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Mechanical behavior and specific energy in elastic phase of aluminum wires and copper wires belonging to low voltage underground electrical cable

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ABSTRACT
Having a reliable power grid precisely underground power cables and optimizing the mechanical safety of its various elements has become extremely important in industry.
Failures of underground cables involve all components particularly the wires, because of their functionality to transmit electric current which causes damage that influence in their turn the reliability and maintenance of underground cables.
The aim of this paper is to have a general idea about the mechanical behavior of aluminum wires and cooper wires of underground cables LV H1XDVAS and LV U1000R2V. For this, a statistical study on the different test specimens is established and a study of the specific energy in the elastic phase of the two types of materials of the electric wires (copper and aluminum) to determine the reliability of electrical wires and set the appropriate confidence interval. Finally, a statistical Weibull method is applied in order to define the reliability and damage of electrical aluminum and copper wires.
***Keywords* -** aluminum wires,copper wires, damage, mechanical behavior, reliability, Underground power cable.

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I. INTRODUCTION

Generally, high loads, high electricity consumption, aging and harsh environments make it increasingly important to be able to locate quickly and prematurely the defects arising in underground cables [1]. Even if the investments related to their installations are prohibitive, their environmental and aesthetic impact is greater.

Copper and aluminum materials could be transformed into wire by wire drawing. The wire drawing is a technique of cold metal shaping which reduces the wire section through continuous traction, from a mechanical point of view: the stretching of a wire causes plastic deformation of the material leading to a general change in its mechanical properties.

The two studied samples are copper wire extracted from underground electric cable LV U1000R2V and Aluminium wire extracted from underground electric cable LV H1XDVAS

Every conductor strand is made up of several wires wrapped in successive layers around a central core wire. Thus, their wires require a detailed study because of the harmful effects of their failure on the entire electrical system. The purpose of our work is to treat the results of mechanical tests and chemical composition applied to aluminum wires and copper wires of underground electrical conductors. All trials are conducted under the guidelines prescribed by the appropriate standards for each type of test. [2]

The aim of this paper is to analyse the mechanical behavior of electrical wire made of copper and aluminum. Results are supported by student statistical analysis that process the reliability and another statistical study results (Weibull) is performed to plot the reliability and damage curves. A comparative study of the two types of electric wire materials (copper and aluminum) is conducted in order to review the various advantages and disadvantages of each material.

II. EXPERIMENTATION

II.1 Chemical Composition and mechanical properties of aluminum wires

II.1.1 Chemical Composition

The chemical composition of aluminum wires and copper wire is obtained by spectrometric analysis using a spectrometer peak spark. The result is reported in Table 1,2:

Table 1. Chemical composition of aluminum wires [3]

Elements	Cr	Cu	Zn	Nb	Se	Cd	Al
Percentage (%)	0.0021	0.001	0.00 39	0.015	0.0022	0.0019	99.94

Table 2. Chemical composition of copper wires[4]

Elements	Ti	Au	C	Nb	Si	Te	Cu
Percentage (%)	**0.0025**	**0.002**	**0.048**	**0.015**	**0.0022**	**0.015**	**99.77**

II.1.2 Mechanical properties

The two studied samples are shown in Fig.1 and Fig.2:

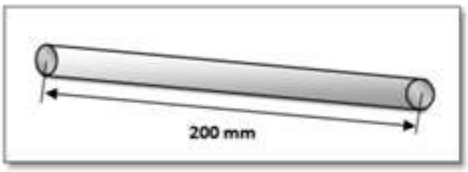

Fig 1. Schematic of aluminum wire specimen

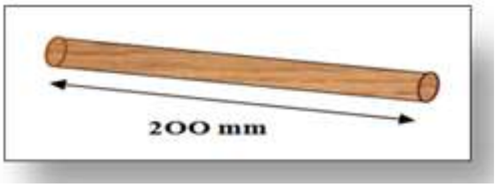

Fig 2. Schematic of aluminum wire specimen

Different mechanical properties are summarized in the table 2.

Table 3 . Mechanical properties of aluminum wire and copper wire

	Elastic stress σe(MPa)	**Breaking stress** σr(MPa)	**Strain** ε(%)	**Young modulus E**(MPa)	**Maximum stress** σu(MPa)
Aluminium wire	120	23	2.5	71	124
Copper wire	358	369	30	124	369

The aluminum used in this type of cable is partially cured, indeed, it undergoes a lower deformation than normal aluminum generally used in electrical cables (might reach 50%) and higher than the cured aluminum (2%), on the other hand, it has a significant breaking stress [5].
The copper used in the second cable is partially annealing, indeed, it undergoes a lower deformation than annealing copper (might reach 35%), but it have an important breaking stress [6].

II.2 Statistical study of the aluminum wires and choice of confidence interval

The STUDENT distribution is used to identify the appropriate confidence limits. STUDENT law determines a confidence interval in which the limits of the maximum stress of the studied specimens is 90 out of 100 to regulate the average distribution of the tensile tests.

We have:

$$P\left[-t_{(\alpha,\mu)}\ ;\ \alpha\ \leq\ \frac{X-\mu}{s/\sqrt{n}}\ <\ +t_{(\alpha,\mu)}\ ;\ \alpha\right]=1-\alpha \qquad (1)$$

Where:
X: Average of maximum stresses of different specimens;
n : Number of specimens
μ : n-1;
s : Standard deviation;
α : Risk threshold ;
$t_{(\alpha,\mu)}$: value from STUDENT table;

the limits in probability μ is defined as:

$$P\left[X-t_{(\alpha,\mu)}\ ;\ \alpha.\frac{s}{\sqrt{n}}\ <\ \mu\ <\ X+t_{(\alpha,\mu)}\ ;\ \alpha.\frac{s}{\sqrt{n}}\right]=1-\alpha \qquad (2)$$

To determine the confidence interval by calculating the upper and lower limits of the true average of the breaking load, the relation STUDENT (2) is applied to results obtained in the static tensile tests on aluminum specimens [7].

II.3 Weibull distribution on maximum stress of wires

Another statistical technique on the experimental results of tensile test on aluminum wires is studied, it is Weibull statistical method. The purpose of this study is to provide a statistical processing to derive the maximum stress that can be applied on the material so that the failure probability (damage) is less than 1%, and then estimate the survival probability (reliability) and the probability of failure.
This part is dedicated to verify that the aluminum wires follow Weibull distribution [8].
A specimen follows the Weibull distribution if there is an m (Weibull modulus) and $\sigma 0$ (Constant), such as:

$$\ln\ln\left(\frac{1}{PS}\right)=m(\ln\sigma-\ln\sigma 0) \qquad (3)$$

Where:

Ps: the probability of survival
$\ln\ln\left(\frac{1}{PS}\right)$ in function of $\ln\sigma$ is plotted in Fig 4.

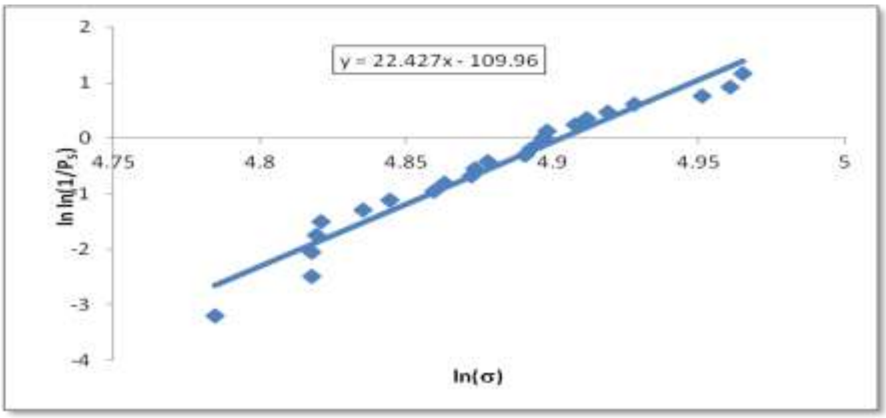

Fig 4 . $\ln\ln\left(\frac{1}{PS}\right)$ in function of $\ln\sigma$(aluminium wires)

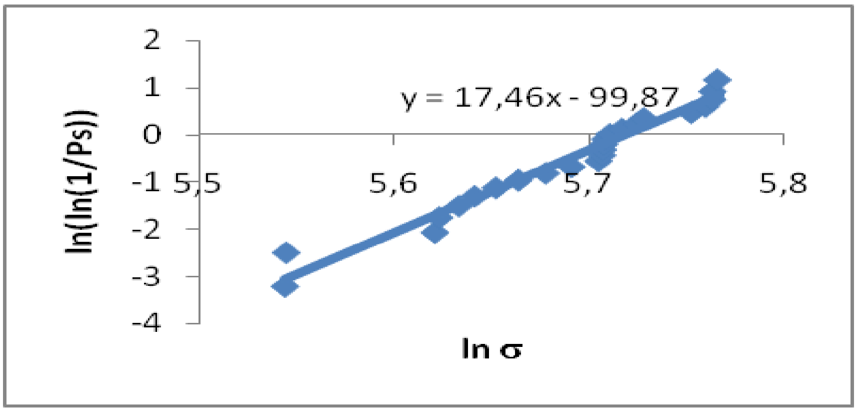

Fig 4 . $\ln\ln(\frac{1}{PS})$ in function of $\ln\sigma$(copper wires)

We obtain a right curve confirming that these specimens do follow Weibull distribution and the equations of these lines are:

For aluminum wires:

$$y = 22.427x + 109.96 \qquad (1)$$

Which means:

$$m = 22.427 \quad \text{and} \quad \sigma 0 = 134.69577 \text{ MPa}$$

For copper wires:

$$y = 17.46x - 99.8 \qquad (2)$$

Which means:

$$m = 17.46 \quad \text{and} \quad \sigma 0 = 305.33\text{MPa}$$

II.4 Calculating the specific energy in elastic phase

Energy of a system is the potential to perform work or produce heat. The specific energy in elastic phase is the energy associated with the elastic deformation of a material. The absorption capacity and energy release per unit mass of a substance undergo elastic deformation is expressed by the relationship [9]:

$$\frac{w}{m} = \frac{\sigma^2}{2\times\rho\times E} \text{ in joule/kg}$$

with

ρ: the density in kg / m3

E: Young modulus in MPa

σ: maximum stress in MPa

III. RESULTS AND DISCUSSION

III.1 Application of statistical methods

III.1.1 STUDENT distribution

We conducted a tensile test of 24 specimens for each material.

The confidence interval (CI) at 90% is an interval of values which have 90% chance to contain the true value of the estimated maximal stress. It is possible to say that the CI represents the interval of values within which we are 90% certain to find the real search value. The confidence interval is the set of values reasonably compatible with the observed result. It provides a visualization of the incertitude.

We have

CI Aluminum = $[129.47, 133.91]$

CI copper = $[289.54, 302.15]$

III.1.2 Weibull distribution

The probability of survival of specimen undergoing stress could be modeled using the following Weibull model:

$$Ps = e^{-(\frac{\sigma}{\sigma 0})^m} \qquad (5)$$

The probability of survival curve and the probability of failure in function of σ are presented in Fig 6

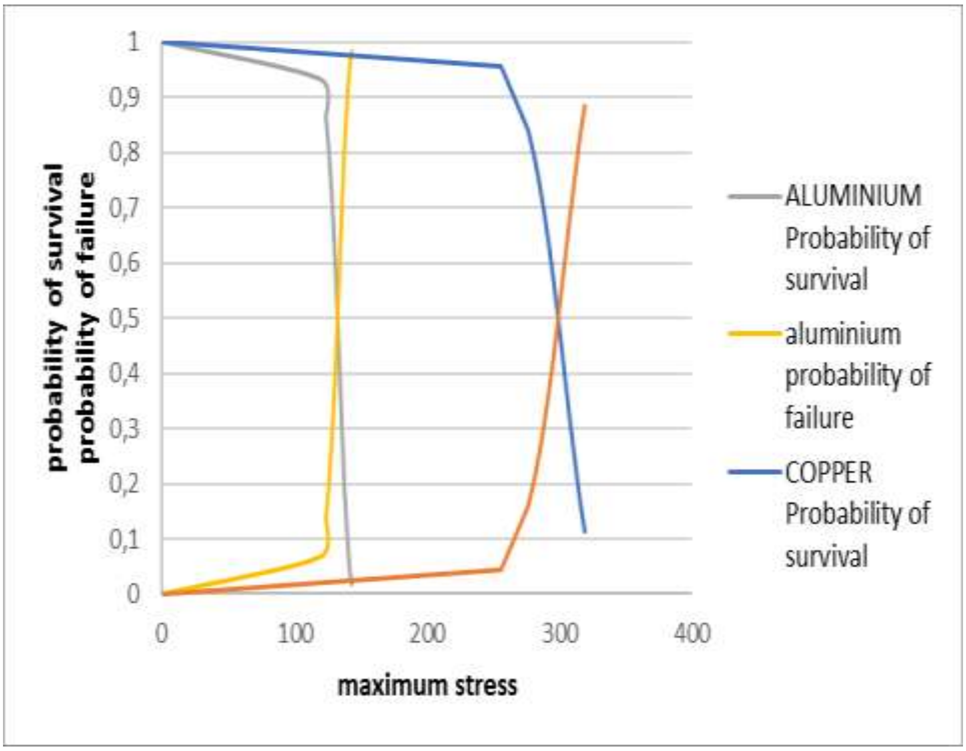

Fig 6. Probability of survival-Probability of failure curve in function of maximum stress

According to the curve in Fig 6, statistical studies carried out on different specimens of aluminum and copper wires have shown that the maximum stress of the copper wires is significantly greater than that of aluminum (σu cu = 295 MPa, σu al = 131 MPa).

III.1.3 specific energy in elastic phase

So, for the different components of our cable we studied the results summarized in the following table:

Table 2. Specify energy of different component

Cable component	**Specify energy(J/Kg)**
Copper wire	0,61
Aluminum wire	3.8

We note that the specific energy in the elastic phase of underground electrical cable are enormously interesting on electrical aluminum wire than copper wire , the increase of the elastic energy more reliable and allows the material of the mechanically protected to withstand external and internal attacks. Aluminum wire material has higher energy that will protect against the internal and environmental stresses relating to the interaction with different elements of the cable.

IV. CONCLUSION

The study of different test specimens of aluminum and copper wires have shown that copper wires can withstand more mechanical loads than aluminum wires (σu (cu) = 295 MPa, σu (al) = 131 MPa). It should also be noted that the modulus of WEIBULL copper is lower than that of aluminum.

However, the critical life fraction of aluminum wires is greater than that of copper, which gives aluminum a longer life compared to copper. For this reason, it can be concluded that aluminum possesses, in addition to its advantages of having a low weight and an economic cost, the advantage of a longer life than copper despite its better mechanical characteristics.

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