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CHARACTERIZATION OF IBERE CLAY FOR THE PRODUCTION OF ELECTRICAL PORCELAIN PIN INSULATORS

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ABSTRACT

The characterization of Ibere clay for the production of porcelain pin insulators was carried out for both the locally made porcelains and the standard. Test samples were made by varying the compositions of feldspar and quartz needed to form a mouldable plastic body with the clay. The following properties were determined: electrical resistivity, apparent porosity, water absorption, bulk density and linear shrinkage. Results obtained showed that apparent porosity, water absorption and electrical resistivity increased with increase in the composition of the non-plastic materials (feldspar and quartz) while bulk density and linear shrinkage decreased with increase in non-plastic materials. The chemical composition of the clay (43.94%SiO_2, 26.54%Al_2O_3) compares well with previous works (40-60%Si_2O, 25-45%Al_2O_3) for the production of ceramic refractories. Linear shrinkage (8.33-9.68%), apparent porosity (10.81-17.30%) and water absorption (5.41-10.84%) are in conformity with standards (7-10%, 16.45% and 8.20% respectively). Electrical resistivities recorded (0.79-1.39 x $10^7 \Omega$-m) are in agreement with results obtained for standard (0.45 x $10^7 \Omega$-m). These results are obtained in samples containing 50-70% clay, 20-30% feldspar and 10-20% quartz. It is therefore concluded that imported porcelains used by Power Holding Company of Nigeria (PHCN) can be replaced with porcelains made from Ibere clay.

KEYWORDS: Characterization, porcelain, clay, feldspar, quartz, porosity, electrical resistivity.

INTRODUCTION

The term porcelain refers to a wide range of ceramic products that have been fired at high temperature to achieve vitreous or glassy qualities such as translucence and low porosity. Porcelains are vitrified and fine grained ceramic whitewares, used either glazed or unglazed. They are widely used in household, laboratory and industrial applications. For technical purposes, porcelain products are designated as electrical, chemical, mechanical, structural and thermal wares (Olupot, 2006).

Ceramics is made up of earth, shaped with water, dried in air, and made durable by fire. Its manufacture comprises the same steps as baking; grinding, mixing with water, kneading, shaping, drying and firing. The essential point in the making of ceramics is that, the product is shaped in the cold state and then exposed to heat. As pottery developed, it was embellished by patterns, colouring, and glazing. (Rado, 1969).

The primary components of electrical porcelain are clay, feldspar and flint (quartz or silica), all characterized by small particle size. *The clay gives plasticity to ceramic mixtures, flint or quartz maintains the shape of the formed article during firing and feldspar serves as flux*, which is added to decrease firing temperature and thus to reduce costs by saving fuel (energy).

Electrical porcelains are widely used as insulators in electrical power transmission system due to the high stability of their electrical, mechanical and thermal properties in the presence of harsh environments. These are the reasons for their continued use over the centuries despite the emergence of new materials like plastics and composites. They form a large base of the commonly used ceramic insulators for both low and high tension insulation. They are considered to be one of the most complex ceramic materials and represent the most widely studied ceramic system (Dana et al, 2004).

By varying the proportions of the three main ingredients, (clay, feldspar and quartz) it is possible to emphasize the thermal, dielectric or mechanical properties of the porcelain. For electrical insulation applications, porcelains are expected to meet minimum specifications of the latter two (dielectric and mechanical) properties (Olupot, 2006).

The porcelain need of Nigeria – a developing industrial nation – is potentially enormous, especially in realization of present government's 7-point agenda which include rural electrification. The country expends a lot of foreign exchange importing porcelains. Yet, a lot of clay deposits abound in the country, which can be developed to meet our local needs.

The possibility of developing some of these mineral resources for the production of porcelain locally is the focus of this research.

OCCURRENCE OF KAOLIN IN NIGERIA

The bulk of kaolinite clay deposits in the country are either of sedimentary or residual in origin and are usually associated with granitic rocks. Occurrences of kaolin are known to exist in different parts of the country and specific abundant deposits have been identified in parts of Enugu, Anambra, Abia, Imo, Katsina, Kaduna, Ondo, Ogun, Oyo, Bauchi and Borno States, etc. (Aliyu, 1996; Nwajagu, 2005, Onyemaobi, 2002).

Adekale (2001) put the quantity of reserves at 350 million tonnes while Aliyu (1996) put the figure at about 800 million tones proven/probable deposits. He added that further field studies are required for detailed exploration and drilling to determine total reserves. In 2005, the Federal Ministry of Solid Minerals Development put the figure in the following way, *"An estimated reserve of 3 billion tonnes of good kaolinite clay has been identified in many locations in Nigeria"* (msmdng.com, 2005).

Nwajagu (2005) stated that many of these kaolinite clay deposits have been studied and characterized, and some of them are already finding various industrial applications.

INDUSTRIAL POTENTIAL OF KAOLIN IN NIGERIA

Kaolin is a versatile industrial mineral with wide application. It is used as a raw material in paper making, rubber, plastic, paints, pharmaceuticals, soap, refractories, cement, fertilizers, textile, insecticides, etc. Medicinally, it is used as absorbent and in anti-diarrhea formulations (Aliyu, 1996).

According Mark (2007), for the wide range of industrial applications, it is estimated (in Aliyu, 1996) that the annual national demand for kaolin would be over, 150,000 tonnes. Adekale (2001) reported that the demand is over 100, 000 tonnes per annum, and that the production in the country is less than 20, 000 tonnes per annum, while consumer industries include: paper, ceramics, paints,, rubber, plastics, soap, fertilizer, pharmaceutical, insecticide, cosmetics, building (titles and bricks). Kaolinite clays are found very suitable as moulding clays in cast iron and steel foundries (Nwajagu, 2005).

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Porcelain Raw Materials

The raw materials for the production of porcelain are grouped into two: the plastic raw materials and the non-plastic raw materials.

(a) Plastic Raw Materials: This group is essentially clay. Plasticity is defined as the property that enables a material to be changed in shape without rupturing by the application of an external force, and to retain that shape when the force is removed or reduced below a certain value (Moore, 1965). Clay has this property.

(b) Non-Plastic Materials

The function of non-plastic materials is twofold:

(i) they are added to clays which are too plastic (having too great a proportion of colloidal particles) to reduce plasticity and thus eliminate cracking or distortion during drying and firing.

(ii) non-plastic materials make it possible for the desired properties to be obtained at lower firing temperatures. (Rado, 1969).

MATERIALS AND METHOD

All experiments, except those involving winning of clays, chemical analysis and firing were carried out in department of Materials and Metallurgical Engineering, Federal University of Technology, Owerri. Sieving and sieve analyses were done at the Erosion Studies; moulding was performed at the Materials Laboratory while electrical resistivity test was carried out at Physics Laboratory and chemical analysis was done at Central Research Laboratories, National Root Crop Research Institute (NRCRI) Umudike

Some of the materials and equipment used for this research include a hoe or spade, raw (as-mined) clay, an Atomic Absorption Spectrometer, pan mill, American Society for Testing and Materials (ASTM) sieves, hydraulic moulding press, electric furnace and oven, electric water heater, digital weighing balance, drying cloth, strong thread or fine cord, Fluke-27 multimeter and spring balance.

Winning of Clay

The raw materials used were sourced from the following sites/deposits:

(1) Clay was mine from Umulu/Ngwugwo deposit, Ibere, Ikwuano Local Government Area, Abia State, by means of a hoe.

(2) Feldspar and quartz were sourced from a dealer at Umuahia, Abia State.

For identification purposes, in this work, the raw materials are designated as ‘I’ for Ibere clay, ‘F’ for feldspar and ‘Q’ for quartz.

Porcelain Production

The procedures include sample preparation or clay processing, moulding (pressing), drying and firing.

Preliminary Crushing/Drying: The as-mined clay sample which was in lumps was crushed to smaller grain sizes using hammer in order to liberate the mineral constituents and to ease drying and grinding. The feldspar and quartz were obtained as already processed samples. The crushed clay was sun-dried before grinding. Drying was necessary, as damp clay is difficult to crush or grind.

Grinding: The dried clay sample was ground into powder form using pan mill in PRODA Ceramic department.

Sieving/Sizing: The ground-up clay was sieved to pass through a set of three sieves of aperture 425µm, 300µm and 125µm. Thus, three classes of aggregates were obtained for use: the coarse aggregates passing 425µm but retained on the 300µm sieve; the medium passing 300µm but retained on the 125µm sieve; and the fines passing 125µm but retained on the pan. Aggregates retained on the 425µm sieve were rejected as too coarse.

Also, the quartz, though already milled, was sieved through 300µm sieve to obtain finer particles. The weighing was done using the CONTEC Digital Precision Weighing Balance in Erosion Control Laboratory, Federal University of Technology, Owerri.

Proportioning, Blending and Wetting of Moulding Materials: The porcelain body was formulated by varying the composition of the plastic (clay) and the non-plastic (feldspar and quartz) materials. Ten porcelain insulator bodies were formulated as shown in Table 1.

These recipes were prepared for the clay and labeled I_0, I_1, ., ., ., I_9. The formulations were thoroughly mixed and blended, temper water was added and the mixture thoroughly worked into a plastic state.

Moulding/Pressing: The pressing was carried out at the Materials Laboratory, FUTO, using Buehler Hydraulic Press. The mould used for the pressing measured 32mm internal diameter. A required quantity of plastic moulding mass was put into the mould and pressed under 2.5MPa pressure. After pressing, the green sample was extruded out and the procedure was followed for each body formulation.

Drying and Firing: The pressed, green test samples were left to air-dry slowly for three days. This was followed by firing. The samples were all fired in the same heating sequence for 8hrs 30mins as follows:

- At the rate of 150^0C/hr to the temperature of 1200^0C.
- followed by soaking at 1200^0C for 15 minutes
- subsequent cooling to ambient temperature.

Characterization

Chemical Analysis

Representative sample of each of the three raw materials was analyzed to determine the chemical composition and LOI (Loss On Ignition). This was done at the Central Research Laboratory, National Root Crop Research Institute (NRCRI) Umudike, Abia State.

Testing

The fired samples were tested for linear shrinkage, apparent porosity, bulk density, water absorption and electrical resistivity.

(a) Determination of Linear Shrinkage

To determine the linear shrinkage of the pressed samples, the green and fired dimensions were noted using a vernier caliper. Linear shrinkage for each sample was computed as a percentage of the original green dimensions, i.e. using the equation:

$$\mathbf{L.S} = \frac{\Delta L}{L} \qquad 1$$

where, ΔL is the change in length, L is the original length.

(b) Determination of Apparent Porosity, Bulk Density and Water Absorption

Apparent porosity, bulk density and water absorption were determined in one and the same test in accordance with American Society for Testing and Materials (ASTM) C 20-80a. The samples were dried over 12 hours at 105^0C in preparation for the test. They were taken directly from the oven for the test. The dry weight in air (W_{da}) was measured using a spring balance, after which the samples were transferred into and suspended in a vessel of boiling water for 1hr. After boiling, the specimens were left to cool to room temperature while still immersed in the water. After a day, the weight in water (W_{sw}) was measured. Each specimen was removed from the water and the surface gently cleaned with a damp cloth, and it was weighed in air to determine the saturated weight (W_{sa}). The apparent porosity, P_a, of each sample was calculated using the following relation:

AP (%)

$$= \frac{\textit{Volumeof water absorbed after boiling } x\ 100}{\textit{Bulk volume (i.e.volume by displacement)}}$$

$$= \frac{W_{sa}-W_{da}}{W_{sa}-W_{sw}} \text{ x } 100 \qquad 2$$

The bulk density, D_b, of each sample was also calculated using the results of the apparent porosity test, thus:

$$\mathbf{D_b, (g/cm^3)} = \frac{\textit{True Weight}}{\textit{Bulk Volume}} = \frac{W_{da}}{W_{sa} - W_{sw}} \ldots 3$$

The water absorption, A_w, of each specimen was calculated using the results of the apparent porosity test via the relation:

$$A_w(\%) = \frac{Bulk\ volume}{True\ weight} = \frac{W_{sa} - W_{sw}}{W_{da}} \ldots 4$$

(c) Determination of Electrical Resistivity

The electrical resistivity, ℓ, was also determined. This was done using a multimeter (Fluke 27 Multimeter). The multimeter measures directly resistances ranging from 0Ω to 200MΩ and so could not give direct resistance readings for the samples because of the very high resistance values of insulators. Therefore, the multimeter was re-set in the conductance mode to get direct readings. The resistances and hence, resistivities of the samples were thus calculated using the following relations:

$$G\,(S) = \frac{1}{R(\Omega)} \qquad 5$$

Thus, resistance, R, was calculated as the inverse of conductance (G), and resistivity was therefore calculated from the resistance values using the relation:

$$\ell = \frac{RA}{L} \qquad 6$$

Where R = resistance (Ω)
G = conductance (S)
ℓ = resistivity (Ω-m)
A = area (mm^2)
L = length (mm).

RESULTS AND DISCUSSION

The results obtained for the various tests are presented in Tables and Figures (graphs). *It is worthy of note that samples containing ≥25% quartz or ≥35% feldspar were difficult to mould and subsequently disintegrated when left for few days after firing. Therefore, results were only recorded for samples that did not experience disintegration*. Figure 1 shows the representative of sintered samples.

Chemical Composition

Table 2 shows the chemical composition of the raw materials.

The chemical quality (% Al_2O_3 = 26.54 and %SiO_2 = 43.94) for Ibere clay is quite good for refractories and porcelains (Chester, 1973; Grimshaw, 1971).

Linear Shrinkage

Table 3 is the linear shrinkage results. From Table 3, it could be seen that the highest linear shrinkage (14.71%) was recorded for 100% clay due to its high plasticity. When inert materials were progressively incorporated, the shrinkage decreased progressively to 5.14%. Addition of non-plastic materials results to decrease in plasticity and hence linear shrinkage. The linear shrinkage values obtained (8.33 - 9.68%) compare well with values (7 - 10%) recommended by Chester, (1973). This result is presented graphically in Figure 2.

Apparent Porosity

Table 4 shows the results of apparent porosity, bulk density and water absorption.

Apparent porosity increased from 10.81% to 17.30% as the contents of the non-plastic materials incorporated increased. This is because, the non-plastic materials (feldspar and quartz) increased the total silica and alumina contents of the clay leading to reduction in the plasticity, which in turn results to increase in apparent porosity. These values were recorded for samples 3, 4 and 5 whose compositions range from 50 - 70% clay, 20 - 30% feldspar and 10 - 20% quartz. Recommended linear shrinkage is necessary to ensure dimensional stability of the product (Kingery, 1975; Ovri, 1997). Also, apparent porosity values recorded (14.00 - 17.30%) are in agreement with the values obtained for standard porcelain (16.82%) and these values were also recorded for samples 3, 4 and 5. Porosity is necessary in insulating refractories (electrical porcelains) because it increases electrical resistivity due to presence of pores (air) which serves as an insulator (Krivandin and Markov, 1980; Nwobodo and Davies, 2000). (See Figure 3.)

Water Absorption

Also, from Table 4, water absorption capacity increased progressively from 5.41% to

10.84% as more non-plastic materials were incorporated. This is because, increase in porosity results to the existence of more pore spaces, which in turn facilitates water absorption when the article is exposed to moisture. Again, water absorption values obtained 8.33% - 10.84% are in conformity with values obtained for standard porcelain (8.20%). For electrical application, porcelains should have very low water absorption capacity because the presence of water reduces the electrical resistivity of the product. As stated earlier, porosity, which is necessary in electrical porcelains, increases water absorption capacity, which is not necessarily beneficial. In order to obtain the needed porosity for optimum electrical resistance with little or no water absorption capacity, electrical porcelains are glazed. (See Figure 4)

Bulk Density

Decrease in linear shrinkage implies decrease in densification and hence decrease in bulk density as could be observed in the result obtained for bulk density. (Table 4, Figure 5).

Electrical Resistivity

Table 5 shows the electrical resistivity results. The electrical resistivity increased progressively from 0.79 x $10^7\Omega$m to 1.39 x $10^7\Omega$m as the composition of the non-plastic materials increased. This is due to the highly porous nature of the porcelain products. Electrical resistivities recorded 0.79-1.39 x $10^7\Omega$-m are in agreement with the value obtained for standard porcelain (0.45 x $10^7\Omega$-m) and that recommended by Khanna (2001) (10^4-$10^{18}\Omega$-m). The higher the electrical resistivity, the better the porcelain. Hence, porcelain pin insulators made from this clay yielded higher electrical resistivities and are assumed better than the standard (imported) porcelain. (See Figure 6).

Table 6 shows the standard values for the parameters investigated.

In general, little variations are observable when results obtained for the locally made porcelains and standard porcelain are compared. These discrepancies could be as a result of the following reasons:

(i) The actual chemical compositions of the raw materials used for the production of the standard porcelain are not certain.

(ii) The actual body composition (percentage clay, feldspar and quartz blended) of the standard porcelain is also not known.

(iii) Again, the temperature to which the standard porcelain was fired was not stated, and

(iv) The actual forming method was not specified.

Some or all of these may have contributed to the slight variations in properties as recorded. However, these slight variations are negligible.

CONCLUSION

Clay Ibere was investigated for electrical porcelain applications. The composition of clay, feldspar and quartz were varied and properties such as linear shrinkage, apparent porosity, bulk density, water absorption, and electrical resistivity were determined.

The investigation has shown that results obtained for locally made porcelain insulators consisting of 50-70% clay, 20-30% feldspar and 10-20% quartz compare well with results of both previous works and the standard porcelain. Therefore, it is possible to replace the imported porcelain used by Power Holding Company of Nigeria with porcelain insulators made from this clay investigated provided the recommended compositional specifications are followed.

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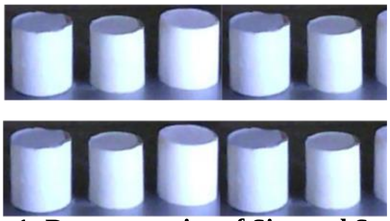

Fig.1: Representative of Sintered Samples

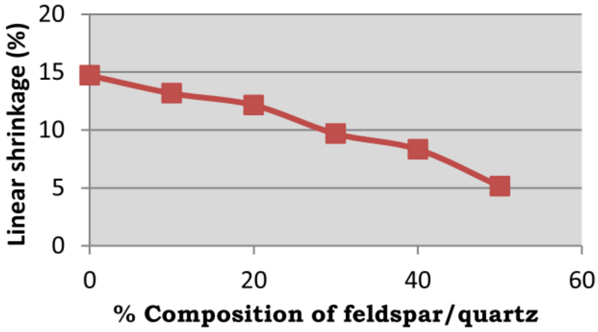

Fig.2: Linear shrinkage as a function of total non-plastic content

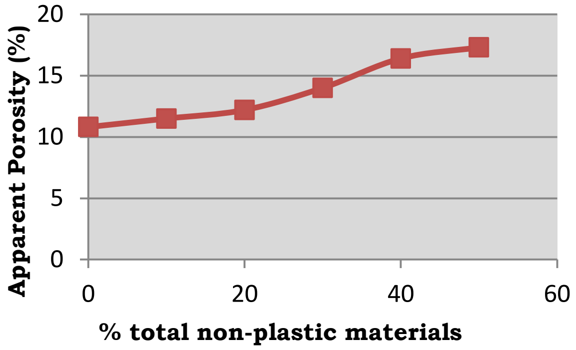

Fig. 3: Apparent Porosity as a function of total non-plastic content

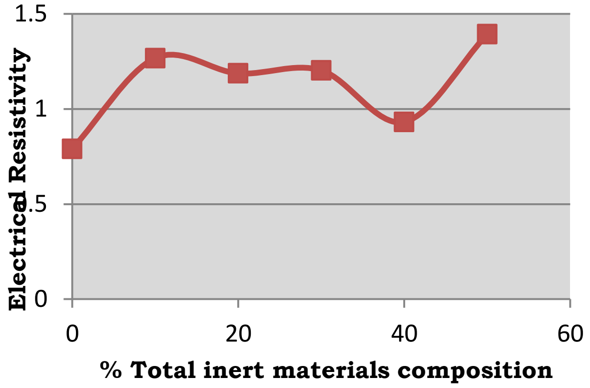

Fig. 6: Electrical Resistivity as a function of Total non-plastic content

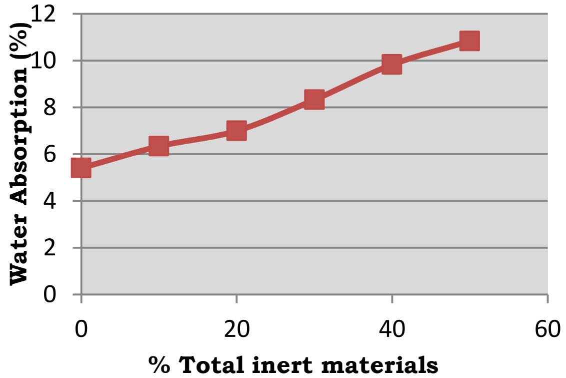

Fig. 4: Water Absorption as a function of total non-plastic content

Table 1: Porcelain Body Formulations

Sample	Clay (%)	Feldspar (%)	Quartz (%)
0	100	0	0
1	90	5	5
2	80	15	5
3	70	20	10
4	60	25	15
5	50	30	20
6	50	25	25
7	50	20	30
8	50	15	35
9	50	35	15

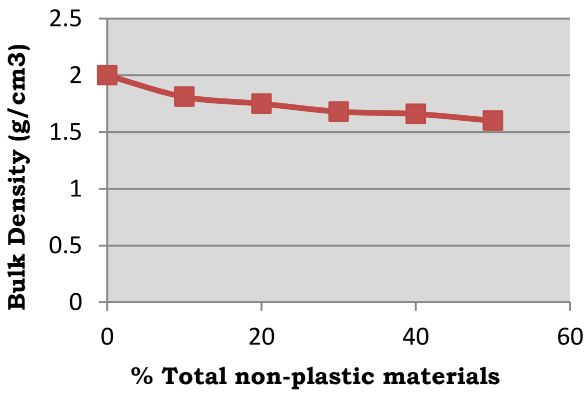

Fig.5: Bulk Density as a function of total non-plastic content

Table 2: Chemical Composition of Raw Materials (AAS)

Composition (%)	Ibere Clay	Feldspar	Quartz
SiO_2	43.94	63.40	97.42
Al_2O_3	26.54	17.32	0.15
Fe_2O_3	0.48	0.83	0.46
MgO	1.61	0.24	-
CaO	3.37	0.42	-
Na_2O	0.28	1.75	-
K_2O	0.77	14.86	-
LOI (H_2O)	16.00	0.51	0.42

Table 3: Linear Shrinkage Result

Sample	Results		
	L_g (mm)	L_f (mm)	L.S (%)
0	34.00	29.00	14.71
1	35.70	31.00	13.17
2	32.10	28.20	12.15
3	31.00	28.00	9.68
4	36.00	33.00	8.33
5	35.00	33.20	5.14

Note: L_g = green length; L_f = fired length;

$$\mathrm{L.S.} = \text{Linear Shrinkage} = \frac{L_f - L_g}{L_g}$$

Table 4: Apparent Porosity, Bulk Density and Water Absorption Results

Variable	Sample	0	1	2	3	4	5
	W_{da}(g)	37.00	41.00	40.20	42.00	41.70	41.50
	W_{sw}(g)	20.50	21.00	20.21	20.50	20.80	20.00
	W_{sa}(g)	39.00	43.60	43.00	45.50	45.80	46.00
Apparent Porosity, P_a (%)		11.50	10.81	12.20	14.00	16.40	17.30
Bulk Density, D_b (g/cm^3)		1.81	2.00	1.75	1.68	1.66	1.60
Water Absorption, A_w(%)		6.34	5.41	7.00	8.33	9.83	10.84

Table 5: Electrical Resistivity Results

Sample	Variables	Results
0	Area (m^2)	0.000577
	Length (mm)	29.00
	Conductance, G (nS)	2.52
	Resistance, R (MΩ)	396.8253
	Resistivity, ℓ (Ω-m x 10^7)	**0.790**
1	Area (m^2)	0.0005813
	Length (mm)	31.00
	Conductance, G (nS)	1.48
	Resistance, R (MΩ)	675.6756
	Resistivity, ℓ (Ω-m x 10^7)	**1.267**
2	Area (m^2)	0.0006327
	Length (mm)	28.20
	Conductance, G (nS)	1.92
	Resistance, R (MΩ)	520.8333
	Resistivity, ℓ (Ω-m x 10^7)	**1.187**
3	Area (m^2)	0.0006838
	Length (mm)	28.00
	Conductance, G (nS)	2.10
	Resistance, R (MΩ)	476.1904
	Resistivity, ℓ (Ω-m x 10^7)	**1.203**
4	Area (m^2)	0.0007071
	Length (mm)	33.00
	Conductance, G (nS)	2.30
	Resistance, R (MΩ)	434.7826
	Resistivity, ℓ (Ω-m x 10^7)	**0.932**
5	Area (m^2)	0.0007071
	Length (mm)	33.20
	Conductance, G (nS)	1.53
	Resistance, R (MΩ)	653.5946
	Resistivity, ℓ (Ω-m x 10^7)	**1.392**

Table 6a: Apparent Porosity, Bulk Density and Water Absorption Results for Standard Porcelain

W_{da}(g)	42.60
W_{sw}(g)	24.30
W_{sa}(g)	46.20
P_a (%)	**16.43**
D_b (g/cm^3)	**1.95**
A_w (%)	**8.43**

Table 6b: Electrical Resistivity Results for Standard Porcelain

Sample	Variable	
Standard porcelain	Area (m^2)	0.0011
	Length (mm)	0.076
	Conductance, G (nS)	3.2
	Resistance, R (MΩ)	312.5
	Resistivity, ℓ (Ω-m x 10^7)	**0.4523**