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Analysis of Electrical and Mechanical Properties of Electrical Cables sold in Anambra State

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ABSTRACT
Electrical materials counterfeiting had become a major menace in Nigeria. This study was carried out to evaluate the adherence of electrical cables used Nigeria, for electrical wiring and installation to International Standards. Four commonly used electrical cables (1 mm^2, 1.5 mm^2, 2.5 mm^2 and 4 mm^2) for electrical wiring and installation were sampled for this study. All the sampled electrical cables were subjected to mechanical and electrical tests, according NIS and ES standards. Results obtained from the laboratory tests revealed that most of the cables sampled, failed to meet NIS and IEC standards. In terms of the tensile strength of the metallic conductor, this study revealed that the 60% of the 1 mm^2, 50% of the 1.5 mm^2, 60% of the 2.5 mm^2, and 70% of the 4 mm^2 electrical cables failed to meet the NIS IEC 60228 recommendation. Likewise, it was observed that the tensile elongation of most of the metallic conductors failed to meet the NIS recommendations. The results revealed that only 20% of the 1 mm^2 cables, 30% of the 1.5 mm^2 cables, 20% of the 2.5 mm^2 cables and 40% of the 4 mm^2 cables met the NIS IEC 60227 recommendations for electrical cables. Furthermore, this study results showed that 50% of the 1 mm^2 cable, 60% of the 1.5 mm^2 cable, 70% of the 2.5 mm^2 cable, and 60% of the 4 mm^2 cable insulators failed to meet the NIS IEC 60811 standard recommendation. In addition, In terms of electrical resistivity, the results showed the 1 mm^2 and 1.5 mm^2 electrical cables had better electrical resistivity, than the 2.5 mm^2 and 4 mm^2 electrical cables. The results obtained from this study had exposed the substandard nature of most electrical cables sold in Onitsha, a commercial hub in southern Nigeria.
Keywords: electrical cables, electrical resistivity, metallic conductors

1.0 INTRODUCTION

An electrical cable consists of one or more metallic conductors, which is used to convey electric current from one point to another, within an electrical installation. Most electrical cables have four main constituents, which are: the metallic conductor, insulating material, mechanical protection, and filler materials. But in some electrical cables, the mechanical protection and the filler materials are excluded from the electrical cables (Adetoro, 2012). The metallic conductors of electrical cables are usually made from either by aluminum or copper, due to their light weight, low resistivity and good tensile properties. This is because these electrical cables are usually subjected to torsion forces, during electrical wiring and installation (Thue, 2005). The insulator part of the electrical cable does not allow free flow of its internal electric charges; hence, a small amount of electric current flows through it under the influence of an electric field. Therefore insulator usually has higher electrical resistivity than semiconductors or conductors. In the field, electrical cables are affected by electricity, heat, moisture, etc. which can eventually leads to electrical system failure, and this can seriously be harmful to human beings and instability in electric power in the electrical installations (Li et al., 2013).

As recommended by Standard Organization of Nigeria (SON), all the electrical components must adhered to national or international standards, before the cable can be certified for usage in Nigeria. The International Electro-technical Commission (IEC) is trying to standardize electrical materials manufactured and sold across the globe. According to the Nigerian Electricity Regulatory Commission (NERC) electrical cables or wires, no matter the electrical conductor, must have conductivity and tensile strength not lower than the values specified in the IEC standards (NERC, 2014). Furthermore, SON stated that the tensile properties of all insulating materials used in the production of electrical cables must conform to the NIS IEC 60811 recommendation (Ukaegbu, 2019). Steward et al. (1998) stated that all the insulating materials used in the production of electrical cables, must has the ability of withstanding the applied voltage and prevent electric current see pages to the wrong directions; therefore, reducing the hazard of electrical fire and electrocution.

Nigeria, just like other Africa countries is flooded with substandard electrical materials. A research conducted by Schneider Electric revealed that 75% of electrical cables in English speaking Africa countries are counterfeits (Schneider Electric, 2015). Schneider Electric (2015) further stated that the consequences of using counterfeit electrical materials are: electrocution, death, accidents, loss of performance, economic/financial losses and loss of properties. According to Eze (2017) counterfeit electrical cables is responsible for the increasing occurrence of electrical fire outbreak in Nigeria. These counterfeited electrical materials are either produced locally by local manufacturer, or imported/smuggled into the country through the country's porous borders. According to SON, most of the imported counterfeit electrical materials are from Asia countries, with China leading the counterfeiting rate (Gabriel, 2017). Counterfeits materials have no economic value and constitute serious threat to the Nigeria power sector (Adekoya, 2019).

The Nigeria standard regulatory agency (SON) had tried to contrail the evil trend in the country, by locating and destroying counterfeited electrical cables in the country. Within the last decade, SON had confiscated and destroyed counterfeit electrical materials worth billions of dollars. In order to strengthen the combat against counterfeit electrical materials in Nigeria, the Standard Organization of Nigeria of called for the more cooperation from Nigerians as recommended by Amaechi (2014); mostly in the area of research into the qualities of electrical materials sold in Nigeria markets. Although several research works (Adetoro, 2012; Onyekachi and Nduka, 2019) had been carried out on the qualities of electrical cables sold across Nigeria, information of the qualities of electrical cables sold in Anambra State is still scanty. In this study, investigations of the mechanical and electrical properties of copper electrical cables sold in Onitsha Anambra State are analysed. Results obtained from this study will further enhance the battle against electrical materials counterfeiting in Nigeria.

2.0 MATERIAL AND METHODS

Study area

This study was conducted within Onitsha metropolis, the commercial capital city of Anambra State Capital. Onitsha has the largest market in Nigeria. A the neighboring states of Delta, Enugu, Imo, Abia, Ebonyi, Edo, Abia, Rivers, Kogi, Bayelsa, Benue, etc. purchased their electrical materials from Onitsha. Therefore, this town is a major hub in the distribution of electrical materials in Nigeria.

Data collection

Primary and secondary data were used for this study. During the primary data collection, four different electrical cables sizes (1 mm^2, 1.5 mm^2, 2.5 mm^2 and 5 mm^2) were selected randomly from ten (10) major electrical shops in Onitsha, Anambra State. Then, the secondary data used in this study was obtained from existing literature such as: Nigeria Industrial Standard (NIS) and Standard Organization of Nigeria (SON).

Mechanical tests

Tensile test of the metallic conductor

The mechanical properties of the cables were measured using the universal testing machine, according to NIS standard. Each sampled cable for the mechanical test was prepared by removing the all insulator from the metallic conductor. At each test, a sampled metallic conductor was clamped between the jaws of the machine, and pulled slowly (speed of 1 mm/min) until fracture occurred (Figure 1). During the test, the corresponding strain was measured by the electronic component of the machine, in relation of the force applied. Four replications were done on each sampled electrical cable size.

Figure 1: Testing the tensile properties of the cable core with UTM

Tensile test of the cable insulator

The tensile properties of the cable insulating material were measured using the universal testing machine, according to the European Standard (EN 50363-0:2011). During the test, each sampled insulator was clamped between the jaws of the machine (Figure 2), and pulled slowly (speed of 1 mm/min) until the insulator snapped. During the test, the corresponding strain was measured by the electronic component of the machine, in relation of the force applied. Four replications were done on each sampled electrical cable size.

Figure 2: Testing the tensile properties of the cable insulating material with the UTM

The tensile strength and tensile elongation of the cable core and the insulating material were calculated using equations 1 and 2.

$$Tensile\ strength, \sigma = \frac{F_{Max}}{Area} \quad (1)$$

$$\text{Tensile } Elongation\ (\%) = \frac{\Delta L}{L} \quad (2)$$

Where: ΔL is extension of the cable
L is original length of the cable
$F_{\max}$ is maximum load applied to the cable.

Electrical test

Electrical resistivity of the metallic conductor

All the cables sampled were subjected to resistance test, and the resistively of the cables was calculated from the measured electrical resistance, using the formula presented in Equation 3.

$$\text{Resistively}(\rho) = \frac{RA}{l} \quad (3)$$

Where R = resistance of the electric cable core
A = Area of the electric cable core
l = length of the electric cable core.

Data Analysis

Data gotten from this study were analyzed by using the MS Excel 2015 (Microsoft Corporation Redmond, WA 98052) software. Then the summaries of the findings were plotted by using the Microsoft Excel 2015 version.

3.0 RESULTS AND DISCUSSION

Mechanical properties of the electrical cables

Tensile strength of the cable core

The results of the tensile strength of the electrical cables are presented in Table 1. It is obvious in the results as presented in Figure 2 that most of the cables are substandard, based on the NIS recommendations of the tensile strength of electrical cables. Figure 3 revealed that 60% of the 1 mm^2, 50% of the 1.5 mm^2, 60% of the 2.5 mm^2, and 70% of the 4 mm^2 electrical cables sampled fell below the NIS IEC 60228 recommendation. This portrayed that only 40% of the 1mm^2, 50% of the 1.5 mm^2, 40% of the 2.5 mm^2 and 30% of the 4 mm^2electrical cables investigated in this study met the NIS recommendations. As specified in NIS IEC 60228, the tensile strength of copper electrical cables must not be less than 196 MPa. Although, the tensile strength of some of the cables sampled within Onitsha metropolis were within the range recommended by NIS, the remaining substandard cables within the State capital suburb can play a significant role in causing electrical disaster within the state. According to International Standard, the metallic conductor of electrical cables must have adequate tensile strength that can withstand field applications, without failing (Haddad, 2009).

Table 1: Tensile strength of the electrical cable core

Sampled	Tensile strength (MPa)			
	1 mm^2	1.5 mm^2	2.5 mm^2	4 mm^2
Batch 1	128.57	155.74	166.46	135.68
Batch 2	137.66	175.68	159.68	158.11
Batch 3	197.68	199.55	186.05	196.44
Batch 4	184.69	198.93	198.93	158.38
Batch 5	155.39	143.44	203.44	188.42
Batch 6	199.34	188.49	208.96	198.09
Batch 7	201.34	198.23	198.63	159.99
Batch 8	198.59	199.92	169.26	165.64
Batch 9	175.83	145.54	145.54	198.05
Batch 10	159.85	199.29	169.92	163.48

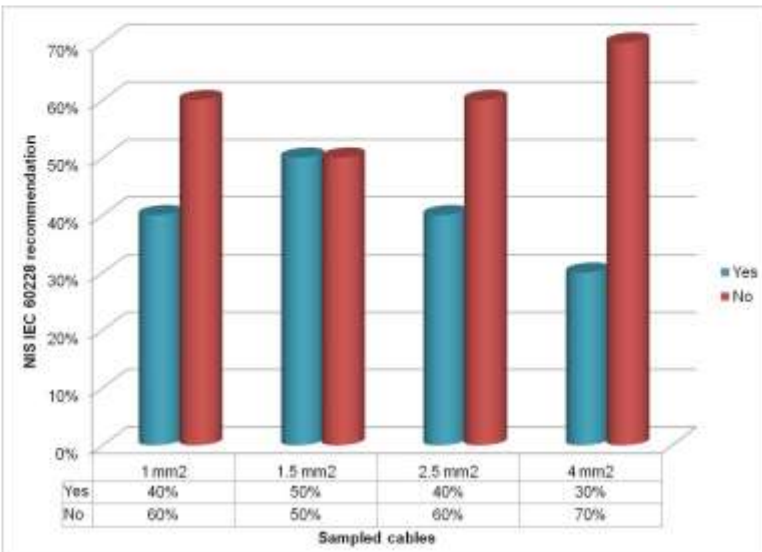

Figure 3: Mean tensile strength of the sampled electrical cable core

Tensile Elongation of the Cable Core

The results of measured tensile elongation of the electrical cables sampled were analyzed with set standard are shown in Table 2 and Figure 4. As showed is Table 2, the tensile elongation of most of the electrical cables sampled fell below the IEC 60228 standard recommendation. According to IEC 60228, the tensile elongation of 1mm^2 to 4 mm^2 copper electrical cables must not be less than 30%. As presented in the study results (Figure 2), only 20% of the 1 mm^{2}cables, 30% of the 1.5 mm^2 cables, 20% of the 2.5 mm^2 cables and 40% of the 4 mm^2 cables met the NIS IEC 60227 recommendations for electrical cables. The results indicated that although the some of the electrical cable had high tensile strength, that met the NIS IEC 60227 recommendations, their tensile elongation fell short of the NIS IEC 60227 recommendations. This portrayed that these cables were not ductile; probably, they were not made from pure copper. Some “substandard” cable manufacturers usually add some metals and other materials to the metallic copper, during cables productions; hence, reducing the tensile strain of the cables. Tensile elongation and tensile strength are two indicators, which are commonly used to determine the mechanical properties of electrical cables (He *et al*., 2020).

Table 2: Tensile Elongation of the electrical cable core

Sampled	Tensile Elongation (%)			
	1 mm^2	**1.5 mm^2**	**2.5 mm^2**	**4 mm^2**
Batch 1	18.33	24.88	12.32	20.08
Batch 2	14.08	21.53	20.31	24.99
Batch 3	18.48	30.42	19.37	30.53
Batch 4	19.54	38.21	23.88	24.48
Batch 5	21.35	20.35	30.43	30.42
Batch 6	31.45	25.43	24.88	30.23
Batch 7	18.42	35.32	37.71	24.24
Batch 8	32.22	20.24	20.54	19.99
Batch 9	19.24	21.45	15.78	33.24
Batch 10	15.35	22.98	19.85	25.41

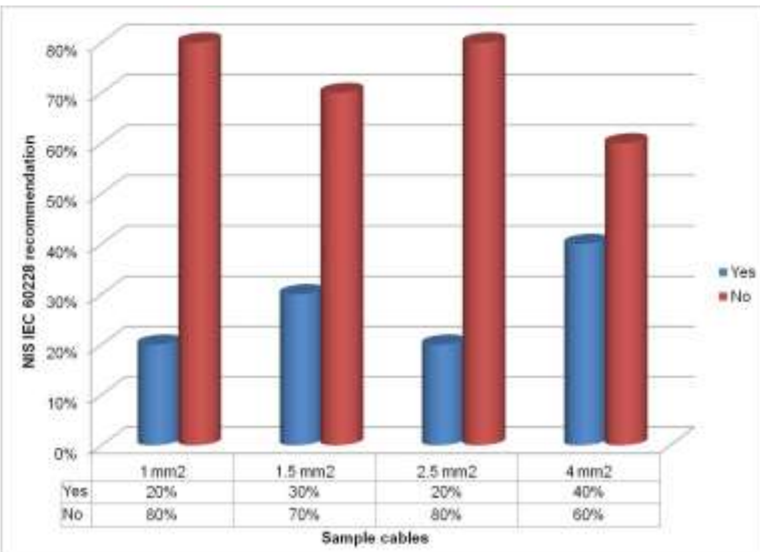

Figure 4: Mean tensile elongation of the sampled electrical cables

Tensile Strength of Electrical Cables Insulators

The results of the tensile strength of the cables insulators are presented in Table 3. As shown in Table 3, the tensile strength of the cable insulators ranged between4.21MPa and 14.33MPa for the 1 mm^2 cable, 4.77MPa and 13.27MPa for the 1.5 mm^2 cable, 5.18MPa and 14.12 MPa for the 2.5 mm^2 cable, and 4.21MPa and 14.52 MPa for the 4 mm^2 cable. The results revealed that most of the cables insulators failed to meet the International Standard, which recommended that the tensile strength of small size and low voltage cables should not be less than 12.5 MPa. As revealed by the study results, 50% of the 1 mm^2 cable, 60% of the 1.5 mm^2 cable, 70% of the 2.5 mm^2 cable, and 60% of the 4 mm^2 cable insulators failed to meet the Standard recommendation. This portrayed that only 50% of the 1mm^2, 40% of the 1.5 mm^2, 30% of the 2.5 mm^2 and 40% of the 4 mm^2 electrical cables insulators met the NIS IEC 60811recommendation. Tensile strength of insulating material is one of the main criteria used by SON to certify electrical cables (produced locally or imported) used in Nigeria for electrical installations. According to SON, most of the electrical cables imported into Nigeria, failed NIS IEC 60811 recommendations, since their insulating materials have very poor tensile strength; hence, they cannot be assigned with SON certification and MANCAP marks (Ukaegbu, 2019).

Table 3: Tensile strength of the electrical cables insulators

Sampled	Tensile strength (MPa)			
	1 mm^2	**1.5 mm^2**	**2.5 mm^2**	**4 mm^2**
Batch 1	5.29	5.74	8.45	5.05
Batch 2	14.33	7.82	8.11	7.09
Batch 3	14.21	12.75	13.44	7.52
Batch 4	5.83	9.89	13.19	12.89
Batch 5	9.58	4.77	8.25	14.21
Batch 6	13.21	8.92	5.18	4.39
Batch 7	13.33	12.89	5.83	5.72
Batch 8	8.58	13.27	14.12	14.52
Batch 9	5.93	9.54	7.17	5.34
Batch 10	12.52	13.04	7.23	13.13

Electrical Properties of the electrical cables

Electrical resistivity of the metallic conductor

The mean results of the electrical resistivity of the four cable sizes, sampled in this study are given in Table 4. As shown in Table 3, most of the electrical cables sampled from the electrical shops were substandard; as they were unable to meet the NIS recommendations (Table 5) of the electrical resistivity of electrical cables, to be used in Nigeria for electrical installations. Summary of the electrical resistivity of the electrical cable presented in Figure 5, revealed that percentage of the cables than failed to meet the NIS and SON standards. As shown in Figure 5, it was only 50% of the 1 mm^2 cables, 40% of the 1.5 mm^2 cable, 20% of the 2.5 mm^2 cable and 30% of the 4 mm^2 cable that met the NIS recommendations. From the study results, the 1 mm^2 and 1.5 mm^2 cables have better electrical resistivity, than the 2.5 mm^2 and 4 mm^2 cables. These results implies that both the 2.5 mm^2 and 4 mm^2 cables fell short of the NIS recommended electrical resistivity expected of them. The high counterfeiting percentage witness in the 2.5 mm^2 and 4 mm^2 cables, could be attributed to the high utilization of these cables sizes, in electrical installations. According to NIS, 2.5 mm^{2}cable is recommended for electrical wiring; while 4mm^{2}is recommended for water heater, kitchen oven, air conditioner, etc. installation. Onyekachi & Nduka (2019) reported similar high percent of substandard 1.5 mm^2 and 4 mm^2 cables in Abia, Kano and Rivers states. According to SON, electrical cables with high electrical resistivity are hazardous to both human beings and electrical materials. This is because these cables can easily be heated up under loading, due to their high resistance, which could eventually lead electrical fire outbreak (Adekoya, 2019). There results obtained from this study will Nigeria standard regulatory to mop up fake and counterfeited electrical cables from the Nigeria markets.

Table 4: Electrical resistivity of the electrical cables

Sampled	Electrical resistivity (Ω mm)			
	1 mm^2	**1.5 mm^2**	**2.5 mm^2**	**4 mm^2**
Batch 1	3.56×10^{-7}	8.89×10^{-7}	2.15×10^{-7}	9.38×10^{-7}
Batch 2	4.05×10^{-7}	7.28×10^{-7}	8.81×10^{-7}	6.77×10^{-7}
Batch 3	1.70×10^{-7}	1.98×10^{-7}	7.39×10^{-7}	1.66×10^{-7}
Batch 4	1.78×10^{-7}	1.84×10^{-7}	1.64×10^{-7}	2.65×10^{-7}
Batch 5	2.93×10^{-7}	6.17×10^{-7}	1.77×10^{-7}	3.07×10^{-7}
Batch 6	1.73×10^{-7}	8.64×10^{-7}	5.27×10^{-7}	1.64×10^{-7}
Batch 7	1.58×10^{-7}	2.06×10^{-7}	9.09×10^{-7}	7.04×10^{-7}
Batch 8	1.79×10^{-7}	1.93×10^{-7}	5.83×10^{-7}	6.32×10^{-7}
Batch 9	4.27×10^{-7}	9.61×10^{-7}	9.69×10^{-7}	1.45×10^{-7}
Batch 10	3.80×10^{-7}	2.61×10^{-7}	3.82×10^{-7}	4.10×10^{-7}

Table 5: NIS recommendation of electrical cable core

Cross sectional (mm^2)	Diameter (mm)	Radial thickness of insulation (mm)	Cable resistance at 20^0C (Ωmm)	Resistivity at 20^0C (Ωmm)
1.00	1.30	0.70	18.30	2.15 X 10^{-7}
1.50	1.38	0.70	13.30	2.0 X 10^{-7}
2.50	1.78	0.8	7.41	1.85 X 10^{-7}

Source: Adebayo (2012).

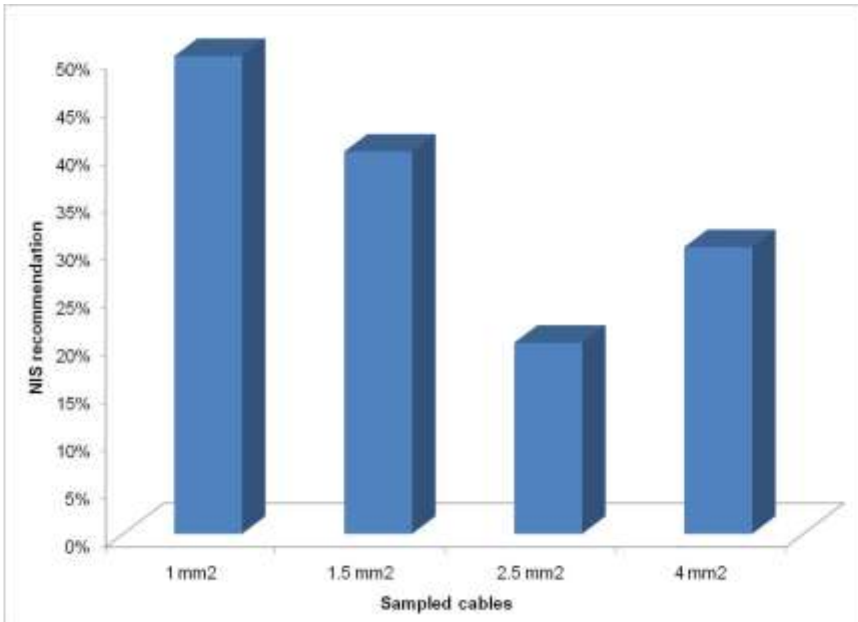

Figure 5: Electrical resistivity of the sampled electrical cable core

CONCLUSION

This study was done to analyze the mechanical and electrical properties of electrical cables, and to ascertain if they are in compliance International standards. Four commonly used electrical cables grades (1 mm^2, 1.5 mm^2, 2.5 mm^2 and 4 mm^2) were sampled from major electrical shops in Onitsha, Anambra State, Nigeria. The mechanical and electrical properties of the sampled electrical cables were tested according to NIS and ES standards. The study results that most of the mechanical and electrical properties of the sampled cables fell short of NIS standards. In terms of the on tensile strength of electrical cables, it was observed that only 40% of the 1mm^2, 50% of the 1.5 mm^2, 40% of the 2.5 mm^2 and 30% of the 4 mm^2electrical cables investigated, met the NIS standard. Considering the tensile elongation of the electrical cable cores, the study results revealed that only 20% of the 1 mm^2 cables, 30% of the 1.5 mm^2 cables, 20% of the 2.5 mm^2 cables and 40% of the 4 mm^2 cables met the NIS IEC 60227 recommendations for electrical cables. Furthermore, the results revealed that 50% of the 1 mm^2 cable, 60% of the 1.5 mm^2 cable, 70% of the 2.5 mm^2 cable, and 60% of the 4 mm^2 cable insulators failed to meet the Standard recommendation. Regarding the electrical resistivity of the sampled cables, regardless of the cable size, most of the electrical cables have resistivity, was higher than NIS recommendations. As seen in the results, there is urgency for Nigeria standard regulatory agencies to mop up the substandard cables from the Nigeria market, to prevent electrical hazards.

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