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EVALUATION OF THE ELECTRICAL AND MECHANICAL PROPERTIES OF ALLOY AL-0.25%CU-0.7%SI-1.0%MG-0.2%FE FOR DETERMINATION OF TERMORRESISTIVITY

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Abstract. *The growing demand for electricity makes it necessary to increase the degree of efficiency in the generation, transmission and distribution of electricity. The high electrical conductivity of aluminum, coupled with low specific gravity and reasonable mechanical resistance, classifies it as potential material to meet the needs of the current context. The present work proposes to characterize the electrical and mechanical behavior of alloy 0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe in order to classify it as thermoresistant or not. The alloy was solidified into a U-shaped metal mold and, after being demolded, was cut to pass through machining and rolling until it became a 3 mm diameter wire. One part of the wires was maintained without heat treatment and the other part was subjected to 1-hour heat treatment in the oven following two normative conditions: the COPPEL protocol and ASTM B941 in the temperatures of 230°C and 280°C, respectively; then the electric conductivity and tensile tests were performed. The results showed that the sample with the best mechanical performance was without heat treatment, and the most satisfactory performance for the electrical conductivity occurred when the proof body was submitted to 230°C for 1 hour.*

Keywords: *Aluminium alloy, Termorresistivity, Rolling, Electrical conductivity, Tensile test*

1. INTRODUCTION

Access to energy is a crucial pillar for the economic growth of any country. In Brazil, according to the Superintendency of Economic and Energy Studies – EPE (2018), electricity consumption grew by 94% in just over two decades. In this context it is necessary to improve transmission and distribution energy systems, making it attractive to discover or improve the materials used in this service.

According to ABAL (2018), aluminum has an exceptional combination of properties, it is one of the most versatile materials used in engineering, architecture and industry in general. According to Hydro (2019), aluminum alloys are generally used to improve aluminum properties for specific engineering structures and components, where lightness or corrosion resistance is important. The most common elements used in aluminum alloys are magnesium, silicon, manganese, zinc and copper. One of the properties of aluminum that is worth mentioning is the electrical conductivity,

and according to Cunha *et al.* (2017), in addition, the material also has low specific gravity and considerable mechanical resistance and corrosion. Such properties can still be bettered, depending on the alloying elements added and the manufacturing processes carried out, and allied with others, such as thermoresistance, and can contribute to the creation of more efficient and less expensive transmission and distribution lines. Furthermore, Aluminum is a good choice as a matrix for an energy conductive alloy made from plastic deformation, according to Çetinarslan (2009), although plastic deformation causes hardening of the alloy, changes in electrical conductivity are almost noticeable.

According to Menezes (2015), copper was the raw material used in the first transmission lines due to its high conductivity, but today, overhead lines use conductors composed mainly of aluminum, either in alloy form or in conjunction with steel, this is mainly due to its lower cost compared to copper or any other conductive material. In addition, according to ABAL (2019), most long-distance transmission systems consist of overhead lines, where the use of aluminum conductors provides great savings in the height and strength of the supporting structures. T-CAA (Steel Core Heat Resistant Aluminum Cable) and ACAR (Aluminum Alloy Core Aluminum Cable) are the main commercial alloys used in power transmission.

At this juncture, aluminum alloys are a viable study option to remedy such circumstances. The objective of this work is to analyze the base alloy Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe under influence of heat treatment for 1 hour at 230°C and 280°C for the determination of thermoresistance, as well as the electrical and mechanical characterization of the solidified alloy in a U-shaped metal shell.

2. MATERIALS E METHODS

The alloy was made by direct casting from Aluminum Electro Conductor (Al - EC). The composition of the other elements composing it was determined by stoichiometric calculation. Then all the elements were placed in a kaolin-coated crucible and melted in a muffle furnace at 900 ° C. The solid solution remained in the oven for a few hours, then it was removed and argon was injected so that the impurities floated on the liquid metal to identify and remove impurities from the crucible, after this process the crucible was placed back in the oven for another 1 hour. to make sure that the solution became homogeneous, the next step was the leakage of the sample testimony. Then a thermocouple was placed to check if the temperature was 10% above the liquidus temperature, the expected temperature range for the casting. The solidification of the alloy was done in a 22 mm diameter "U" shaped metallic chill mold as shown in Fig. 1.

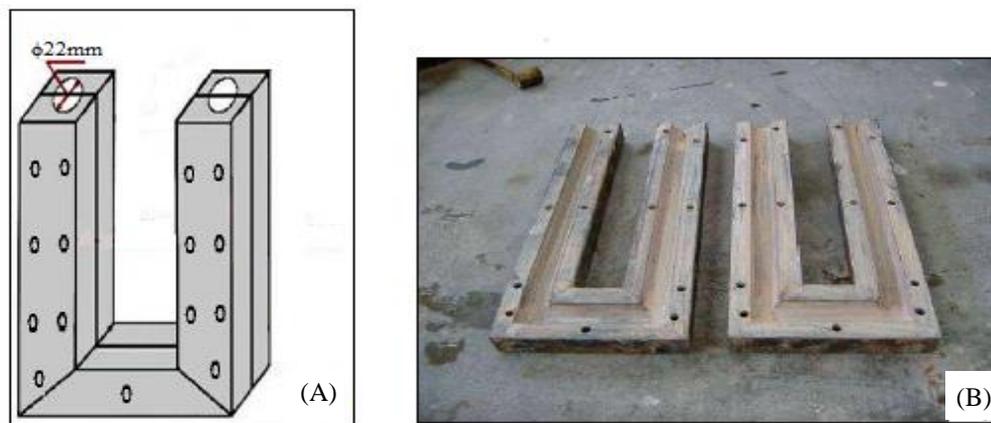


Figure 1. (a) Schematic drawing of the metal chill in "U" format and (b) the metal chill in the real "U" shape.
Available from: GPemat file.

After removal of the mold the material was sectioned and machined to the diameter of 18.5 mm, then all samples were deformed by cold rolling, each sample passed 3 times through each rolling mill channel shown in Fig. 2.a until it became 3.0 mm diameter wires. Of the wires obtained strands one part was preserved without heat treatment (WHT) and the other was heat treated for 1 hour at temperatures of 230°C and 280°C. For the heat treatment, the NEVONI stove, showed in Fig. 2.b, was used in order to validate if the Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe alloy presents characteristics of thermoresistivity.

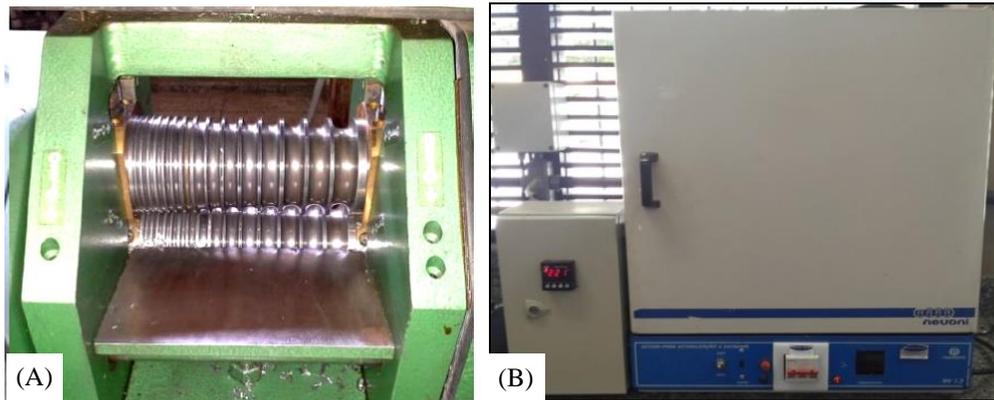


Figure 2. (a) Laminator machine and (b) Greenhouse used for heat treatments. Available from: GPEMat file.

The thermoresistance test was performed according to two standards: ASTM B941, which describes as thermoresistant electrical conductor materials that, after remaining for 1 hour at 280°C, do not present loss greater than 10% of their tensile strength limit (TSL) and Copel Protocol, where the criterion of analysis is the same, but when submitted to 230°C for 1 hour.

The chemical composition of the alloy was obtained by analyzing the sample testimony in an optical emission spectrometer model Q4 TASMAN. In Fig. 3.a is shown the test sample obtained from the leak, Fig. 3.b shows the apparatus used to perform the test and Fig. 3.c shows the three burns made in the sample, after this procedure the arithmetic mean of the data obtained to then generate a chemical composition value.



Figure 3. (a) Testimonial sample, (b) optical emission spectrometer and (c) sample after reading.
Available from: GPEMat file.

The electrical and mechanical tests were performed on the wires with a diameter of 3.0 mm, the samples were divided into three groups: without heat treatment, thermally treated at 230°C for 1 hour and thermally treated at 280°C for 1 hour. The association of small times at low temperatures characterizes thermal treatment with relief heat treatment or recovery treatment. The electrical characterization was carried out by means of electrical resistivity tests carried out in a multi-ohmmeter of the manufacturer Megabrás, shown in Fig. 4.a, the data provided by the instrument quantify the electrical resistivity, the acquisition of electrical conductivity occurs by means of software manipulation, also necessary to correct the temperature of the test in accordance with standards NBR 6810 and NBR 6815. Fig. 4.b shows the specimens used in the electrical resistivity test. After the acquisition of these data, the samples were cut with 20.0 cm length and subjected to tensile test on the Kratos machine, model IKCL 1 - USB, as shown in Fig 4.c, this test is based on the standards for electrical cables, NBR 6810, and metallic materials, NBR 6892.

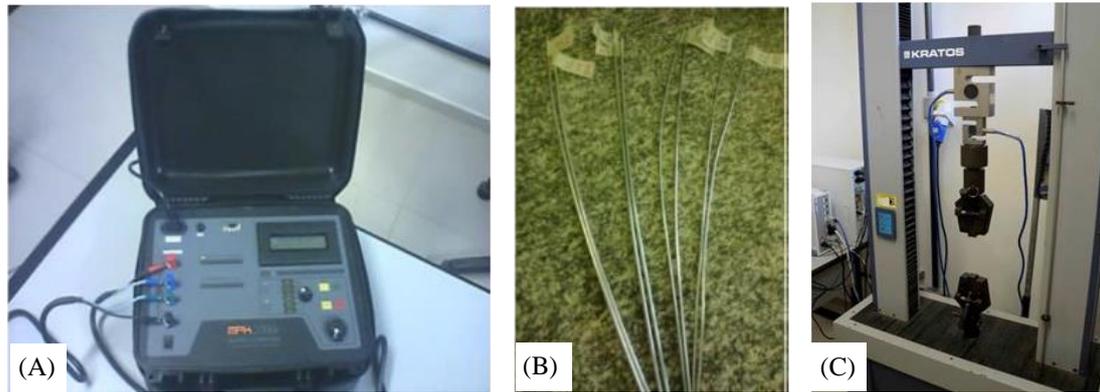


Figure 4. Equipment used for (a) electrical resistivity testing, (b) specimens used for test and (b) tensile testing. Available from: GPENat file.

3. RESULTS E DISCUSSIONS

3.1 Chemical analysis

Table 1 shows the chemical composition of the Al-Cu-Si-Mg-Fe alloy samples. This composition was previously obtained through stoichiometric calculations and validated from the analysis performed by the Optical Mass Spectrometer, for this, 3 burns were performed in the core sample. Thus, it is confirmed that the alloy is within the desired values for the purpose of the work.

Table 1. Chemical composition of aluminum alloy fabricated.

| Alloy | Elements (% in massa) | | | |
|---|-----------------------|-------|-------|-------|
| | Cu | Si | Mg | Fe |
| Proposed composition of the alloy Al-Cu-Si-Mg-Fe | 0.2 | 0.7 | 1.0 | 0.2 |
| Composition obtained of the alloy Al-Cu-Si-Mg-Fe | 0.247 | 0.759 | 1.046 | 0.211 |

The addition of alloying elements in casting alloys aims to improve their properties. According to Gomes and Bresciani (1976), the addition of copper substantially improves the mechanical strength and hardness of aluminum in the conditions as molten and heat treated, besides providing high solubility in aluminum at high temperatures and slight solubility at room temperature.

According to Fernandez (2011), the 0.7% Si percentage presents more satisfactory results regarding the tensile strength limit (LRT), good susceptibility to hardening and the workability of the alloy.

According to Hatch (1984), the addition of magnesium percentages in the alloy provides mechanical strength gain while maintaining a good level of ductility, as well as excellent corrosion resistance and weldability.

Iron has limited solubility in the aluminum matrix, so it is used in electrical conductors to increase the mechanical strength of the alloy by forming intermetallic phases that arise when reacting with aluminum, and to moderately improve its creep resistance characteristics at high temperatures (Davis *et al.* 1998).

3.2 Electrical and mechanical characterization of the alloy

Table 2 shows the values obtained with the electrical conductivity and tensile tests for Al-0.25% Cu-0.7% Si-1.0% Mg-0.2% Fe alloy.

Table 2. Electrical conductivity tests and tensile strength limit values.

| Temperature (°C) | Tensile Strength Limit (MPa) | Al – Cu – Si – Mg – Fe | | |
|---------------------|---------------------------------|-----------------------------------|-----------------------------|---------------------------------|
| | | Loss of TSL ⁽¹⁾ (%) | Electrical Cond. (%IACS) | Gain of Electrical Cond. (%) |
| 25 | 407.89 | - | 51.79 | - |
| 230 | 241.27 | 40.84 | 60.69 | 17.4 |
| 280 | 258.75 | 36.56 | 60.36 | 16.55 |

(1) Tensile Strength Limit

A significant decrease in the tensile strength limit values and an increase of approximately 17% in the electrical conductivity of the alloy after being submitted to the treating is noticeable.

Based on Tab. 2, electrical conductivity and tensile strength limit graphs were plotted as a function of the heat treatment temperatures of Al-Cu-Si-Mg-Fe alloy shown in Fig. 5.a and 5.b, respectively. Figure 5.c, 5.d and 5.e show the images of fracture topographies obtained after the tensile test.

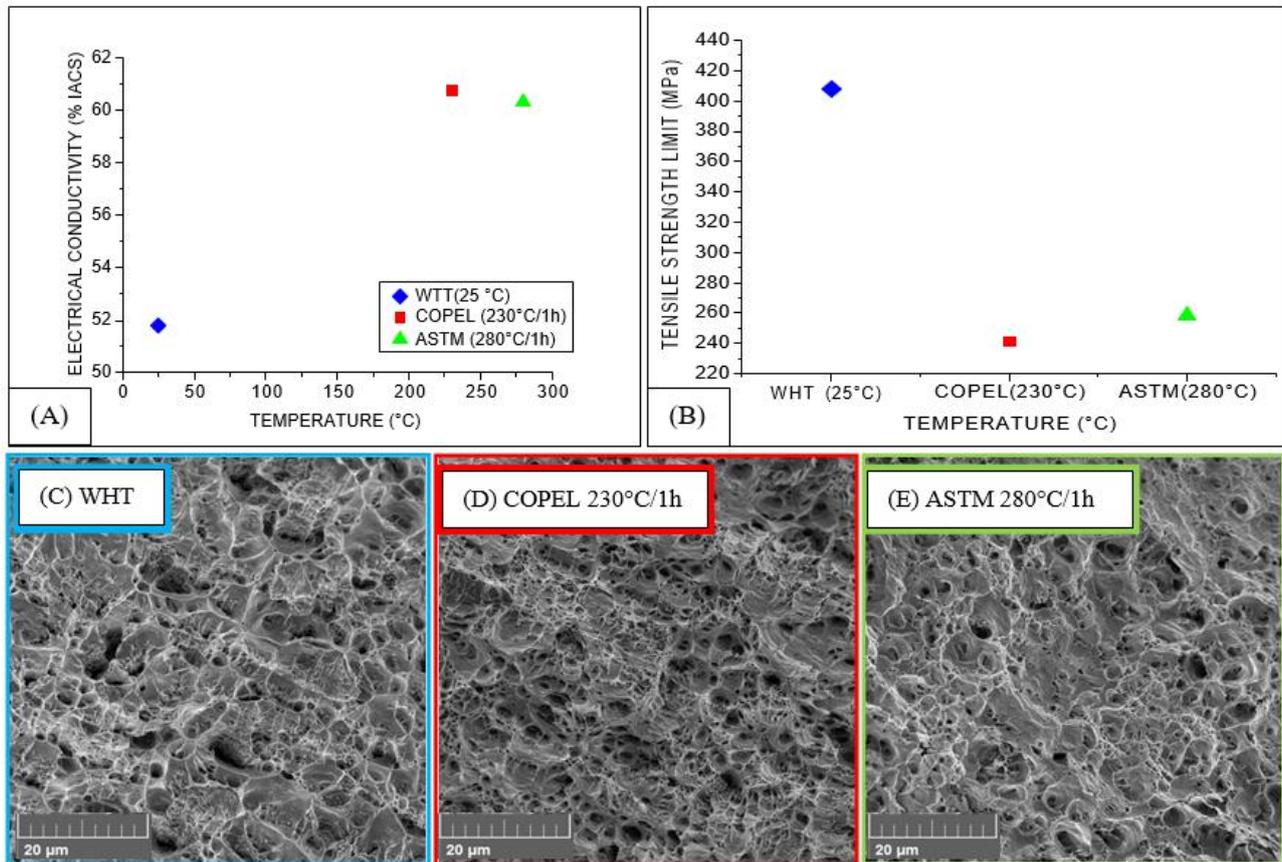


Figure 5. (a) Electrical conductivity and (b) limit of tensile strength in relation to the heat treatment temperatures, (c) topography of the fracture of the specimen without heat treatment, specimen fracture topography (c) without heat treatment, (d) with heat treatment at 230°C/1h and (e) heat treatment at 280°C/1h. Available from: Vital, 2018.

The highest tensile strength limit (TSL) reading occurred in the untreated sample after cold deformation, such performance must be related to the fact that the alloy is subjected to high level of hardening. The significant decrease in TSL may be associated with the fact that the alloy has been exposed to treatment at temperatures of 230°C and 280°C, this may have caused better dissolution of the particles in the aluminum matrix causing stress relief.

Moreover, according to Padilha and Siciliano (1996), warming causes rearrangement of discordances (undoing the tangle), this new configuration facilitates the movement of free electrons, which helps in electrical conductivity. According to Ohana (2017), the material undergoes static recovery, so the conductivity gain may be linked to this recovery caused by temperature fluctuations after deformation.

As shown in the graphs in Fig. 5.a and 5.b, the increase or decrease in the discordances tangle influences both the TSL and the electrical conductivity. The large concentration of discordances generates resistance in the passage of free electrons, causing a decrease in electrical conductivity. However, the same concentration of discordances is responsible for the increase of mechanical resistance through distortion of the crystal lattice.

The WTT and COPEL 230°C/1h fractures shown in Fig. 5.c and 5.d show deeper and more open dimples compared to the ASTM 280°C/1h fracture shown in Fig. 5.e, which shows shallower dimples. This behavior, according to Davis *et al.* 1998, is related to alloy ductility, materials with higher ductility have deeper tapered equiaxial dimples, while materials with lower ductility have dimples.

The fracture topography shown in Fig. 5.c presents more open dimples, characterizing a more ductile material. In contrast, the WTT (25 ° C) sample underwent cold deformation, which justifies the high TSL value shown in the graph. Fig. 5.b. Photomicrograph of fracture 5.d shows deeper dimples, appearance related to higher ductility values, this behavior may be related to the application of the 230°C for 1h heat treatment imposed on the material after cold

deformation, which may also explain the TSL decrease of the COPEL (230°C/1h) sample in Fig. 5.b. The Fig. 5. e shows the fracture topography of the ASTM (280°C/1h) sample, the dimples are shallower when compared to those of Fig. 5.d, which is responsible for lower ductility values, this appearance may be the reason for the small increase in TSL shown in Fig. 5.b.

4. CONCLUSION

Based on the tests carried out in order to characterize the alloy Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe, it can be concluded that in the electrical characterization the most satisfactory performances are of alloys subjected to heat treatment of 230°C and 280°C for 1 hour, with slight difference in the conductivity results in relation to the applied treatments.

Alloy TSL values after 1-hour treatments at 230°C and 280°C decreased by more than 10% compared to the TSL of the without heat treatment sample. Thus, the alloy Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe is characterized as not thermoresistente.

However, it is important to highlight that, despite not having the thermal resistance property, the Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe alloy had good TSL and electrical conductivity results when compared with values of commercial alloys T-CAA, ACAR and Aluminum Alloy 1120 (manufactured with alloy elements similar to those of the alloy studied in this work), which were obtained in Alubar (2019). In this sense, it is possible to infer, based on TSL and electrical conductivity results, that wires made from Al-0.25%Cu-0.7%Si-1.0%Mg-0.2%Fe alloy are good electrical conductors as long as they are not subjected to high temperatures.

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7. RESPONSIBILITY FOR THE INFORMATION

The authors are solely responsible for the information included in this work.