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Mechanical comparison and statistical study of copper and aluminum wires used for underground low voltage electric cables

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Abstract

Electrical cables are usually made of copper or aluminum materials because they require a compromise of mechanical and electrical characteristics, and the choice between these two specific materials involves economic and technical factors and necessitates a broad knowledge of materials.

Hence the interest of the present work which is firstly the mastery of mechanical behavior of copper and aluminum wires to improve and optimize the mechanical characteristics of the cable, another characterization approach was considered in this paper; it is a statistical study of Student that allows the selection of the most reliable results with a risk threshold of 10% for the both types of materials. On the other hand, a weibull statistical study is carried out to extract the weibull elements and subsequently define the reliability theory and damage of We bull.

As result of this study, the maximum stress of the studied electrical wire made of copper is significantly higher than that of the wire made of aluminum, it is also noticed that copper wire have a plastic behavior which undergoes mechanical deformations unlike the fragile behavior of aluminum wire. However, we have concluded that the critical life fraction of aluminum wire is higher than that of copper wire.

Key Words:

Statistical study; reliability; damage; tensile test; cooper; aluminum.

1. Introduction

Generally, 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.

This variation in mechanical properties according to material hardening is exploited to obtain a wire having good tensile strength, a high elastic limit, a controlled elongation, These specific characteristics are required for electrical wire to ensure the transmission of electrical energy. The aim of this paper is to study 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)

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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.

2. Experimentation

2.1 Studied Specimen

The two studied samples are:

• Copper wire extracted from underground electric cable LV U1000R2V

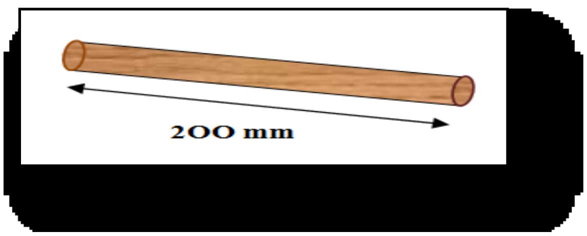

Figure1: Schematic of copper wire specimen [1].

•Aluminium wire extracted from underground electric cable LV H1XDVAS

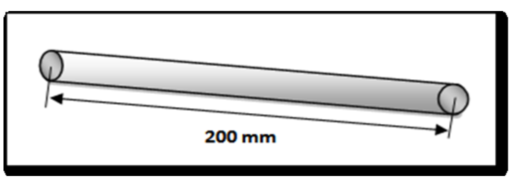

Figure 2: Schematic of aluminum wire specimen [2].

3. Chemical Composition and mechanical properties of cooper and aluminum wires

3.1 Chemical Composition

The chemical composition of copper and aluminum wires is obtained by spectrometric analysis using a spectrometer peak spark. The result sare reported in Table 1 and table 2 [3]:

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

Table 2: Chemical composition of copper wires

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

3.2 Mechanical properties

Different mechanical properties extracted from stress-strain curves are summarized in the table 3 and table 4 :

Table 3 . Mechanical properties of aluminum wire (cable H1XDV AS) [3]

Elastic stress σe(MPa)	Breaking stress σr(MPa)	Strain ε(%)	Young modulus E(MPa)	Maximum stress σu(MPa)
120	23	2.5	71	124

Elastic stress σe(MPa)	Breaking stress σr(MPa)	Strain ε(MPa)	Young modulus E(GPa)	Maximum stress σu(MPa)
358	369	30	124	369

Table 4 . Mechanical properties of copper wire (cable U1000R2V)

The aluminum used in this type of cable is partially cured, indeed, it undergoes a lower deformation than normal aluminum

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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].

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 [4].

4. STUDENT Statistical study of the aluminum and the copper wires

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. The relation STUDENT[3] is applied to results obtained in the static tensile tests on aluminum and copper specimens [4].

5. We bull distribution on maximum stress of aluminum and copper wires

Another statistical technique on the experimental results of tensile test on aluminum and copper 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.

$\ln\ln(\frac{1}{PS})$ in function of $\ln\sigma$ is plotted in Figure 3 and Figure 4.

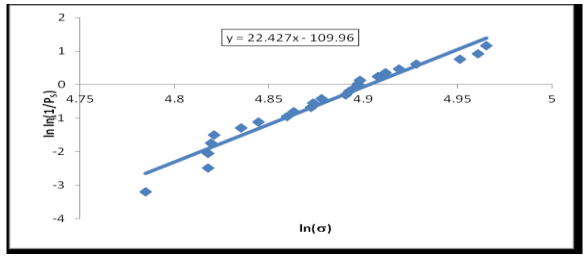

Figure3 .$\ln\ln(\frac{1}{PS})$ in function of $\ln\sigma$(aluminum wires)

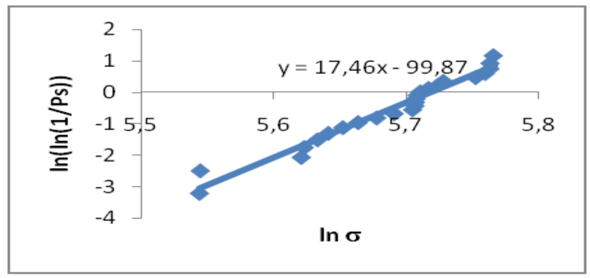

Figure4 .$\ln\ln(\frac{1}{PS})$ in function of $\ln\sigma$(copper wires)

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

For aluminum wires:

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

Which means :

m =22.427 and σ0 = 134.69577 MPa

For copper wires:

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

Which means :

m =17.46 and σ0 = 305.33MPa

6. Results and discussion

6.1. STUDENT distribution

To develop a statistical study of the studied aluminum and copper wires, we

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conducted a tensile test of 24 specimens for each material.

The confidence interval (CI) at 90% is an interval of values which have90% 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 cooper = $[289.54, 302.15]$

6.2 *Weibull distribution*

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

$$Ps = e^{-(\frac{\sigma}{\sigma 0})^m} \quad (3)$$

The probability of survival curve and the probability of failure in function of life fraction β for the two materials are presented in Fig 5.

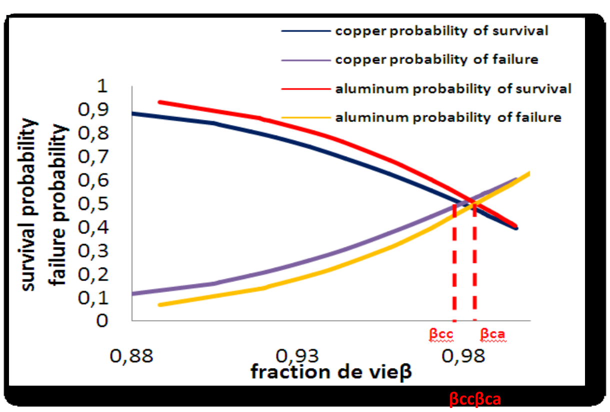

Figure 5: Probability of survival-Probability of failure curves in function of life fraction

According to figure 5, it is clear that the life fraction of aluminum wires isgreater than the life fraction of copper wires.

The task is to estimate the maximum stress that can be applied to the materials so that the failure probability is lower than 1%. This means that:

$$Ps > 0.99 \quad (4)$$

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

$$e^{-(\frac{\sigma}{\sigma 0})^m} = 0.99 \quad (5)$$

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

For aluminum wires:

$$\sigma = 109.71 \text{MPa}$$

For copper wires:

$$\sigma = 234.63 \text{MPa}$$

7. Conclusion

Copper wires have several strong advantages in their mechanical properties, they have a greater maximal stress and an important strain (30 % of strain) than aluminum wires, in studied statistical analysis, it is noticed that the specimens of copper have a less dispersion than copper wires; STUDENT distribution helped us to refine the confidence interval.

The value of the maximum stress obtained that could be applied on the copper wires so that the failure probability is less than 1% is greaterthan maximum stress value for aluminum wires.

On the other hand, aluminum wires have a greater critical life time, which means that they have an important life time compared to aluminum wires.

Weibull modulus m is a characteristic parameter of material defects dispersion, the lowest it is, the more heterogeneous is the defect distribution. On the other hand, Weibull distribution permits the definition of survival probability therefore determine the aluminum wires damage, and thus to intervene in time for predictive maintenance, in order to ensure the efficiency of electrical aluminum wires and electrical installation generally.

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