ANALYSES OF HIGH VOLTAGE TRANSMISSION CABLES IN SOUTH WESTERN NIGERIA

A.Y. FASASI[1,+], B.I. IMASOGIE[2], W.O. SIYANBOLA[1], L.E. UMORU[2], P.O. OGUNLEYE[3] and A. BANKOLE[2]

1. Centre for Energy Research & Development, Obafemi Awolowo University, Ile-Ife, Nigeria.
2. Department of Materials Science & Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria.
3. Centre for Energy Research & Training, Ahmadu Bello University, Zaria, Kaduna State, Nigeria.

Abstract

This paper presents the report of an investigation of the electrical and structural integrity of overhead and underground electrical cables in the south western part of Nigeria. Overhead and underground transmission cables were collected around the Obafemi Awolowo University environment, melted and cast into cylindrical shapes for electrical, structural as well as mechanical analyses to determine their adequacy as transmission cables. Results obtained indicate that while the load bearing capability (in terms of breaking load per unit diameter) of the analysed underground cable is good compared with the standard conductor, the overhead cable has a poor load bearing capability. SEM and EDX analyses show that both the underground and the overhead cables contain impurities that are deleterious to the structure and their functional properties. More importantly, the electrical resistivity measurement showed that the tested underground and the overhead cables are respectively 4 and 10 times higher in resistivity than the standard conductors. The implications of these results in respect of the high power transmission losses in Nigeria are discussed.

1. Introduction

All around the world, electricity is transmitted from the power stations to various sub-stations at a very high voltage, which in turn transmits electricity to inhabited localities – residential, industrial, and commercial-at lower voltages. In Nigeria, power transmission has been made possible through overhead conductors with a small proportion being transmitted through underground cables. Although there had been many technological improvements, electricity is yet to be transmitted without some losses.

Even if new methods of power transmission cannot be achieved at the moment, the present method of transmission through overhead and underground cables must be efficiently carried out. It should ensure that the cable materials are capable of transmitting the generated power with minimal losses and should conform to specifications adequate for the different levels of voltages transmitted, often classified as high, medium and low tension[1]. The conductors must be able to transmit electricity in bulk of the standard voltage levels, ensuring safe, efficient and reliable power delivery.

A systematic approach should be adopted in the selection of the conductors. Factors such as tension, load-bearing capability, current loading of the line, voltage stability, environmental effect, electrical losses, and many others must be considered in the process. The goal is to select a conductor that exemplifies the best conductivity– to- weight ratio (which means high conductivity and low density) and also the highest strength – to - weight ratio (high strength and low density) at minimal cost of application. The electrical and mechanical properties, thermal properties and stress-strain relationship of the conductor will dictate the choice of conductor type and size for a given transmission line design[2]. In Nigeria, these overhead and underground cables are being purchased from different part of the world. Under normal situation, the Power Holding Company of Nigeria (PHCN) should be the sole source of these cables in the country, but this is not the case. So many contractors are involved in the purchase and supply of transmission cables in Nigeria. Consequently, the suppliers in the South West are not the same as the suppliers in the North Central, South East or any other part of the country. Since these contractors purchase their cables from different manufacturers all over the world, the compositions as well as the characteristics of these cables are not always the same.

Over the past two decades, Nigeria has been faced with incessant power outages despite the effort of the Federal Government in terms of huge financial support given to the National Electric Power Authority (NEPA) to reduce this problem to the barest minimum. In fact, high power transmission losses in Nigeria are reputed to be one of the highest in the world with a value of 31.82% in 1999[3] and about 35% in 2006[4]. The origin of the power failures may be due to many factors amongst which are (i) insufficient power production (ii) low transformer

+ *corresponding author* (email:ayfasasi@yahoo.co.uk)

capacity (ii) vandalisation and (iv) non-conformity of the cables employed. As far as the conformity of the cables employed is concerned, preliminary studies on the overhead cables in the southwestern part of Nigeria have shown that the conductors are alloys of copper and zinc with iron as an impurity[5].

Since all the factors responsible for the incessant power outages are to be studied individually, this study is therefore aimed at studying the non-conformity of these overhead and underground cables in terms of their microstructural, mechanical and electrical properties. Direct comparison of these properties with the international standard specifications for overhead and underground conductor materials will be made to facilitate the determination of the adequacy of the overhead and underground materials being employed in south western Nigeria as transmission cables.

2. Experimental Procedure

Samples of overhead and underground cables were collected around Obafemi Awolowo University while underground cables were collected from the premises of the Centre for Energy Research & Development in Obafemi Awolowo University in Ile-Ife. These materials were thoroughly cleaned before being cut into small pieces for melting using steel crucible. The melting temperature for the overhead cable was around 700°C while that of the underground cable was well above 1000°C. The molten materials were then cast into cylindrical rod shapes of 15mm diameter and 130mm length using standard sand casting method. 2mm thick specimen were cut from the rod and these were mechanically grinded with various grades of emery paper before using a colloidal silica suspension for the final polishing step.

The polished samples were characterized microstructurally using a Philips XL-30 Field Emission Scanning Electron Microscope (FESEM) equipped with Energy Dispersive X-ray (EDX) accessory. The elemental compositions were determined using PGT. Both methods of characterisation were carried out at Princeton Institute of Science and Technology of Materials (PRISM), Princeton, USA. The samples were tested in tension on the Monsato tensometer available at the Materials Science & Engineering Department of Obafemi Awolowo University, Ile-Ife.

Brinell hardness test was performed with a load of 125kg and 250kg on the overhead and underground specimens respectively for a period of 15sec using a hardened steel ball as an indenter. The diameters of indentation were read under a magnifying lens of a low powered optical microscope (Timing, 1998).

Since the specimens were not drawn into a wire form, resistivity measurements were performed with a circuit shown in Fig. 1 with the specimens having the same dimension. From the circuit diagram, the resistance of the sample is R_X. The current passing through R_X and R_S are the same and can be obtained from the measurement of V_S and the known resistance R_S. From the relation $V_X = V_T - V_S$, V_X and hence R_X can be determined. Also, from the dimension of the specimen, especially the diameter, and the value of R_X the resistivity can then be obtained.

3. Results and Discussion

(a) Composition and Morphology

The PGT bulk sample analysis of the overhead as well as the underground specimens for compositional determination is shown in Table 1. The table indicates that the overhead cable is mainly made up of an alloy of aluminum (55.03wt %) and zinc (34.83wt %) with traces of Si, Ce, Pb, Au, Mg and Nd, which are very deleterious to the structure and hence physical as well as electrical properties. Typical scanning electron micrograph of the overhead cable is presented in Fig 2a. The morphology indicates that the specimen is highly heterogeneous. This is manifested in the texture. Moreover, the concentration of Al and Zn, which are the major elements, is very close to the concentration of Al-Zn alloy normally being employed as anodes in the cathodic protection of steel structures[6,7]. With the presence of Au and Nd, it is then plausible to say that the specimen must have been recycled using different sources without adequate purification.

The compositional analysis of the underground cable shows that it consists of mainly copper (98.97wt %) with traces of Al, Si, Sn, Zn, Mg and Nd. This is corroborated by the EDX spectrum of Figure 2c. The photomicrograph of the specimen is depicted in Fig. 2b with equiaxed grain structure of wrought copper with the trace elements distributed mostly within the grains. The trace elements, like in the case of overhead cable, indicates that the origin of the specimen is from various sources and that it may not have been properly melted but cold-worked all the same to produce the cable.

(b) Tensile Test

The results obtained from the tensile tests of the overhead as well as the underground conductors are presented in Figs. 3a and 3b. The figures clearly show the difference between the tensile characteristics of the two specimens in the value of the breaking load of 2.352 and 8.624 kN and the maximum tensile strengths of 210 and 458.3 N/mm² for the overhead and the underground conductors respectively. This is in addition to the fact that the underground cable exhibited a much smaller ductility as compared with the overhead cable[8,9].

Table 1: Elemental composition of the overhead and the underground specimens studied.

Element	Concentration (wt%)	
	Overhead specimen	Underground specimen
Al	55.03	0.13
Si	1.70	0.02
Cu	0.00	98.97
Sn	0.00	0.10
Zn	34.83	0.72
P	0.04	0.00
Mg	1.99	0.05
Mn	0.00	0.00
Ca	0.20	0.00
Pb	0.89	0.00
Ba	0.00	0.00
Au	1.81	0.00
Cr	0.09	0.00
Ti	0.27	0.01
Ce	1.47	0.00
Nd	0.68	1.68

Table 2: Tensile test result performed on the cables and comparison with standard conductors.

Measurement	OH	UG	AAC	ACSR
Guage Length(mm)	27.00	27.00		
Final Length(mm)	31.90	27.90		
Elongation(%)	18.15	3.33		
Initial Diameter(mm)	5.00	5.00	6.18	7.08
Final Diameter(mm)	2.40	4.50		
Ultimate Tensile Strength(N/mm^2)	210	458.3		
Breaking Load(kN)	2.352	8.624	3.99	9.61
Breaking load per unit diameter(kN/mm)	0.4704	1.7248	0.6456	1.357

AAC: All aluminium conductor, **ACSR:** Aluminium conductor steel reinforced.
OH: Overhead cable; **UG:** Underground cable

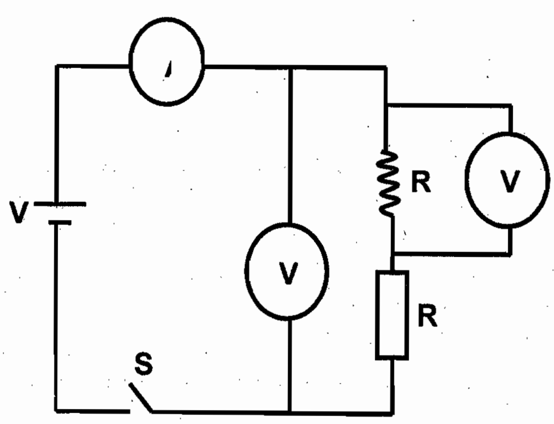
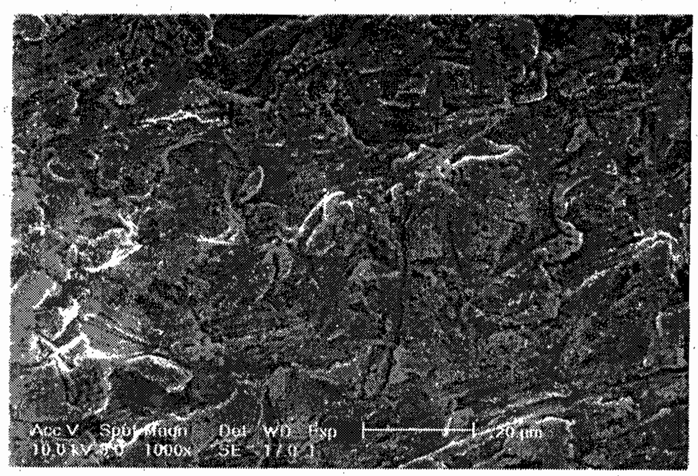


Figure 1: Circuit employed in the determination of the resistivity of the studied

a



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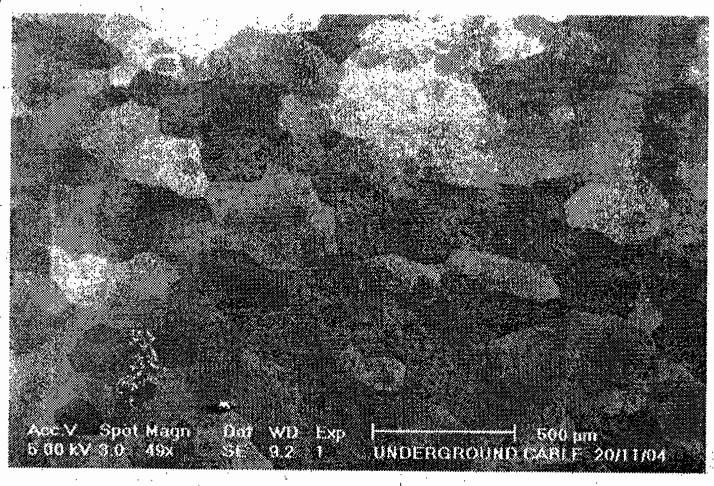

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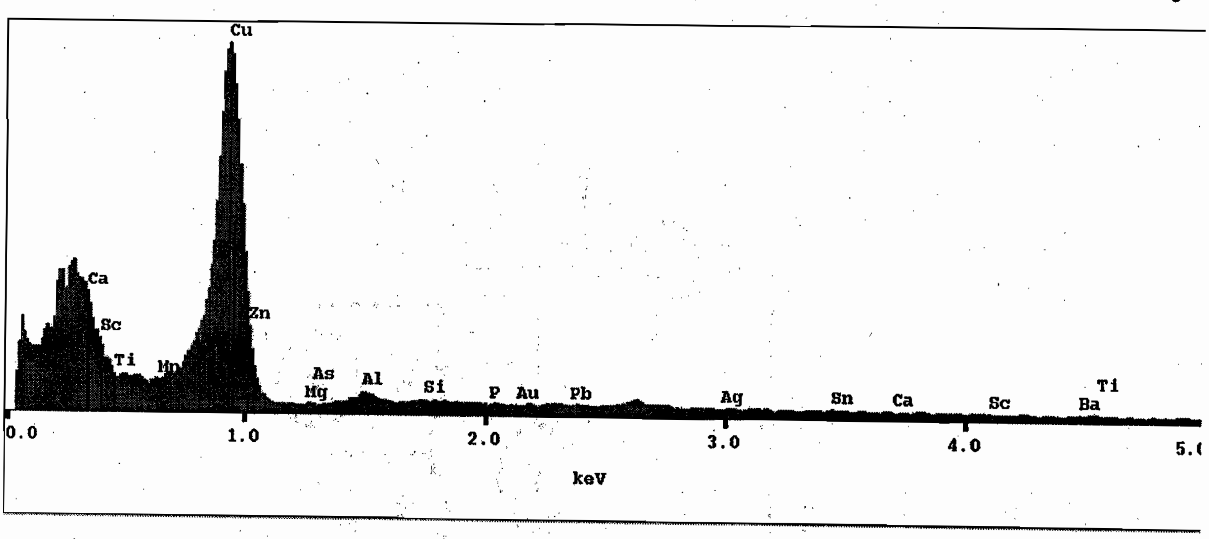


Figure 2: Micrographs obtained from (a) overhead (b) underground conductor specimen and (c) EDX spectra of the underground specimen.

Comparing the result obtained on the normalized breaking load per unit diameter of the overhead and the underground samples, Table 2, with specifications for standard conductors, called all aluminium conductor (AAC[10-13], usually employed as standard overhead cables) for overhead transmission and aluminium conductor steel reinforced (ACSR[10-13], usually employed as standard underground cables), obtained from Nigeria Wire and Cable Product Manual, it is evident that the underground specimen under investigation is superior to ACSR. On the other hand, the overhead conductor tested has a lower value of breaking load per unit diameter compared with AAC. This is an indication of a physical limitation in terms of load bearing capability and may explain the sagging nature of the conductor that is always being observed.

(c) Hardness Test

Hardness measurement is an indication of the resistance of a material to plastic deformation by indentation. In most practical cases, a high hardness value always point towards brittleness. The obtained hardness measurement showed that the underground cable is harder than the overhead counterpart; 51.4 and 17.8 kg/mm^2 respectively. The brittleness of the underground cable with respect to the overhead cable is corroborated by the tensile test (Fig. 3a and 3b), which showed the breaking load per unit diameter of 8.624 kN/mm for the underground cable and 2.352 kN/mm for the overhead cable. In addition, the underground cable did not manifest the existence of a plastic region as compared with the parabolic tensile curve of the overhead cable. This is an indication that the overhead cable is more ductile than the underground cable.

The high tensile strength of the underground cable may certainly be an indication of smaller grain size since the smaller the grain size, the more the grain boundaries per unit volume and hence the more the resistance of the material to deformation which will certainly lead to brittleness, high hardness and high breaking load values.

(d) Electrical Characterization

The values of the resistivity obtained from the specimens using the circuit in Fig. 1 were

$\rho_{OH} = 11.31*10^{-6}$ Ω-cm (overhead cable) and

$\rho_{UG} = 7.53*10^{-6}$ Ω-cm (underground cable)

Comparing the result obtained for the overhead conductor with the resistivity of all aluminium conductor (AAC), which is 1.35 μΩ-cm, it is obvious that the resistivity of the studied overhead cable is an order of magnitude greater than that of standard conductor. If we also compare the underground conductor with that of aluminium conductor steel reinforced (ACSR) which is 2.15 μΩ-cm, it is again obvious that the resistivity of the studied underground cable is almost 4 times higher.

These observations simply showed that the studied samples have very high resistivity values than the standard conductors that are naturally used as transmission cables. This can be said to be due to the presence of other alloying elements in our samples, which is plausible since alloying leads to an increased resistance compared with that of the individual constituent elements because the impurities introduced represent irregularities in the host lattice. These irregularities impede or deflect the movement of electrons thereby leading to a reduction in the mean free path, mobility, conductivity and hence an increase in resistivity[14]. The implications of this increase in resistivity can be viewed from the angle of transmission losses[15]. If we employ the expression:

$$P = I^2 R = I^2 \frac{\rho \cdot l}{A},$$

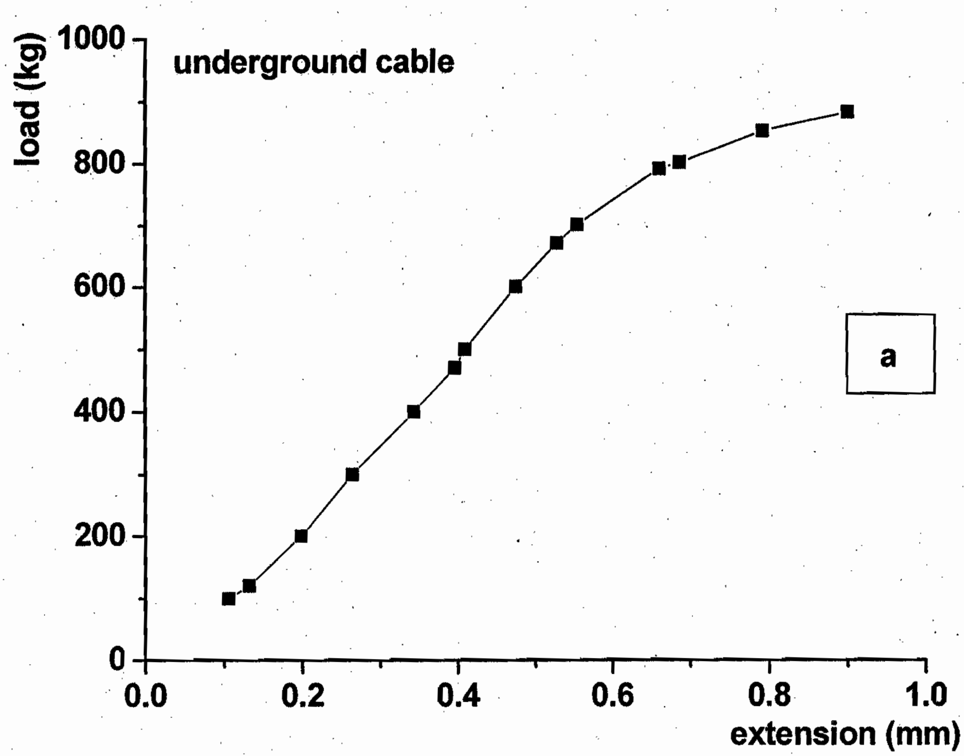
then it becomes obvious that as the resistivity of the material increases, so does the power loss. Comparing the level of power loss with that of standard conductors, the power loss is superior by 4 and 10 times for the underground as well as the overhead cables respectively.

4. Conclusion and Recommendation

Various tests carried out on the specimens gave an indication that the materials used for overhead and underground electrical conductors are not actually the best for the application. Comparing the values of the resistivities obtained in this study with those of standard conductors, it was observed that overhead and the underground conductors are respectively 4 and 10 times more resistant than those of standard conductors. This implies that transmission losses through joule's heating will definitely occur with the use of these materials and thus resulting in incessant transmission problems.

From the tensile test, it was discovered that these cable materials have a low breaking load per unit diameter when compared with some standard specifications of conductor materials, a parameter that can be very critical when wind loading is taken into consideration. This would therefore lead to problems during usage of these materials as transmission cables; problems that will definitely affect the transmission of electricity from places of generation to places of use.

Apart from the impact on electricity generation, the mere fact that the studied specimens characteristics fall short of that of standard transmission materials points to the fact that some of these materials that are being imported do not undergo proper quality control tests. The health implication of this absence of quality control is that these materials will find their ways into a foundry house where they will be transformed to kitchen utensils such as cooking pot, plates, spoons and forks, without any form of



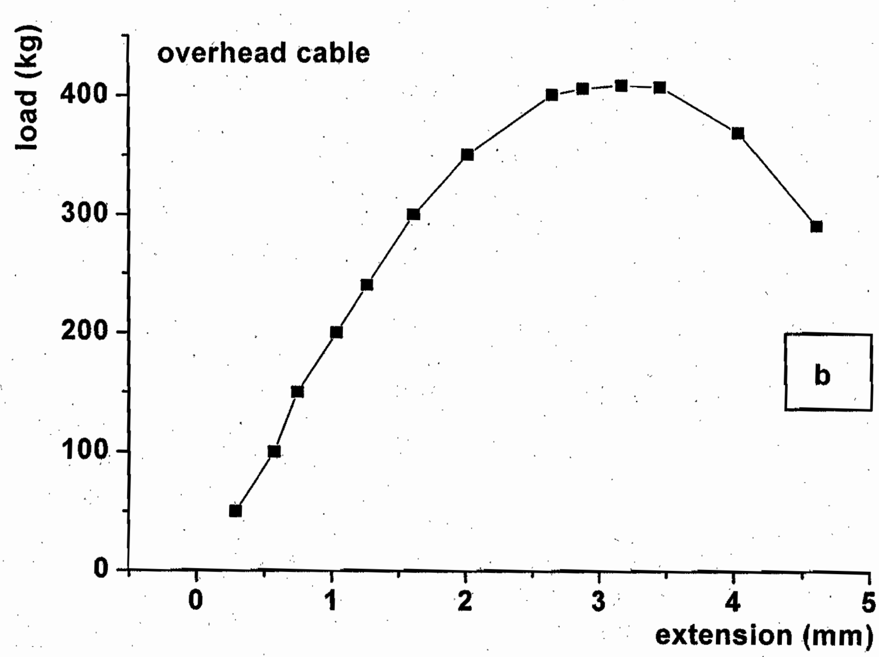


Figure 3: Tensile test results for (a) underground (b) overhead electrical conductors.

purification to remove unwanted impurities. What follows is simply the human intake of these impurities through dissolution into foods prepared with these utensils.

It is then necessary that the Standard Organisation of Nigeria (SON) should as much as possible be at the forefront of making sure that these imported as well as locally made goods conform to the standard required for the particular application envisaged in the South Western part of Nigeria in particular and the whole country in general. Many well-equipped research centres are now in Nigeria without mentioning some other well-equipped university laboratories with lots of expertise. The SON should coordinate the quality control activities by knowing where the experts are and liaising with them on their areas of expertise to carry out certain quality control tests that are not possible elsewhere. With the result of the tests, any importer found importing goods without regards to specification should be penalized by forfeiting all the goods and at the same time paying a heavy fine. This kind of penalty will surely force these importers to stop importing fake products into the country.

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