EVALUATION OF THE ELECTRICAL PROPERTIES OF DIFFERENT MIXTURES OF CEMENT -SAND CONCRETE

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ABSTRACT

The electrical properties of a material determines whether the material is a good conductor or an insulator. Therefore this work was necessary to evaluate the electrical properties of different compositions of sand - cement concrete. The mixtures of the concrete ranged from 100 % cement to 80 % sand and 20 % cement. The simple ohm circuit method was employed to measure the current ant potential difference across the concrete. The results show variations in the electrical properties of different composition of sand and cement. It shows that the concrete with 100% cement has the highest conductivity value of 2.165 $\times 10^3$ $(\Omega m)^{-1}$ and lowest resistivity value of 0.462 $\times 10^{-3}$ Ωm while the concrete with 80% sand exhibiting the lowest conductivity of 0.343 $\times 10^3$ $(\Omega m)^{-1}$ and highest resistivity value of 2.915 $\times 10^{-3}$ Ωm. The values of resistivity obtained from this study compared to that of standard metallic material are higher may be because of the difference in the nature of the materials and the temperature at which the experiments were carried out. It is recommended that concretes with much quantity of sand and less quantity of cement if could form paste could be used as alternative shielding materials for electrical conductors and as protective shield against ionizing radiation.

INTRODUCTION

Electrical properties of a material are those properties which either aid or hinder the flow of electric current through the materials. These properties include electrical resistivity, conductivity and permittivity. Materials are electrically classified into three broad groups namely insulators, conductor and semiconductor. Insulators are those materials that do not allow the flow of electrical current through them. In terms of energy band, it has a large forbidden gap of which no valence electron can be energetic enough to cross into the conduction band. In the case of conductors, there are free mobile electrons hence; this class of materials allows the flow of electric current through it. In terms of the energy band, conductor has no forbidden gap. Permittivity is mainly associated with insulators while conductivity and resistivity properties are associated with conductors. Of course, a material with high conductivity has a low resistivity and is regarded as being a good conductor. However, an insulator is a material with a zero conductivity or infinite resistivity. Semiconductors are materials which can behave as an insulator and as well as a conductor. At very low temperature it behaves as an insulator and at room temperature it becomes a conductor. In this class of material, the forbidden gap is very small in the width and at room temperature an electron in the valence band can have enough energy to cross into the conduction band.

Electrical conductivity is a property of a body which measures the rate of flow of charged particles through a body in a specified direction. If a net charge ΔQ flows through an area in a time Δt, then the current (I) is defined as equation 1.

$$I = \frac{\Delta Q}{\Delta t} - - - - - - - - (1)$$

Electric current in a conductor such as a copper wire is due to the drift of electrons. When a conducting wire is connected to a terminal of a battery, the free electrons in the wire are attracted to the positive terminal of the battery, by the positive electric field set up by that terminals. Electrons also leave the negative terminal of the battery and enter the wire and thus there is a continuous flow of electron from the negative terminal of the battery, through the wire to the positive terminal of the battery, this set up the current through the wire.

Resistance is that property of a substance, which opposes the flow of electric current through it. Different materials have different levels of resistance they pose to the flow of electric current. Some allow electric current to readily pass through them and are called good conductors example, copper, iron, silver with low resistivity. Others have a very high resistivity as such, allow very little current to flow through them and are called poor conductors. These materials include manganese, constantan, Eureka etc. and are mainly used in making resistance wires. There are still third class materials which do not allow current to pass through them at all. In such materials their resistance is infinite. These materials are called insulator e.g. Plastic, dry wood, oil etc. Resistance of a material is obtained mathematically from the relationship of Ohm's law in equation 2.

$$V = IR \text{ ------------------------ } (2)$$

From equation (2) above resistance of a conductor can be defined as the ratio of the potential difference between the ends of a conductor to the current flowing through. Certain factors affect the resistance R offered by a conductor against the flow of electric charges and these factors include nature, length and cross sectional area of the material as related in equation 3

$$R \propto \frac{I}{A} \text{ -------------------------- } (3)$$

This relation is linearized into equation 4

$$R = \frac{\rho L}{A} \text{---} \qquad (4)$$

Or $$\rho = RQ \qquad (5)$$

Where $$Q = \frac{A}{L} \qquad (6)$$

Where ρ a constant is called the resistivity of the material and Q is the ratio of the cross sectional area of the concrete and the length of the concrete.
From the expression we see that the resistivity of a material is expressed in ohm meter units and it is numerically equal to the resistance of a conductor made of the material of length/meter and area of cross-section/squared meter.

Resistivity is used to compare the inherent resistance characteristics of different materials. A material with the lowest resistivity will be the best conductor and the poorest insulator. Conductors are defined as materials having resistivity's from 10^{-6} to 10^{-8} Ωm. Semiconductors are defined as materials with resistivity between 10^{7} to $10^{-6}\Omega$m (Simpson, 1992).

The reciprocal of resistivity is conductivity, which is assigned the symbol σ. The relationship between resistivity and conductivity is expressed by

$$\sigma = \frac{1}{\rho} \text{-------------------------- } (7)$$

Concrete is a heterogeneous mixture of cement, sand and water with an interconnected pore network. It could be conductive depending on the degree of moisture content while it exhibit high degree of resistance when dry (Madhavi and Annamalai, 2016). Concrete can also be use as a biological shielding material from ionizing radiation. It could attenuate gamma and neutron radiations (Samarin, 2013). In addition the information on the electrical properties of the cement mixtures are relevant as it sheds light on the structure of the materials, concerning the interfaces in the composite materials when it is applied (Abhyankar and Bhole, 2012).

The factors that affect the electrical properties of soil cement materials, include, type of soil, cement and water because sufficient quantity of water content is required for complete hydration of the concrete to occur (Hammad, 2013). Another factor that affects the electrical properties of concrete is the water –cement (W-CM) ratio. The higher the W-CM ratio the more permeable the concrete is and the higher the electrical conductivity of the medium but exhibits high electrical resistance when the medium is dry (Song *et al.,* 2008). The reason for the effect of moisture on the electrical properties are also reported in (Hlavacova, 1994, 2007). Again it is reported that a decrease in the water content of the sand – cement concrete at constant porosity results in the decrease in the degree of saturation leading to increase in the electrical resistivity of the concrete (Song *et al* ., 2008).

One of the advantages of assessing the conductivity **(σ)** of concrete made of cement is that it could be used to determine the setting time of cementitious materials (Madhavi and Annamalai, 2016) which could be helpful to those in the building industries. This work was carried out to determine the electrical properties of concrete material with different proportions of sand and cement mixtures.

MATERIALS AND METHODS

Materials used for the research work include; cement, sharp sand purchased from building materials markets in Uyo, Akwa Ibom State, Nigeria. Measuring cylinder, spatula, electronic weighing balance, vernier caliper, micrometer screw gauge, ammeter (A), voltmeter (V), rheostat, a 9V battery, soldering iron, lead wire, cylindrical mould and a resistance wire. It is important to note that different cements have different chemical composition and the quantity of ions in them differs hence the electrical properties of the concrete is related to the cement type. Therefore the same type of cement, the Dangote brand was used for this study.

The different proportions of cement and sharp sand were measured using the measuring cylinder and weighed using an electronic weighing balance. Each sample with varying weight of cement and sand were mixed with water and stirred to form paste and turned into a cylindrical mould with a constantan wire inserted at both ends of the mould and allowed to set. A total of 100 g of the mixture equivalent to 10 cups of the mixture was used for the study. The height of the cylinder was measured as 3.01 cm while diameter was 1.08 cm and the cross sectional area of the cylinder was calculated from the length and diameter of the cylinder to be 20.75 cm^2. A circuit was connected in series with rheostat, ammeter and key while voltmeter was connected across the concrete as seen in Figure 1. The applied current and the corresponding voltage were obtained by increasing the slider on the rheostat to vary the values of current (I) and potential difference (V).

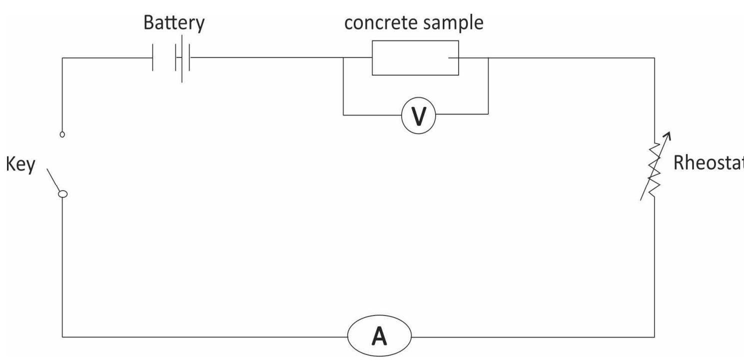

Figure 1: Circuit diagram showing the experimental set-up

RESULTS

The different proportions of cement and sand mixed together to form the required concrete and their distinguishing codes are presented in Table 1showing code a as the controlled experiment with 100 % cement concrete. Table 2 records the current and the corresponding measured potential difference (Pd). In addition the calculated resistance (Ω), resistivity (ρ) and the conductivity (σ) are also reported in Table 2

Table 1: Table describing different Cement / sand proportions

% concentration of cement and sand	Sample Code
100 cement	A (controlled experiment)
80 of cement : 20 of sand	B
70 of cement : 30 of sand	C
60 of cement : 40 of sand	D
50 of cement : 50 of sand	E
40 of cement : 60 of sand	F
30 of cement : 70 of sand	G
20 of cement : 80 of sand	H

In Table 2 the resistance was obtained using equation 2 and the resistivity (ρ) of the concrete was obtained using equation 6 with a Q value of 6.89 cm and the conductivity (σ) is obtained as the reciprocal of resistivity as shown in equation 7. The mean value of each of the parameters was used in the computation of the selected electrical properties. Table 2 shows that the selected current ranged from 0.20 to 0.60 A with a mean value of 0.37 ± 0.04 A.

Table 2: The relationship between I (A) and V values per sample

	I(A)	V(mV) per Sample							
		A	B	C	D	E	F	G	H
	0.20	3.0	*	50.0	50.0	*	*	140.0	190.0
	0.25	9.0	6.0	*	50.0	140.0	40.0	140.0	140.0
	0.30	50.0	90.0	50.0	*	*	60.0	150.0	150.0
	0.35	*	50.0	*	50.0	160.0	*	150.0	150.0
	0.40	55.0	50.0	60.0	60.0	150.0	90.0	10.0	150.0
	0.45	*	*	90.0	*	*	50.0	*	*
	0.50	10.0	59.0	15.0	10.0	10.0	10.0	10.0	*
Mean	0.37	25.4	51.0	53.0	44.0	92.0	50.0	120.0	156.4
R (Ω)		0.067	0.138	0.143	0.119	0.249	0.135	0.324	0.423
$\rho \times 10^{-3}$ (Ωm)		0.462	0.951	0.985	0.820	1.716	0.930	2.232	2.915
$\sigma \times 10^{3}$ $(\Omega m)^{-1}$		2. 165	1.052	1.015	1.220	0.583	1.075	0.448	0.343

* Values are insignificant therefore, not included in the table.

The pd ranged between 3.0 to 55.0 mV with a mean value of 25.4 ±10.4 mV was obtained for sample A, while pd ranging from 6.0 -90.0 mV with mean of 51.0±10.6 mV was obtained for sample B. Sample C, 10.0 – 70.0 (53.0 ± 15.0) mV, sample D, 10.0 – 60.0 (44.00 ±10.0) mV and sample E, 10.0 – 160 (92.0 ± 30.0) mV. Samples F, G and H produced Pd (mean) of 10.0 – 90 (50.0 ±16.0) mV, 10.0 – 150.0 (120.0 ± 28.0) mV and 140.0 – 190.0 (156.0 ±10.0) mV respectively. The mean evaluated resistance ranged from 0.067 – 0.423 Ω, while the evaluated resistivity ranged between 0.462 – 2.915 $\times 10^{-3}$ Ω m and the corresponding value of conductivity range obtained was 0.343 – 2.165 $\times 10^{3}$ $(\Omega m)^{-1}$ with 100% cement concrete having the highest conductivity and lowest resistivity values while the concrete with 80% sand exhibiting the lowest conductivity and highest resistivity values.

DISCUSSION

Concrete is made up of a composition of different materials. It is a heterogeneous mixture with interconnected pore network. The results obtained shows that concrete exhibit some conductive characteristics. In this study Table 1 shows the percentage concentration of mixtures of sand and cement with a 100 % concentration of cement without a mix of sand used as the control experiment. The percentage concentration ranged from high 80% cement and 20% sand to high concentration of sand (80%) to a low concentration of cement (20%). It is observed that the electrical conductivity of concrete is influenced by the type of cement used (Madhavi and Annamalai, 2016) therefore the same brand of cement was used in the study for homogeneity of the results. The electrical properties of the concrete evaluated in this work where, resistance, resistivity and conductivity. It was observed that the corresponding potential difference (pd) at some values of current were not significant and could not be recorded by the meter hence these values were not included in the evaluation. This could be because the current applied was not enough to create significant pd capable of transporting the ions in the concrete. The major raw materials known to be used in the production of cement is the calcium carbonate ($CaCo_3$) otherwise called limestone, ash, aluminates and silicates while sand contains silicon all these elements are known to exhibit the tendency to ionize. Again the presence of CO_3^{2-} ions present in the limestone increases the conductivity of the concrete.

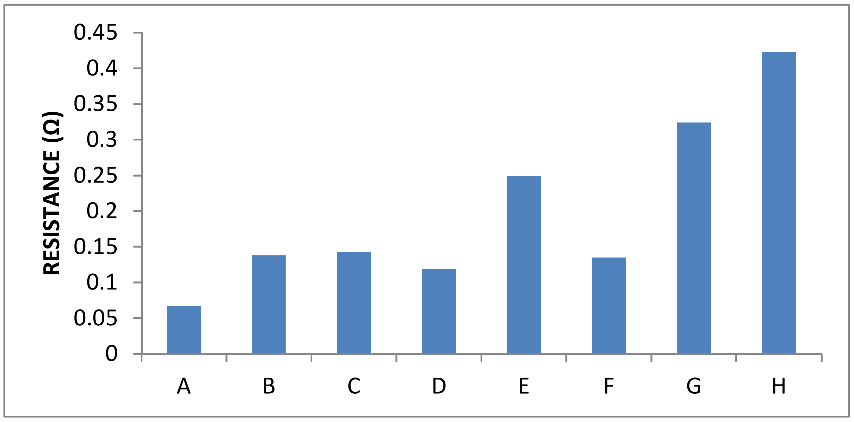

Figure 2: Variation of resistance with concrete mixtures

The mean Pd was lowest in sample A which has 100 %.cement only (Table 2) showing ionic homogeneity of the concrete where there is no ionic interaction between the ions of the cement with the ions of sand while the concrete with the highest percentage of sand and lowest percentage of cement (sample H) recorded the highest mean Pd. This implies that the sample (H) offers the highest resistance (Fig. 2) to the flow of electrical charges within the concrete.

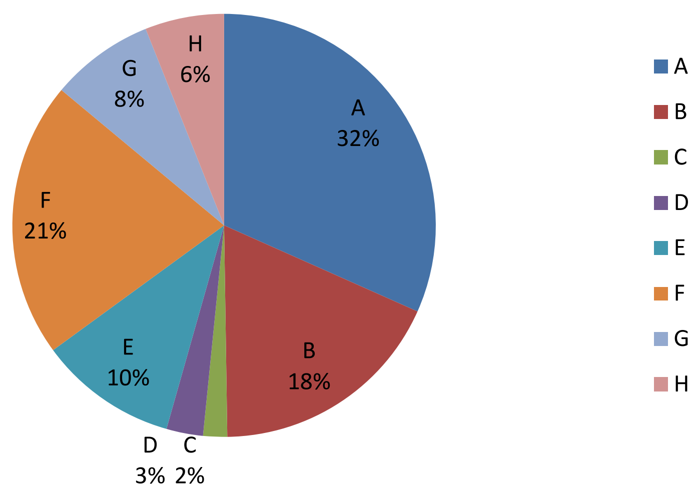

Figure 3: Percentage conductivity variations per concrete mixtures

The percentage conductivity of concrete made of cement only is the highest with 32 % as seen in fig. 3 above (Sample A). This is because there is no soil- cement interaction and only the ions of cement are involved in the transport process. It could also be observed that the percentage conductivity decreases as the quantity of cement in the concrete decreases while resistivity of the concrete increases with increase in sand-cement ratio (Fig.2). Secondly the variation in the electrical properties of the concrete evaluated also depends on the water to concrete ratio. As the quantity of sand increases and less quantity of cement less quantity of water was added to form a better paste hence the water to concrete (W-C) ratio decreases thus increasing the resistivity of the concrete (Mancio *et al.,* 2009) (Table 2).

CONCLUSION AND RECOMMENDATION

This work was set up to evaluate the electrical properties of different compositions of sand - cement concrete. The results showed variations in the electrical properties of different sand – cement ratio. The concrete with 100% cement had the highest conductivity value of **2.1**65 $\times 10^3$ $(\Omega m)^{-1}$ and lowest resistivity value of 0.462 $\times 10^{-3}$ Ωm while the concrete with 80% sand exhibited the lowest conductivity of 0.343 $\times 10^3$ $(\Omega m)^{-1}$ and highest resistivity value of 2.915 $\times 10^{-3}$ Ωm. The values of resistivity obtained from this study are higher than resistivity values obtained for standard metallic materials (Simpson 1992, Ham and Slemon, 1965) and may be due to the difference in the nature of the materials and the temperature at which the experiments were carried out. It could be observed that concretes with much quantity of sand and less quantity of cement if could form paste could be used as alternative shielding materials for electrical conductors, biological shield against ionizing radiation and also to protect transformer cage against vandals.

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