3a) products to get them ready for drying and firing. In this experiment, the surfaces of the resulting casted products were then fettled with the help of a grit paper and then a little foam, socked with water was used to remove the deposits before glazing. Figure 3b is a sample of the fettled product.

(a) Casted specimen; unfired, unglazed and unfelted.

(b) Fettled specimen; unfired and unglazed

Fig. 3: Produced samples

2.2.4 Glazing

The fettled products were then subjected to glazing prior to loading into Glost kiln furnace for firing. Zinc oxide was mixed with powdered calcium carbonate and milled. The resulting mixture was then sprayed on the produced specimens.

2.2.5 Drying and firing

The glazing operation was followed by a drying process. The products from the casting operation, were placed on a wooden board for 24 hours for air drying. This was followed by oven drying at 105^0C for 6 hours to eliminate vapour. Fig. 4 shows the fired samples.

Fig. 4: Fired sample

2.3 Determination of insulator properties

The linear shrinkage was determined using the three equations below [1; 4; 5] while the value of the water absorption was obtained using Equ. 4.

Drying shrinkage = $\frac{L_W - L_d}{L_d}\ X\ 100$ 1

Fired shrinkage = $\frac{L_W - L_f}{L_d}\ X\ 100\%$ 2

Total shrinkage = $\frac{L_W - L_f}{L_W}\ X\ 100\%$ 3

Where L_W = Wet length, L_F = Fired length and L_D = Dry length.

Water Absorption = $\frac{W_s - W_d}{W_d}\ X\ 100\%$ 4

Where W_S = Soaked weight after boiling for 100^0C for 2 hours and W_d = Dry weight.

Also, the strength of the porcelain insulators was investigated by determining their failing load according to [4]. The failed load was determined using Equ. 5, while loss in ignition was determined using Equ. 6. The percentage residue was determined using Equ. 7:

$\sigma_T = \frac{\rho}{A}$ but $A = b * t$ hence $\rho = \sigma_T(b * t)$. 5

And the young modulus can be calculated using the formula below: $E = \sigma_t/e$, where σ_t = tensile strength of the composite material, ρ = Maximum load, b = width and t = thickness.

$L.O.I = \left(\frac{m_2 - m_3}{m_2 - m_1}\right) x\ 100$ 6

Where m is the mass of the porcelain.

$\%Residue = \frac{Dry\ Weigth\ x\ 100}{A}$ 7

Where A, is the mass of the sample obtained using; A = (Litre)(Weight) – 1000dm^3 x 1.625.

2.4 Insulation resistance, dielectric strength and x-ray fluorescence spectrometer (XRF)

A 5kV Megger (model No:AM-5KV) insulation tester was used to measure the insulation resistance of each sample at the Enugu Electricity Distribution Company (EEDC) after firing at 1250^O. Copper plates with terminal heads were placed on both side of the porcelain material and voltage of 5000V was passed through the porcelain material and the resistance of the insulator was then measured from device in MΩ and GΩ. The dielectric strength test was measured at Enugu Electricity Distribution Company (EEDC) Achalla Layout office in Enugu, Enugu State using Hipotronics (model number 880/PL-10mA-B). An x-ray fluorescence spectrometer was used in determining the chemical compositions of the raw materials. This test was conducted on the five samples using an X-Ray fluorescence spectrometer method available at National Geoscience Research Laboratory (NGRL) Kaduna and the result of the experiment is tabulated in the appendices.

3. Results and Discussions

3.1 Constituent charge materials and chemical analysis of constituent materials

The constituent percentage composition of each material used in the production of each of the ten specimen is presented in Table 1, while the ore composition and the result are presented in Table 2.

Table 1: Constituent percentage compositions of porcelain insulators

Specimen	Feldspar	Quartz	Clay		Talc
			Kaolin	Plastic clay	
	%	%	%	%	%
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 2: Chemical characterization of the materials (kaolin, plastic clay, feldspar, quartz and talc).

Oxide Composition %	Feldspar	Quartz	Kaolin	Plastic Clay	Talc
SiO_2	68.4	94.5	66.7	58.75	52.9
Al_2O_3	17.9	0.06	23.71	27.6	17.38
SO_3	ND	3.07	ND	1.2	ND
K_2O	9.33	0.39	0.31	0.38	0.31
CaO	0.19	0.6	0.8	0.16	2.1
Fe_2O_3	0.73	0.422	0.478	0.637	8.4
MgO	0.16	ND	0.08	ND	3.73
SrO	0.032	ND	0.024	0.014	0.088
PbO	0.017	0.015	ND	0.019	ND
BaO	0.065	0.03	ND	0.08	ND
MnO	0.08	0.025	0.005	0.018	0.37
TiO_2	0.12	0.11	0.133	0.11	0.559
V_2O_5	0.01	ND	ND	0.035	0.02
Cr_2O_3	ND	0.01	ND	0.032	0.772
CuO	0.02	0.029	0.016	0.024	0.077
Cl	ND	ND	ND	0.604	ND
ZnO	ND	0.055	0.002	0.004	0.01
Na_2O	2.13	ND	0.23	ND	0.02
ZrO_2	0.022	0.054	0.02	0.171	ND
Ta_2O_5	ND	ND	ND	ND	0.07
NiO	ND	ND	ND	ND	1.28
L O I	0.73	0.63	7.49	10.16	11.91

ND = NOT DETECTED

It was observed from Table 2, that the percentage of silica present in the quartz is about 94.5% which follows the requirement. The clay is also an alumino-slilicate clay judging from the silica and alumina content of the clay which was 58.75 and 27.6% respectively. Ta_2O_5 and NiO were detected in Talc but absent in the other constituents. About 0.604% of chlorine was found in plastic clay and then absent in other constituent materials.

3.2 Physical tests of the produced specimens

Several physical tests, which includes bulk density determination, shrinkage test (total shrinkage, fired shrinkage and dry shrinkage), failing load and water absorption were carried out on the produced specimen and the result is presented in Table 3, it should be noted that physical test was not carried out on Specimen 1 and 2, because they did not come out well after the casting operation (they stuck on the mold after casting).

Table 3: Physical properties of produced porcelain insulators

				Specimen				
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 (g/cm3)	2.14	2.16	2.29	2.37	2.42	2.49	2.74	2.52
Failing Load (kN)	1.97	2.55	2.57	2.67	2.69	2.73	1.92	3.01

From Table 3, it was observed that average total shrinkage for each of the samples was within the recommended value for porcelain production [6]. Higher shrinkage values result in warping and cracking of the porcelain wares resulting in reduction in its strength. Specimen 9 with a shrinkage percentage of 5.76% warped after the firing operation while Specimen 3 with a shrinkage percentage of 8.70% came out well but with cracks.

These observed anomalies are also as a result of the high shrinkage values, high feldspar content (in the case of specimen 9), and low amount of feldspar (in the case of specimen 3) and quartz since quartz serves as the main refractory backbone. But generally, the shrinkage values are still within the accepted ranges. Also, from Table 3, it was noted that water absorption decreases with increase in kaolin content and decrease in feldspar content. Feldspar as a flux which permits better flow of the mixture and allows for reaction with impurities to form slag which are burnt off at elevated temperatures during firing.

It was noted that too low amount of feldspar result in the formation of immature wares characterized with the formation of cracks and warpage. It could also result in high water absorption and consequently, high shrinkage. It is therefore advisable to use moderate amount of feldspar in porcelain insulator preparation. Similarly, the bulk density experienced a general slight reduction with increasing amount of kaolin as feldspar was reducing as shown in Table 3. This was because of higher value of loss on ignition of kaolin (7.49) as against feldspar (0.73) given by the chemical analysis shown in Table 4. Bulk density is an important property in porcelain wares. Bulk densities of the mixed samples lie within the range of 2.14 – 2.74g/cm^3 which fall in standard requirements for porcelain body [7]. It was observed from Table 3 that the failing loads increases with increase in percentage of kaolin, this goes to show that porcelain strength are enhanced as kaolin content is increased.

3.3 Electrical properties of the porcelain insulators

3.4

The results of the test for electrical resistivity and di-electric strength carried out for the porcelain specimens are shown in Table 4.

Table 4: Dielectric properties of the produced insulator samples

Sample	Frequency (Hz)	Dielectric Constant	Loss Angle	Dissipation Factor
3	50	11.4	8.06	0.133
4	100	11.1	7.21	0.127
5	1000	10.9	7.01	0.119
6	10000	10.3	6.93	0.112
7	20000	9.7	5.47	0.079
8	30000	9.4	4.22	0.061
9	40000	11.1	3.8	0.056
10	50000	8.7	3.2	0.052

It can be seen from Table 4 that the values of the di-electric test ranges between 8.7 and 11.4. Though increases were observed in the value of dielectric constant for samples 3, 4 and 11 dues to the physical defects associated with the porcelain insulators. The ranges of the values of dielectric constant observed for the samples suggestive of a good insulating material. Good insulating materials are materials with dielectric constants below 12 [8-10]. The significance of the reduced dielectric constant is that the charge storage capacity of the insulator is low which also result in low possibility of electrical shock. The values of the electrical resistance of the tested insulators is presented in Table 5.

Table 5: Measure electrical resistance and the corresponding voltage applied and leaked voltage

Specimen	Voltage (Volts)	Resistance (Ω)	Leakage Current
3	5000	3.52×10^{8} Ω	1.42×10^{-5} A
4	5000	4.06×10^{8} Ω	1.23×10^{-5} A
5	5000	5.25×10^{8} Ω	9.52×10^{-6} A
6	5000	5.27×10^{8} Ω	9.48×10^{-6} A
7	5000	9.13×10^{8} Ω	5.48×10^{-6} A
8	5000	1.15×10^{9} Ω	4.35×10^{-6} A
9	5000	3.62×10^{8} Ω	1.38×10^{-5} A
10	5000	2.05×10^{9} Ω	2.44×10^{-6} A

It can be seen from Table 5 that the values of the electrical resistance of the produced specimen ranges between 3.52×10^{8} Ω and 2.05×10^{9} Ω. This shows that the electrical resistance range of the produced materials is more than the recommended range of 1.0×10^{6} Ω [11-12]

4. Conclusions

This research focused on local development of electrical porcelain using kaolin, ball clay, feldspar, quartz and talc, sourced from Niger State, Nigeria. Mechanical, physical and electrical tests were carried out on the produced material. The outcomes of the research are hereby summarized as follows;

1. Good porcelain bodies were produced from kaolin clay, ball clay, feldspar, talc and quartz. Sample 8 with composition 20.63% kaolin, 7.37% plastic clay, 35% feldspar and 35% quartz and 2% talc, was found to possess the highest failing load of 8.0kN, water absorption of 2.5%,

bulk density of 2.49 g/cm^3, with appreciable insulation resistance of 1.15 Giga ohms at injection of 5,000 volts.
2. That using the locally available raw materials, electrical porcelain with good dielectric properties can be produced since it has dielectric constant below 12.
3. The insulators may be employed for usage at high frequencies where the dissipation factor is correspondingly lower.

References

[1] Norton, F.H (1980), Ceramics for the Artist Potter, Addison-Wesley Publishing Company Inc., Massachusetts, USA.

[2] Onaji, P. B. and Usman M, (1988), Development of Slip Cast Electrical Porcelain Body: Bomo Plastic Clay, Nigeria Journal of Engineering (NJE), Vol. 5, No.2, pp.89-96.

[3] Biffi GO (2002) Grit Porcelain: Manual of Manufacture and Techniques of Employment. Ed. Faenza Editrice do Brasil.

[4] ASTM C356-17, Standard Test Method for Linear Shrinkage of Preformed High-Temperature Thermal Insulation Subjected to Soaking Heat, ASTM International, West Conshohocken, PA, 2017, www.astm.org

[5] Clay Shrinkage Testing (2010), [online], Accessed 13th August 2017, Available from World Wide Web: http://www.potters.org/subject01835.htm

[6] Chester J.H (1973), Refractories, Production and Properties. The Iron and Steel Institute, London, Pp 4-13, 295-315.

[7] Omotoyinbo.J.A and Oluwole O.O (2008) “Working Properties of Some Selected Refractory Clay Deposits in South Western Nigeria” Journal of Minerals and Materials Characterization and Engineering, Michigan Technological University, USA. 7(3),233-245

[8] Anih, L.U (1988). Characterization of Kaolin-Quartz-Feldspar Triaxial Porcelain for Insulation Application (Msc). Obafemi Awolowo University, Ile-Ife.

[9] Salawu, E. Y., Okokpujie, I. P., Afolalu, S. A., Ajayi, O. O., & Azeta, J. (2018). INVESTIGATION OF PRODUCTION OUTPUT FOR IMPROVEMENT. International Journal of Mechanical and Production Engineering Research and Development, 8(1), 915-922.

[10] Azeta, J., Okokpujie, K. O., Okokpujie, I. P., Osemwegie, O., & Chibuzor, A. (2016). A Plan for Igniting Nigeria’s Industrial Revolution. International Journal of Scientific & Engineering Research, 7(11), 489.

[11] Anih, L. U. (1997) "Characterization of kaolin- feldspar quartz triaxial porcelain for insulator applications" Proceedings of Electric Power Engineering Conference University of Nigeria, Nsukka

[12] Anih L.U. (2005) “Indigenous manufacturer and Characterization of Electrical Porcelain Insulator” Nigerian Journal of Technology, 24 (1).