Volume 2 No.8, August 2012 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

Analysis of Copper Cable Types Commonly used in Nigeria for Electrical Wiring and Power Distribution

E. P. Ogherowo, B. J. Kwaha, +O. V. Oyelade
Department of Physics, University of Jos, Jos. Nigeria
+Department of Physics, Bingham University, Karu, Abuja. Nigeria

ABSTRACT

The compositional constituents of five (5) copper cable types labeled E_1, E_2, E_3, E_4 and E_5 were determined using two (2) different test methods namely- X-ray fluorescence spectrometry (XRFS) and resistivity test with the main objective of ascertaining their purity, resistivity and conductivity features. These factors are expected to provide the clue as to why some cables of the same gauge manufactured by different companies fail under the same load conditions. Samples of the 5 cable brands of equal dimensions were grounded to fine powder and subjected to purity test by the XRFS method. Another set of similar samples were subjected to resistivity test. From the XRFS result, E_1 had purity of 99.30%, E_2, 99.10%, E_3, 98.50%, E_4, 99.20% and E_5, 98.80%, while the resistivity tests revealed that the respective resistivity and conductivity values were: for E_1 [2.324×10^{-9} Ω m and 430.29×10^{6} $(\Omega m)^{-1}$], E_2 [3.921×10^{-9} Ω m and 255.04×10^{6} $(\Omega m)^{-1}$], E_3 [2.689×10^{-9} Ω m and 371.89×10^{6} $(\Omega m)^{-1}$], E_4 [2.614×10^{-9} Ω m and 382.56×10^{6} $(\Omega m)^{-1}$], and E_5 [2.890×10^{-9} Ω m and 346.60×10^{6} $(\Omega m)^{-1}$]. Comparing these values to the standard resistivity value of pure copper [2.82×10^{-8} Ω m], it would be seen that these results are in agreement with each other. The test methods used in this research could be used to test the purity of copper or any other metal suitable for domestic electrification before stretching into cables. It can also be used to determine the standard of copper products.

Keywords: *Qualitative analysis, copper, electrical cables*

.

1. INTRODUCTION

Copper, a chemical element with symbol Cu, atomic number 29 and atomic mass $63.5463 gmol^{-1}$, is a non ferrous ductile metal with an excellent thermal and electrical conductivity [1], [8]. It is widely used as thermal conductor, electrical conductor, museum artifacts, decorative art and a constituent of various metal alloys. Copper is rated the second highest electrical and thermal conductor amongst pure metals at room temperature [8]; [9]. Pure copper inside flex and plastic materials is widely used as connecting wires for domestic and commercial electricity supplies. When impurities, however small, are mixed with pure copper, an alloy is produced of much lower conductivity or in other words of much higher electrical resistance. If the conducting material has a significant resistance (for instance iron wire) then the conductor will show the effect of the electric current passing through it, usually in the form of an appreciable rise in temperature to produce a heating effect [1], [8]. As a conductor of electricity, copper has been used since the early days of the electrical industry. It has a high resistance to atmospheric corrosion.

2. THEORETICAL BACKGROUND

In the simplest microscopic model of conduction, each atom in the metallic crystal gives up one or more of its outer electrons. These electrons are then free to move through the crystal colliding at intervals with the stationary positive ions. The motion of the electrons is analogous to the motion of the molecule of a gas moving through a porous bed of sand and they are often referred to as electron gas. From this model, an expression for the resistivity, ρ of a material is, as given by [7], [5]:

$$\rho = \frac{E}{J} \tag{1}$$

E is the magnitude of electric field created by the free electron and J the current density. The current density is in turn given as [7], [5]

$$\vec{J} = nq\vec{V}_d \tag{2}$$

where n is the number of free electrons per unit volume, q is the charge of each electrons and V_d is the average drift velocity. Relating the drift velocity V_d to the electric field E. The value of V is determined by a steady state condition in which, on average, the velocity gains of the charges due to the force of the electric field are just balanced by the velocity losses due to the collisions.

A typical electron has velocity V_o at time t = o and the value of V_o average over many electrons (that is the initial velocity of an average electron) is zero: $(V_o)_{av} = 0$. If at time t = 0 a constant electric field E is turned ON, the force, F exerted on each charge of mass m, and its acceleration *a* in the direction of the force is given by [7], [5]:

$$\vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m} \tag{3}$$

Table 1: General Features/Characteristic of Copper [6], [2]

Name, symbol, number	Copper,Cu,29
Element category	Transition metal
Group, period, block	11, 4, d
Appearance	Metallic bronze
Standard atomic weight	63.546(3)g.mol^{-1}
Electron configuration	[Ar] 3d^{10} 4S^{1}
Electron per shell	2, 8, 18, 1
Physical Properties	
Phase	Solid
Density (near room temperature	8.96g.cm^{-3}
Liquid density at melting point	8.02g.cm^{-3}
Melting point	(1084.62^{0}c, 1984.32^{0}F) 2835k
Heat of fusion	13.26kJ.mol^{-1}
Heat of vaporization	300.4KJ.mol^{-1}
Specific heat capacity	(25^{0}c) 24.4 40J mol^{-1}K^{-1}
Mechanical properties [6]	
Magnetic ordering	Diamagnetic
Young's modulus	110 – 128 GPa
Shear modulus	4GPa
Bulk's modulus	149GPa
Poisson ratio	0.34
Mohs hardness	3.0 of the order of 10^{-4}m/s
Vickers's hardness	369MPa
Brinell hardness	874MPa
Electrical Properties [7]	
electrical conductivity	60Mmhos/m – 2nd highest
huge charge density	13.6 x 10^{9} c/m^{3}
drift velocity	Slow – of the order of 10^{-4}m/s
electrical resistivity	1.7 x 10^{-8} Ωm
Atomic Properties [6]	
Crystal structure	Face centered cubic
	0.3610nm
Oxidation states	+1,+2,+3,+4
	(Mildly basic oxide).
Electro negativity	1.90 (pauling scale)
Ionization energy	1st: 745.5kjmol-^{1}
Atomic radius	128pm
Covalent	138pm
Vander walls radius	140pm.

After time T, the electron acquires an average velocity, V_{av} [7], [5]:

$$\vec{V}_{at} = \vec{a}T = \frac{qT}{m}\vec{E}$$

After time= T, the tendency of the collision to decrease the velocity of an electron by means of randomizing collisions, just balances the tendency of the E – field to increase this velocity. Thus the velocity of an average electron given by equation (4) is maintained over time and is equal to the drift velocity V_d given by [7], [5]:

$$\vec{V}_d = \frac{qT}{m}\vec{E} \qquad (5)$$

Now substituting the equation for the drift velocity V_d into equation (2), we obtain:

$$J = nq\vec{V}_d = \frac{nq^2T}{m}\vec{E} \qquad (6)$$

The resistivity is given by [7], [5]:

$$\rho = \frac{m}{ne^2T} \qquad (7)$$

If n and T are independent of E then the resistivity is independent of E and the conducting material obeys ohms law. The drift velocity of conduction electron in an applied field is affected by the mean free path or the average time between collisions of the electrons with the lattice, it is possible to express the resistance R of a metal specimen in terms of their relaxation time. In terms of the average drift velocity V the current density is given by [3], [4]:

$$\vec{J} = neV \ \text{Amp/m}^2 \qquad (8)$$

The external force which causes electron drift is $F = eE$. The average impulse arising from the effect of the drift velocity and the collision interval is (Grant and Phillips 1990).

$$F_T = eE_T \qquad (9)$$

As a result the average drift momentum acquired by carrier in the field E is [3, [4].

$$m\vec{V} = eE_T \qquad (10)$$

Hence the velocity of electrons in a wire (copper) can be given as [3], [4]:

$$V = \frac{eE_T}{m} \quad (4) \qquad (11)$$

2.1 Resistivity and Conductivity

The electrical resistance of a wire is higher for a longer wire and less for a wire of large cross-sectional area. Experimentally, the resistance of a wire can be expressed as [4]:

$$R = \frac{\rho L}{A} \qquad (12)$$

where ρ is the resistivity, L is the length and A is the cross sectional area. The factor in the resistance which takes into account the nature of the material is the ***resistivity*** and is given in ohm meter (Ωm). Electrical resistivity can also be defined as [7], [5]:

$$\rho = \frac{E}{J} \qquad (13)$$

where E is the magnitude of the electric field ($^V/_M$) and J is the magnitude of the current density ($^A/_{M^2}$). Metals and alloys have the smallest resistivity and are the best conductors. The resistivity of a metallic conductor nearly always increases with increasing temperature. Over a small temperature range (up to 100°C or so) the resistivity of a metal can be represented approximately by [7], [5]:

$$\rho(T) = \rho_0[1 + \alpha(T - T_0)] \qquad (14)$$

where ρ_0 is the resistivity at a reference temperature, T_0 is often taken as 0°c and $\rho(T)$ is the resistivity at temperature T which is often low or higher than T_o, The factor α is the temperature coefficient of resistivity. The inverse of resistivity is called conductivity which is the measure of a material's ability to conduct electric current [4]:

$$\text{Electrical conductivity } \sigma = \frac{1}{\rho} \qquad (\Omega m^{-1}) \ (15)$$

3. X-Ray Fluorescence Spectrometry (XRFS)

XRFS is an instrumental, analytical and non-destructive technique used in identifying and determining constituent concentration of elements present in solids, liquids or powder samples. XRFS can be applied over a wide range of concentration from 1 part per million (ppm) to

100%. It is also capable of measuring all elements from Beryllium (Be) to Uranium (U).

The copper cable samples for XRFS analysis were first grounded to a fine powder and observed under the instruments' spectrometer to conform to requirement of homogeneity. These metal samples are milled or ground to give a flat surface. The XRFS machine is powered from a high voltage source which provides power to an attached x-ray tube. The x-ray from the tube irradiates the sample introduced into its chamber generating secondary (fluorescence) x-rays which are characteristics of each element in the sample. The characteristics x-rays are separated by spectrometer into individual wavelengths or energies and measured by a detector. The results displaying the features of the individual constituents as observed from the wavelengths or energies are noted and printed out from a computer monitor.

3.1 Chemical Analysis Method

Samples: a.10mm *Curtix* cable [E_1];
b.10mm *Alind* cable [E_2];
c. 10mm *Nocaco* cable [E_3];
d. 10mm *Union* cable [E_4];
e. 2.5mm *Sunrise* cable [E_5]

The samples were grounded, sieved to 75μm particle size and 4g of the sieved sample was thoroughly mixed with 1g of lithium tetra-borate binder ($Li_2B_4O_7$) and pressed in a mould under a pressure of 12 tons/in^2 to form a pellet. The pellets were dried at 110^{0}c for 30minutes in an oven. The spectrometer was turned ON, allowed to warm up and stabilize. Calibrations were done to determine the elements present in the samples. The samples were then tested using the prepared programs (calibrations) which calculated and displayed the elements concentrations present in the samples after applying automatic statistics to the results by the spectrometer. The analysis results were then printed out from a computer monitor.

4. RESISTIVITY TEST USING METER-BRIDGE SETUP

Equipment: a. Meter-bridge b. Jockey
c. Key d. Galvanometer
e. A 2Ω standard resistor;
f. Dry cells g. Micrometer screw gauge

Samples: a. *Curtix* cable [E_1]; b. *Alind* cable [E_2];
c. *Nocaco* cable [E_3];d. *Union* cable [E_4];
e. *Sunrise* cable [E_5]

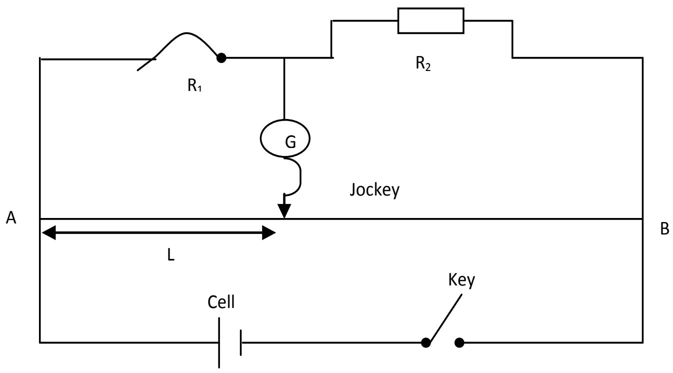

Fig 1: Meter Bridge Set Up

4.1 Method of Resistivity Test

The circuit was set up as shown in Fig 1, AB is the length of the wire, R_1 is the unknown resistance wire, and R_2 is a known resistor 2Ω. The balance point was located by the null-deflection method of the galvanometer G; and the value of the unknown resistance, R_1 was determined from [4]:

$$\frac{R_1}{R_2} = \frac{L}{100 - L} \qquad (16)$$

The procedure was repeated for the lengths 10, 20, 30, 40 and 50cm, and the resistivity for each wire-sample determined using :

$$\rho = \frac{RA}{L} \qquad (17)$$

Also the cross-sectional area of each wire was measured using the micrometer screw gauge.

5. RESULT FROM CHEMICAL ANALYSIS

Table 2: XRFS Test Result (Chemical Composition Analysis)

Sample	% Al	% Si	% Ti	% Cr	% Mn	% Fe	% Ni	% Cu	% Zn	% Sb	% Ba	% Pb	% Ca	% Ag	% Sn
E_1	ND	ND	0.02	0.06	ND	0.36	0.09	98.95	ND	ND	0.10	ND	0.40	ND	ND

Volume 2 No.8, August 2012 ISSN 2224-3577
International Journal of Science and Technology

http://www.ejournalofsciences.org

E_2	ND	ND	0.02	0.07	ND	0.28	0.08	98.84	ND	ND	0.09	ND	0.28	ND	ND
E_3	0.05	ND	0.03	0.07	ND	0.31	ND	99.26	ND	ND	0.10	ND	0.30	ND	ND
E_4	ND	ND	0.02	0.06	ND	0.33	0.06	98.48	ND	ND	0.18	ND	0.36	ND	ND
E_5	ND	ND	0.02	0.07	0.03	0.49	0.06	98.18	ND	ND	0.20	ND	0.44	ND	ND

ND – Not Detected

6. RESULT FROM METER BRIDGE APPARATUS

Table 3: Resistivity Test Result

Sample	Length (CM)	Balance point y(cm)	$R_1 = \frac{Lx R_1}{100-L}$
E_1	10.00 20.00 30.00 40.00 50.00	4.40 4.50 4.60 4.70 5.10	0.09205 0.09424 0.09644 0.09864 0.10748
E_2	10.00 20.00 30.00 40.00 50.00	8.70 9.30 9.50 10.00 10.70	0.19058 0.20507 0.20994 0.22220 0.23964
E_3	10.00 20.00 30.00 40.00 50.00	4.40 4.50 4.60 4.70 5.10	0.09205 0.09424 0.09644 0.09863 0.10080
E_4	10.00 20.00 30.00 40.00 50.00	10.10 10.40 10.60 11.00 11.30	0.22469 0.23214 0.23713 0.24719 0.25479
E_5	10.00 20.00 30.00 40.00 50.00	4.30 4.40 4.50 4.60 4.70	0.08986 0.09205 0.09424 0.09644 0.09863

Graphs of resistance versus lengths were plotted and their corresponding slopes determined

Table 4: The Values of Resistivity, Conductivity and Standard Resistvity For Pure Copper

Samples	**MEAN RESISTANCE, R (Ω)**	**RESISTIVITY (Ωm)**	**CONDUCTIVITY (Ωm)-^{1}**	**STANDARD VALUE OF RESISTIVITY (Ωm)**
E_1	0.140	4.8048 x 10^{-7}	430.29 x 10^{6}	1.678 x 10^{-8}
E_2	0.137	9.44672 x 10^{-7}	255.04 x 10^{6}	1.678 x 10^{-8}
E_3	0.338	7.04231 x 10^{-8}	371.89 x 10^{6}	1.678 x 10^{-8}
E_4	0.136	1.04218 x 10^{-6}	382.56 x 10^{6}	1.678 x 10^{-8}
E_5	0.170	3.73327 x 10^{-7}	346.60 x 10^{6}	1.678 x 10^{-8}

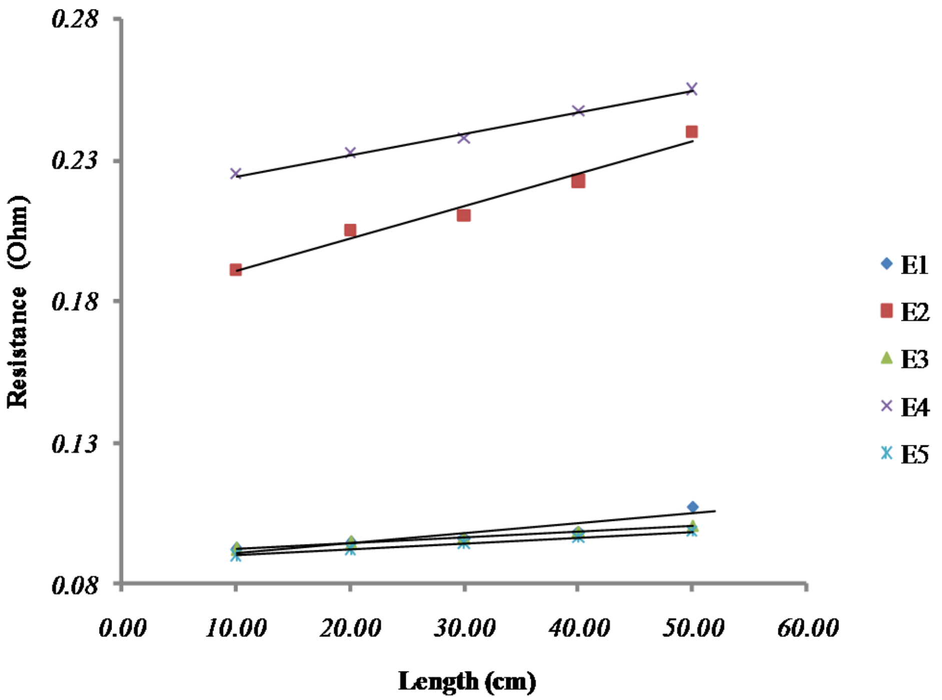

Fig. 2: Resistances against Lengths of Sample Cables

7. DISCUSSION AND CONCLUSION

Copper is widely used in electrical systems due to its excellent conductivity and low electrical resistance. This quality makes it a candidate domestic electrification and for use in industries as electrical conductor. Another reason why copper is used in electrical systems is its density advantage ($8.933 g/cm^3$). This research stemmed from the fact that some cables, when connected to load, fail, while others of the same gauge do not fail under the same conditions even when powered from a common source. The bulk properties of copper which are density and resistivity of the materials are independent of size or shape of the material but depends only on the material itself. Apart from the conductivity and density of copper, another criterion that qualifies it to be an electrical conductor is that it is mechanically strong and durable. In addition its thermal expansion coefficient is low which means it does not expand so much when warming up, hence to the question "what is the safe operating current for a cable?" the safe operating current or current rating of a cable is the current it can carry safely without overheating. It is imperative that the temperature of the conductor should not rise above 90^0c because this will cause the insulation to degrade and eventually break down. Hence a cable should always be protected by a protective device - a fuse or a circuit breaker that corresponds to its current rating.

The operating current of a cable is affected by a number of variables.

1. The resistance of the cable: a higher resistance cable will get hotter at a given current.
2. The insulation on the cable: this will tend to keep it warm.
3. The environment of the cable: if it is in a duct (especially with no air flow) it will tend to get hotter.

After considering all this properties that makes copper a good conductor for domestic electrification, it is also important to take note of the effect of the presence of impurities in copper wires as detected from this research.

1.The presence of impurities reduces the electrical conductivity of copper wires.
2.Quite small amounts of some impurities will also cause serious reduction in the mechanical properties of which bismuth is possibly the most offender.
3.Antimony produces similar effects and in particular, impairs the cold working problem.

The effect of impurities in the cables under consideration could be drawn from taking a look at the different impurities found in each wire as presented on Table 2. It was noticed that all the copper cables E_1,E_2,E_3,E_4 and E_5 have the following impurities in common - titanium, chromium, iron, nickel (with an exception of E_3), copper ,barium and calcium. The only different combination is found in E_5 which contains aluminum in place of nickel. These impurities increase the internally generated heat of this wire as it conducts thereby making it prone to failure. This is further corroborated by the relatively high resistivity values experimentally determined.

The percentage composition of each wire was obtained using a chemical analysis which is called the x-ray fluorescence spectrometry test at the National Metallurgical Development Centre (NMDC) Jos. This test is a non-destructive technique and can be applied to most solids and liquids. It can be applied to a wide range of concentration from approximately 1ppm to 100%. It can be used to determine almost all elements in the periodic table except very light elements.

Resistivity test was also carried out on the same samples of copper wires using the meter bridge set up. The purpose of the resistivity test is to obtain the resistivity values of each sample and compare because high resistivity value would imply a low conductivity and a low resistivity value would imply a high conductivity, with the latter being the condition necessary for a wire to be termed a good conductor of electricity.

From the result obtained through chemical analysis, it was seen that E_3 has the highest percentage concentration of copper after which is E_1, E_2, E_4 and the last of which is E_5. Apart from the fact that E_3 has a very high concentration of copper it is also seen that it is the only sample that contains aluminium, another distinctive observation is made when considering E_5, and it is the only sample that contains manganese. Hence it became paramount to look up the effects of aluminium and manganese, the result is that they are both used in strengthening copper wires. It was also observed that E_3 does not contain nickel. Nickel is known increases the electrical contact property for high yield point and sufficient flexibility for use under difficult condition in an aggressive atmosphere.

From tables 3 and 4, it could be deduced that E_3 has the lowest resistivity value of $7.04231 \times 10^{-8}\Omega$m and an appreciable conductivity value of 1.41999×10^{6}s/m. The next is E_5 which has a resistivity value of $3.73327 \times 10^{-7}\Omega$m and a high conductivity value of 2.67862×10^{6}s/m. E_1 has resistivity value of $4.8048 \times 10^{-7}\Omega$m and a relatively high conductivity value of 2.0813×10^{6}s/m while E_2 has a resistivity value of $9.44672 \times 10^{-7}\Omega$m and an appreciable conductivity value of 1.05857×10^{6}s/m. The last is E_4 with resistivity value of $1.04218 \times 10^{-6}\Omega$m and a very low conductivity value of 0.95952×10^{6}s/m.

From these analyses (tables and graphs), is can be concluded that cable E_3 meets up the highest standard for domestic electrification; this is followed by E_1, E_2, E_4, and E_5. This is further corroborated by the results from the chemical analysis in table 2 which showed that E_3 has the highest percentage composition of copper.

REFERENCES

[1] Allen D. K. (1983) Metallurgy theory and practices. American Technical Society, Chicago, U.S.A.

[2] Callister W.D. Jr. (2003): Material Science and Engineering (An Introduction) 6th Edition. John Wiley and Sons Inc. New York.

[3] Grant. I. S. and Phillips. W. R (1990): Electromagnetism (2nd Edition).John Wiley and Sons Baffins Lane,Chichester. England.

[4] Ike, E.E. (2003): Essentials of Physics Enic Education Consultants and Publishers. Aba, Abia State.

[5] Kwaha, B. J. and Durodola, O. M. (2011) X-Ray fluorescence spectrometry (XRFS) analysis of aluminum cable types commonly used in electric power distribution. Indian Journal of Science and Technology. Vol. 4 No. 5 (May 2011) ISSN: 0974- 6846

[6] O'brien W. (1997): Bronze age copper mining in Britain and Ireland. Shire Publication. London.

[7] Paul T. and Freeman W.H. (2004): Physics for Scientist and Engineers: Electricity, Magnetism, Light and Elementary Modern Physics (5th Edition). John Wiley and Sons, New York

[8] Thompson, F.G. (1983): Electrical Installation and workshop technology volume I. Longman, Singapore.

[9] Wikipedia (2011) www.wikipedia/allelectricalproducts.com.