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Mechanical behavior and statistical study of aluminum wires belonging to low voltage underground electrical cable

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ABSTRACT

Increasing demands of quality expressed by customers require short delay to recharge in the case of incidents on low voltage power grids.

Therefore, having a reliable power grid precisely underground power cables and optimizing the mechanical safety of its various elements has become extremely important.

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 of underground cables LV H1XDVAS. For this, a tensile test on aluminum wires is executed, and then a statistical study on the different test specimens is established to determine the reliability of experimental results and set the appropriate confidence interval. Finally, a statistical Weibull method is applied in order to define the reliability and damage of electrical aluminum wires.

Keywords - *aluminum wires, damage, mechanical behavior, reliability, Underground power cable.*

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I. INTRODUCTION

The increase in electricity consumption, high loads, aging, harsh environments and density of residential areas 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.

The structure of the cable tested in this study is shown in Fig.1. This cable consists of three aluminum conductors strands identified by black insulation (XLPE) and a neutral conductor. The outer sheath of these conductors is composed of polyvinylchloride (PVC) and a thin galvanized steel metal screen.

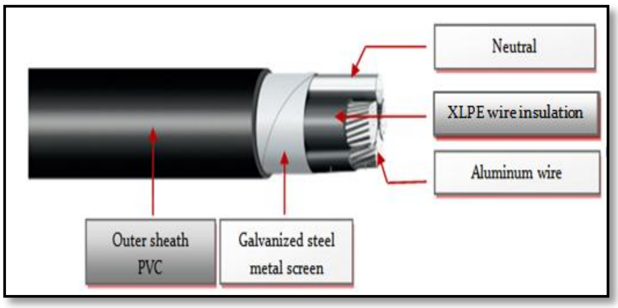

Fig 1. Components of an underground electrical cable LV H1XDV AS

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 of underground electrical conductors. All trials are conducted under the guidelines prescribed by the appropriate standards for each type of test. [2]

II. EXPERIMENTATION

II.1 Chemical Composition and mechanical properties of aluminum wires

II.1.1 Chemical Composition

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

Table 1. Chemical composition of aluminum wires

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

II.1.2 Mechanical properties

In order to characterize mechanically this material, a tensile test is applied to 5 specimens according to the standard. The minimum length of the samples is equal to the length of the test (200mm) plus the necessary for the mooring. Therefore, a length of 300 mm was anticipated as the length of the test for aluminum wires (Fig.2).

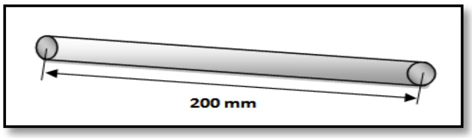

Fig 2. Schematic of aluminum wire specimen

The stress-strain curve of the aluminum wire is shown in Fig 2.

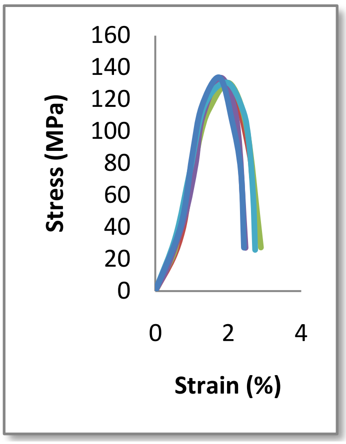

Fig 3. Stress-strain curve of the aluminum wire

Different mechanical properties are summarized in the table 2.

Table 2 . Mechanical properties of aluminum wire (cable H1XDV AS)

Elastic stress σe	Breaking stress σr	Strain ε	Young modulus E	Specific energy Wm	Maximum stress σu
120 MPa	23 MPa	2.5 %	71 GPa	215 J /Kg	124 MPa

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 [3].

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:

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

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 [4].

II.3 Weibull distribution on maximum stress of aluminum 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.
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.

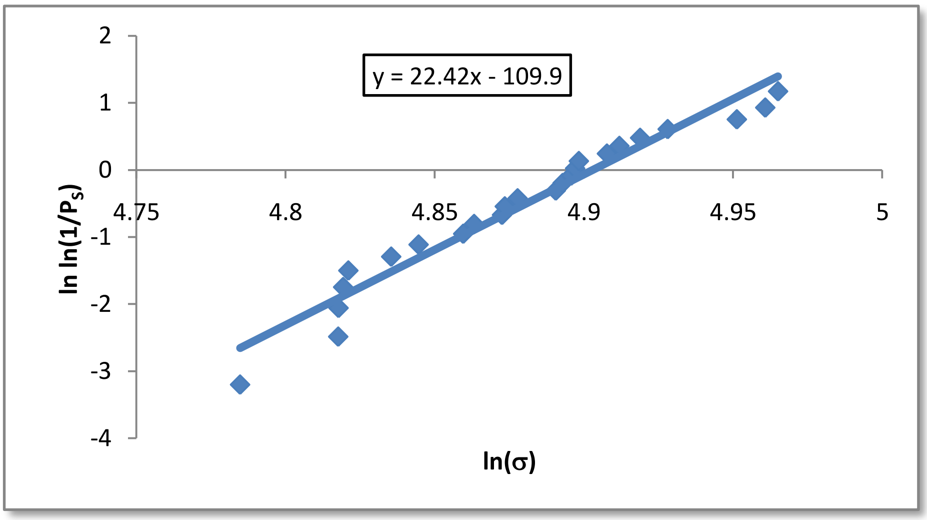

Fig 4 . $\ln\ln\left(\frac{1}{PS}\right)$ in function of $\ln\sigma$

We obtain a right curve which validates that these aluminum specimens do follow Weibull distribution.
And the equation of this line is:

$$y = 22.427x + 109.96 \quad (4)$$

Which mean :

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

III. RESULTS AND DISCUSSION

III.1 Application of statistical methods

III.1.1 STUDENT distribution

To make a statistical study of the test results on the studied aluminum wires, we conducted a tensile test of 24 specimens. Results of these tests are presented in Fig 5.

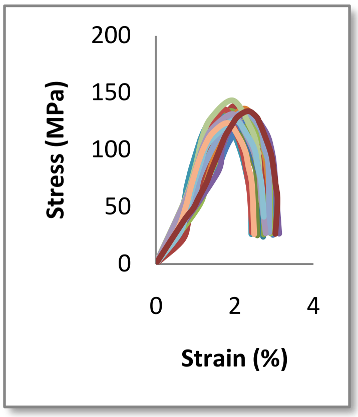

Fig 5 . Stress-strain curve of 24 aluminum specimens

The average and standard deviation estimated of maximum stress that correspond at 24 specimens subjected to static tests are:

X = 131.69 MPA ; s = 6.355; n = 24 specimens; $\alpha = 0.1$; $t\,(\frac{\alpha}{2}; 23) = 1.714$ (value from STUDENT table)

Resulting:

$$\mu = 131.69 \pm 1.714 \sqrt{\frac{40.39}{24}} = [129.47, 133.91]$$

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.

Table 3. shows the values of the maximum stress that exist in the confidence interval:

Table 3 . Aluminum specimens acceptable from the confidence interval

Specimens	Maximum stress
1	133.89
6	130.651
9	133.716
15	130.774
16	133.028
18	133.333
22	131.337

III.1.1 *Weibull distribution*

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

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

The probability of survival curve and the probability of failure in function of life fraction β are presented in Fig 6.

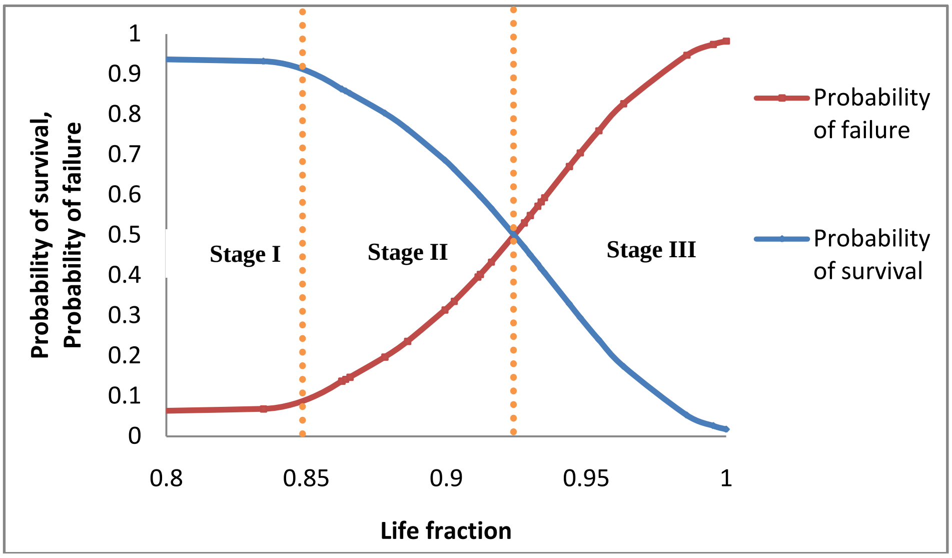

Fig 6. Probability of survival-Probability of failure curve in function of life fraction

According to the curve in Fig 6, we could distinguish three stages of reliability progression , the first stage represents an elevated Reliability which corresponds damage initiation , stage II is characterized by a regression of the reliability to reach the stage III defining unstable area.
The task is to estimate the maximum stress that can be applied to the material so that the failure probability is lower than 1%. This means that:

$$Ps > 0.99 \tag{6}$$

It has been shown previously that our specimens follow Weibull distribution. We have:

$$e^{-(\frac{\sigma}{\sigma 0})^m} = 0.99 \tag{7}$$

The value of the maximum stress obtained that could be applied on the material so that the failure probability is less than 1%:

$$\sigma = 109.716758$$

IV. CONCLUSION

In general applications, the most used material is copper, currently, we tend to use aluminum conductors for electric power transmission lines, in fact, in addition to the advantage of low weight and financial constraints, aluminum has several strong points in its mechanical properties, in our statistical analysis, it is noticed that the specimens of aluminum have a minimal dispersion, STUDENT distribution helped us to refine the confidence interval.

Weibull modulus m is a characteristic parameter of defects dispersion material, when it is low; the defect distribution is very heterogeneous. On the other hand, Weibull distribution allows us to define the appearance of probability of survival and therefore determine the damage of aluminum wires, then have the key elements for use of predictive maintenance and determine the three stages of reliability progression in order to ensure the efficiency of electrical aluminum wires and electrical installation in general.

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