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MECHANICAL CHARACTERIZATION AND STATISTICAL STUDY OF COPPER ELECTRICAL WIRES IN AN OVERHEAD LINE

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Abstract- Electrical wire is a component widely used in most applications in the fields of electricity, electronics, electrical engineering, aeronautics; naval, etc. It is normally the main component of some electronic boards. it is also generally made of copper thanks to its excellent electrical conductivity. the aim of this work is to study the mechanical properties of copper wires taken from underground cables, to improve and optimize the mechanical and electrical characteristics of the cables. for this purpose, a series of tensile tests on the copper wires is carried out. After that, a statistical analysis is applied to our different samples to indicate the quality of the experimental results and to determine the appropriate confidence period. Finally, check the reliability and failure of these wires with a Weibull law.

Keywords: Weibull Law, Student Law, Electrical Wire, Reliability, Tensile Test, Failure.

1. INTRODUCTION

Copper wire has always been considered a noble element since its discovery [1, 3], and because of its extensive uses in most fields including human health [4]. Thanks to their high thermal conductivity, low electrical resistance and high tensile strength [5].

Until today, the electrical wire is still in use and has undergone intrinsic modifications to adapt to increasingly severe residual and external (electrical and environmental) constraints [6]. For this reason, it is always necessary to carry out studies to guarantee the correct functioning of a system that contains this type of material, as well as to estimate its evolution over time, in order to be able to make a repair of the systems in which it is used, and to have the possibility of putting in place a provisional solution at an acceptable cost, in order to avoid any significant damage with catastrophic results [7].

Electrical wires represent basic components for many types of electrical underground cables [8, 10]. The components of these cables often undergo external stresses (mechanical, temperature, humidity, etc.) which are generally the cause of premature deterioration of the network [11, 12]. A complete system can fail due to a poor electrical connection [13].

For this purpose, the control of the mechanical behavior of the underground electric cable and the identification of the mechanical phenomena that most affect the availability of underground cables become a priority necessity for mechanic who aims at establishing a model for predicting residual service life [14].

Several general syntheses from the different theoretical and experimental models on the study of cables have been carried out. One can refer mainly to the work of Retima and al [15] who carried out a series of experimental tests on the copper material and its 4% silicon solid solution and compared their experimental results with the results that exist in the literature.

Ouaomar, et al. [16, 17] studied the mechanical behavior of aluminum wires of LV H1XDVAS underground cables. As a result, tensile tests on aluminum wires are done, and validated their results by statistical laws. Morale and al [18] have mechanically characterized copper alloy joints. Hojo and al, studied the stress-strain behavior of copper and bronze in Nb_3Sn / Cu by separating the stabilizing copper from the composite wire. They also analyzed the thermal stress distribution in the stabilizing copper and gradually removed the copper from the composite wire.

The objective of our work is to address the mechanical behavior of copper electrical wires while supporting our results with a statistical study that addresses the reliability and failure of the results obtained.

2. EXPERIMENTAL TRIALS

To better choose a material, it is essential to characterize and analyze its mechanical properties. In this part, we have made a chemical characterization and mechanical characterization on a sample of an electric copper wire, which is used in electrical installations either domestic, industrial… [19, 20].

2.1. Chemical Characterization

A chemical characterization was performed using an AMETEK optical emission spectrometer on a sample of electrical copper wire to determine its chemical composition (Figure 1), within a temperature range of 20 °C and 27 °C. The results obtained are those presented in Table 1.

Figure 1. Chemical characterization test of an electrical copper wire using a spectrometer

Table 1. Chemical characterization of an electrical copper wire

Zn	Pb	Sn	P	Mn
0.0449	0.00085	0.0002	0.002	0.00026
Fe	Ni	Si	Mg	Cr
0.0111	0.00042	0.0028	0.00061	0.0011
Te	As	Sb	Cd	Bi
0.009	0.0031	0.0252	0.0001	0.00099
Ag	Co	Al	S	Be
0.00093	0.0004	0.0054	0.0002	0.0001
Zr	Au	B	Ti	Se
0.0002	0.0005	0.0002	0.00032	0.0006
Pt	Cu			
0.002	99.9			

2.2. Mechanical Characterization

2.2.1. Materials

The electric wire used in this study of type H 07 V-U, it was taken from an electric cable used especially in low voltage installations, the wire is characterized by a length of 400 mm and a diameter of 1.8 mm (Figure 2).

Figure 2. Test tube of copper wires

2.2.2. Experimental Procedure

In order to find the mechanical characteristics of the material used, we carried out a series of tensile tests on 15 standardized specimens, according to the electrical cable standard 50525 A traction machine was used with a capacity of 2.5 KN and its brand Zwick Roell (Figure 3). The tensile machine was set to a loading speed corresponding to 2 mm/min.

After the mechanical characterization tests, we took the specimens broken under the effect of the tensile tests. To measure the reduction of their cross-section after the break in relation to the initial cross-section, i.e., to obtain the value of the wire's stress coefficient, we used the scanning microscope (Figure 4).

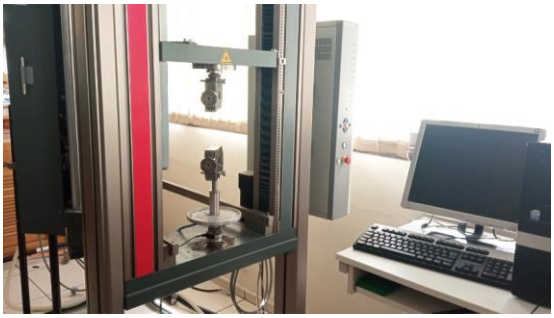

Figure 3. Mounting a test specimen in the machine

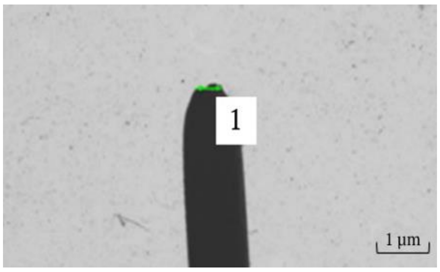

Figure 4. Section measurement tests after breakage by profile projector

3. RESULTS AND DISCUSSION

3.1. Mechanical Behavior

The set of tests leading to the tensile tests, to draw the tensile curves, which represents the evolution of the stress as a function of deformation and then extract the mechanical characteristics grouped in Table 2.

According to Figure 5, we conclude all the mechanical characteristics of this material as shown in the Table 2.

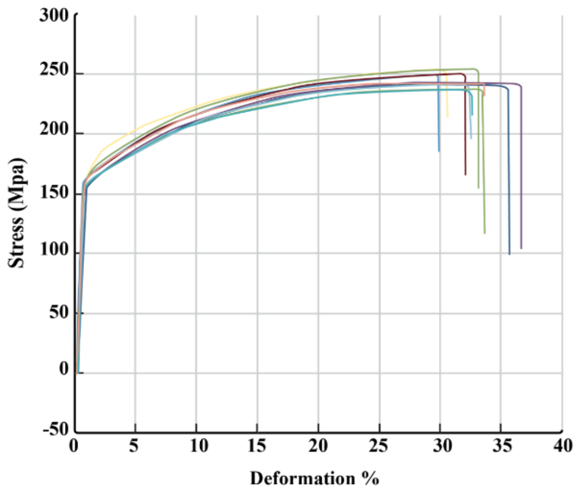

Figure 5. Tensile curves of copper wire specimens

Table 2. Mechanical characterization of copper wires

E(MPa)	σ_e (MPa)	σ_r (MPa)	$\mathcal{E}$ (%)	S (%)
120	167	212	30	88

E: Young's module
σ_e: Elastic limit
σ_r: Breaking strength
$\mathcal{E}$: Deformation
S: Striction

3.2. Static Study

3.2.1. Student Law

The student distribution (t) is used to find confidence intervals for samples with very low numbers and an unknown standard deviation [16 - 21]. in this state, it is applied to adjust the distribution of the results obtained from our tests. Knowing that:

$$P[-t(\alpha,\mu) \le \frac{X-\mu}{\frac{S}{\sqrt{n}}} < +t(\alpha,\mu)] = 1-\alpha \quad (1)$$

X: the average of the maximum stresses of the different specimens
n: number of specimens
μ': n-1
S: the standard deviation
α: risk threshold
t (α, μ): Value given by the table annexed to Student

The confidence range is determined, by applying a student statistical law to all the results obtained by the tensile test, to calculate the lower and upper limits of the true average maximum stress of different electrical wire specimens. The mean and estimated standard deviation of the maximum stress corresponding to 15 static test specimens are as Table 3.

Table 3. Results of elastic limits and maximum stresses

Trial No	Elastic Limit [MPa]	Maximum Stress [MPa]
1	161	213
2	162	214
3	163	217
4	163	218
5	163	218
6	164	219
7	165	219
8	166	219
9	166	219
10	166	219
11	167	219
12	168	220
13	168	220
14	169	220
15	170	220
16	170	220
Average	165.6875	218.375
Standard Deviation	2.3515625	1.484375

3.2.1.1. The Yield Strength

X=165.69 MPa; s=2.36; n=16 samples; α=0.05.
t (α ; 15) = 2.13 "Value of the Student Table".

$$\mu_{elastic} = 165.69 \pm 2.13\frac{2.36}{\sqrt{16}} = [164.43;167] \text{ MPa}$$

Table 4. The set of elastic limits belonging to the confidence interval

Trial No	Elastic Limit [MPa]
6	164
7	165
8	166
9	166
10	166
11	167

3.2.1.2. The Maximum Stress

X=218.37 MPa; s=1.48; n=16 samples; α =0.05;
t (α; 15) =2.13 "Value of the Student Table".

$$\mu_{\max} = 218.37 \pm 2.13\frac{1.48}{\sqrt{16}} = [217;219] \text{ MPa}$$

Table 5. Set of maximum constraints belonging to confidence interval

Trial No	Maximum Stress [MPa]
3	217
4	218
5	218
6	219
7	219
8	219
9	219
10	219
11	219

The 95% confidence interval (μ or IC) is a range of values is obtained with a 95% probability of finding the true value of the estimated constraint in it, we can say that the confidence interval represents a cloud of conforming values including the required true value. All of these values are accepted and consistent with the observed result. it gives insight into the uncertainty of the estimate.

3.2.2. Weibull Law

in this part, we use the Weibull law to study statistically the lifetime of our material, and then give us the estimation of an infinity of probability laws [22, 23]. According to this law the probability of survival of stressed specimens could be modelled by Equation (2).

$$P_S = e^{-(\frac{\sigma}{\sigma_0})^m} \quad (2)$$

where,
P_s: Probability of survival
σ: The applied constraint
σ_0: Scale parameter
m: Module of WEIBULL (dimensionless)

The WEIBULL curve has special specifications that are designed so that if the data follow a WEIBULL distribution [27], the points will be linear (or nearly linear) such that:

$$\ln(\ln(\frac{1}{P_{st}})) = m(\ln(\sigma) - \ln(\sigma_0)) \quad (3)$$

To find the WEIBULL Module (m), and the scaling parameter σ_0. We used the MINITAB software.

3.2.2.1. Maximum Stress

Starting first with the calculations of the Weibull law parameters for maximum stress, we found according to the MINITAB software m=184.9 and σ_0=219.2.

And the Equation for this regression line is:

$$Y_{\text{elastic}} = 184.9x - 966.6 \quad (4)$$

Alternatively, the survival probability P_s can be modeled from the maximum stress results using Equation (2) as shown in Figure 7. As well as modeling the failure probability P_f by applying (P_s+ P_f =1).

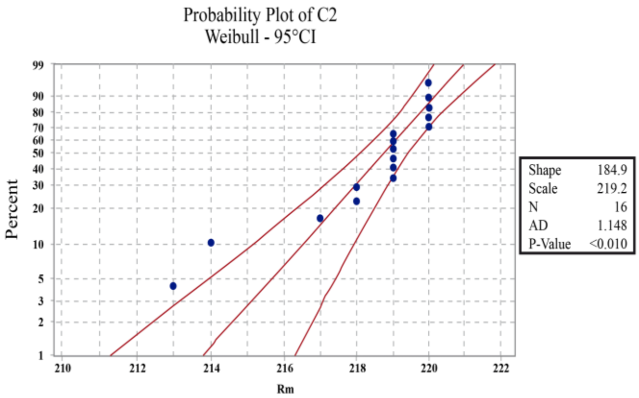

Figure 6. Estimation of Weibull Law parameters by Minitab software

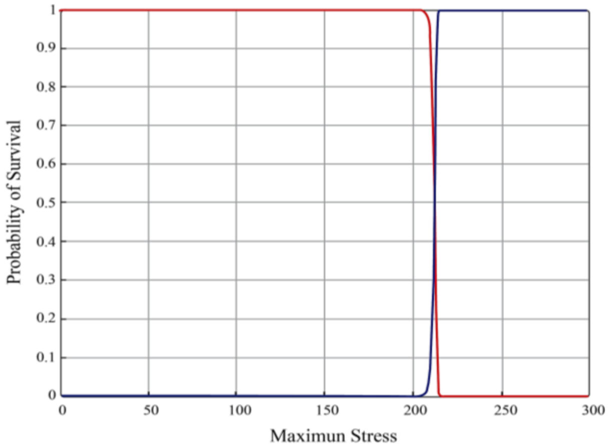

Figure 7. Probability of survival and probability of failure as a function of maximum stress

3.2.2.2. Elastic Stress

The parameters of the Weibull law for elastic stresses using the MINITAB software are m=66.26 and σ_0=167

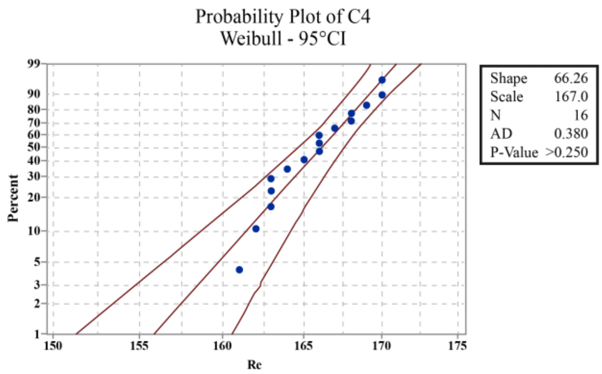

Figure 8. Estimation of Weibull Law parameters by Minitab software

And the Equation for this regression line is:

$$Y_{\text{elastic}} = 66.26x - 339.11 \quad (5)$$

According to Equation (3) and the results of the elastic stresses, the survival probability P_s was modulated. and then a modulation of the failure probability P_f by applying the equation (P_s+ P_f=1) as shown in Figure 9.

As a combination of the two curves of elastic and maximum stresses, the result will be curve in Figure 10.

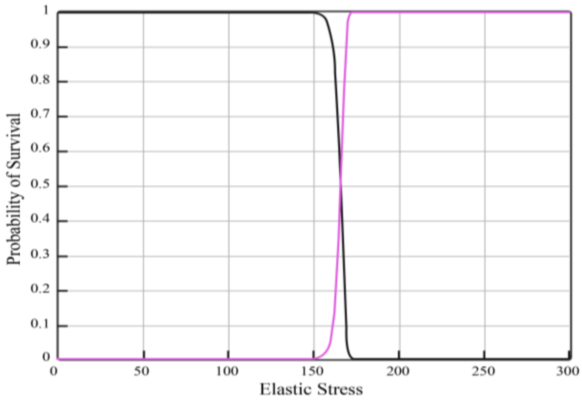

Figure 9. Elastic limit curve to give the estimate of the reliability and the estimate of the failure

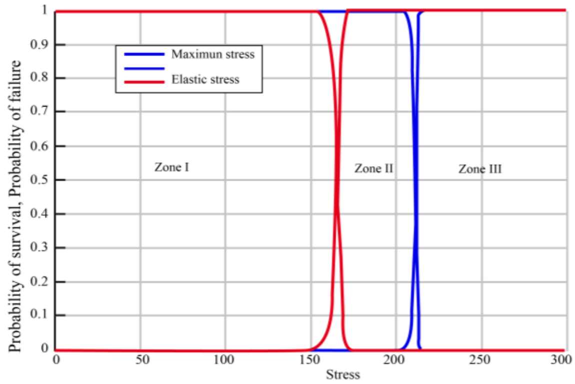

Figure 10. Overlapping of the curves for estimating the reliability and estimating the rupture of the elastic and maximum stresses of the copper wire

From Figure 10 it can be concluded that the roundness of the copper wire is somewhat coherent and highly homogeneous with a great uniformity of dispersion of the defects, and thanks to these curves we were able to determine the following 3 critical zones, namely:

- Zone I [0 MPa, 166 MPa]: This is the elastic zone which has maximum reliability, it is the safest zone.
- Zone II [166 MPa, 212 MPa]: The stable plastic zone, the probability of failure begins to increase in a controllable manner, this is the less safe zone.
- Zone III [≥ 212MPa]: the reliability of the material will become uncontrollable, the unstable plastic zone, this is the most dangerous zone.

4. CONCLUSION

The experimental study that we have carried out, has allowed us to determine the mechanical characteristics of the copper wires as well as their chemical compositions. On the basis of the experimental tests, it was possible to carry out a statistical study to determine the confidence interval using the student law and to follow the evolution of the probability of survival using the Weibull law. We were also able to determine the life span of this material and its failure, then define the 3 zones from the elasticity zone to the unstable plasticity zone during its use, in order to predict the decisive moments to intervene for a preventive maintenance.

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BIOGRAPHIES

Abdelouahed Ouafik was born in Settat, Morocco, in 1988, He is a doctoral student, at Faculty of Sciences, Ben M'sik, University of Hassan II, Casablanca, Morocco since 2018. He works on materials engineering.

Achraf Wahid was born in Berrechid, Morocco, in 1992. He is a doctor of mechanical engineering at Faculty of Sciences, Ben M'sik University of Hassan II, Casablanca, Morocco, in 2019. He works on materials engineering and analytical study of damage mechanisms and prediction of the lifetime of a lifting wire rope based on static experimental results. He has dozens of scientific publications.

Mouhamed Idiri was born in Casablanca, Morocco in 1969. He received the license in physical science and national doctorate in physical metallurgy from Hassan II University (Casablanca, Morocco) in 1995 and 2000, respectively. He obtained his Habilitation to direct scientific research in 2018. He is a Professor of several physics' disciplines. He is a member of several scientific committees of international scientific congresses. He is the author of dozens of international publications. His areas of expertise relate to metallurgy, smart materials for energy harvesting and nanomaterials.

Abderrahim Abouzaid was born in Casablanca, Morocco in 1961. He graduated from the Higher Normal School ENSET (Rabat, Morocco) in 1987. He obtained his diploma of advanced studies and a Ph.D. in metallurgical physics from Ben M'sik Faculty of Sciences, University of Hassan II (Casablanca, Morocco) in 1997 and 2004, respectively. Currently, he is a Professor at Regional Center for Education and Training Professions in the field of mechanical technology and its didactics (CRMEF) in Casablanca, Settat, Morocco. He is an Associate Professor at Laboratory of Engineering and Materials, Faculty of Sciences of Ben M'sik (Casablanca, Morocco). His research and interests are evaluation of damage to steels by measuring residual stresses by observation and measurement techniques, quality controls in the metallurgical and mechanical field and its applications and authorized metrology and instrumentation. He has dozens of scientific publications.

Brahim Boubeker was born in Casablanca, Morocco 1957. He received postgraduate doctorate and a state doctorate in metallurgy in 1995. He was an Associate Professor-Researcher at Physical Metallurgy Laboratory University of Poitiers, France. He was collaboration and training at Technical Center for Mechanical Industries CETIM, France. Currently, he is a Professor of Higher Education at Hassan II University, Casablanca since 1985. He has 50 publications in the field of metallurgy on both bulk materials and nanomaterials. He was Speaker and Consultant to several industrial companies in the field of metallurgy. He is supervising several doctoral theses, DEA, DESA, master, engineers and professional internships. He works in the fields of materials engineering, metallurgy, bulk materials, nanomaterials and on industrial issues. he has twenty scientific publications.