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EVALUATION OF THE ELECTRICAL PROPERTIES OF AL-CU-FE-MG-NI ALLOY WITH AND WITHOUT HEAT TREATMENT

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Abstract. *Due to the growing demand for electricity, it is necessary to produce more and more efficient electric cables for transmission and distribution of energy. In this reality a study was carried out with the objective of evaluating the Al - Cu - Fe - Mg - Ni alloy for the electric characterization in order to allow its applicability in the transmission and distribution of electric energy. The study was carried out by inserting 0.05% Cu, 0.40% Fe and 0.6% Mg and 0.03% Ni in the aluminum base. The alloy was obtained by direct static solidification in metallic shell. After obtaining the material as cast, it passed through the machining process to the diameter of 18.5 mm and then the cold working process until the diameters of [4.0; 3.8; 3.0 and 2.7] mm. The alloys were characterized electrically by the electrical resistivity test and structurally through the analysis of the microstructures, in addition, the alloys were also subjected to heat treatment at temperatures of [230 and 280] ° C. As a result of the study, it was observed that nickel improved electrical properties. In relation to the heat treatment the alloy maintained an electrical conductivity close to 60% IACS.*

Keywords: *Aluminum, electric energy, heat treatment.*

1. INTRODUCTION

Electric energy is one of the most widely used forms of energy in the world and is of fundamental importance for the development of society, its use is both domestic and industrial. With the advancement of technology and globalization, the demand for electric energy has increased more and more in the world. This requires the development of technologies that improve the transmission of this energy to meet such demand (Inter Academy Council, 2007). In this context, it is very important to invest in the improvement of transmission systems, that is, to invest in research, aiming at the use of more efficient materials. Among the materials used in the electrical sector, there is the Electro-Conductive Aluminum (Al-EC), which can be manufactured with additions of other elements, such as Magnesium (Mg) and Nickel (Ni), forming metal alloys.

Copper is a metallic element that can be used in many applications, can be used pure or in alloys with other metals. It substantially improves the mechanical strength and hardness of aluminum when it is cast and heat treated.

Because of its limited solubility, iron is used in electrical conductors to increase the mechanical strength of the alloy and to moderately improve its fluence characteristics at high temperatures. (ASM INTERNATIONAL, 1998).

Magnesium is one of the few elements with high solid solubility in aluminum, with its balance around 15% at 450 ° C, although this solubility approaches zero to 20 ° C. Al-Mg phase equilibrium offers good potential for precipitation hardening, however the effect of such precipitates is small. Consequently the primary effect resulting from magnesium additions to aluminum will be solid solution hardening (metastable) (KAUFMAN; ROOY, 2004).

According to Souza (2013) the addition of Ni, in the presence of aging heat treatment, makes the aluminum alloy have good mechanical resistance without a considerable loss of its electrical properties, suggesting that this material may have potential use in industry.

Researchers in the area of materials have shown interest in alloys such as Al-Ni, because combinations of the Al-Ni intermetallic system are characterized by low density and high mechanical strength, even at high temperatures. In addition, some authors such as Souza (2013) and Canté (2009) show that Ni is able to form the intermetallic compound Al_3Ni that can harden the material.

Adding Ni by up to 2% by weight results in increased strength of the alloy, however, reduces its ductility. As can be seen in Figure 1, the addition of contents below 0.05% Ni allows the alloy to be heat treated (BATALU; GEORGETA; ANGEL, 2006). Figure 1 shows the details of the aluminum-rich portion of the Al-Ni binary diagram.

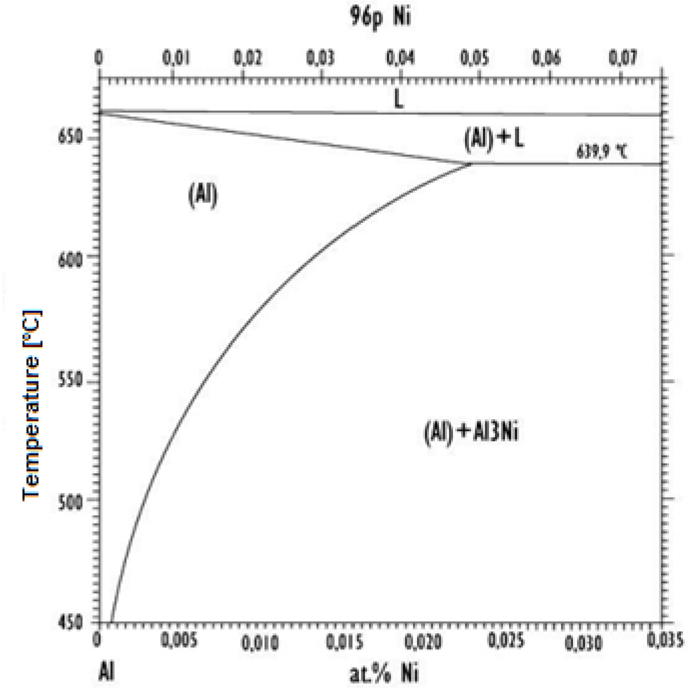

Figure 1. Part of the Al-Ni phase diagram.

The interdendritic arrangement of the Al3Ni hard particles, which are stable at temperatures below 500 ° C, provides a reinforcement to the dendritic matrix, thereby conferring greater mechanical strength to the material.

The present work seeks to develop and study the al-0.05% Cu-0.26% Fe-0.6% Mg-0.03% Ni alloy, with and without heat treatment, that is capable of presenting properties mechanical and electrical characteristics for transmission and distribution of electricity.

2. MATERIALS AND METHODS

In the alloy casting process, the elements (Cu, Fe, Ni, Mg and Al) were added to the crucible and taken to a BRASIMET muffle furnace (Figure 2.E) at a temperature of 900 ºC for 4 h, temperature and time ensuring complete fusion of all elements. Para que houvesse homogeneização dos elementos no metal líquido, antes do vazamento foram realizadas duas agitações com espátula de aço. This spatula was previously sanded and coated with a kaolin solution to prevent it from contaminating the alloy.

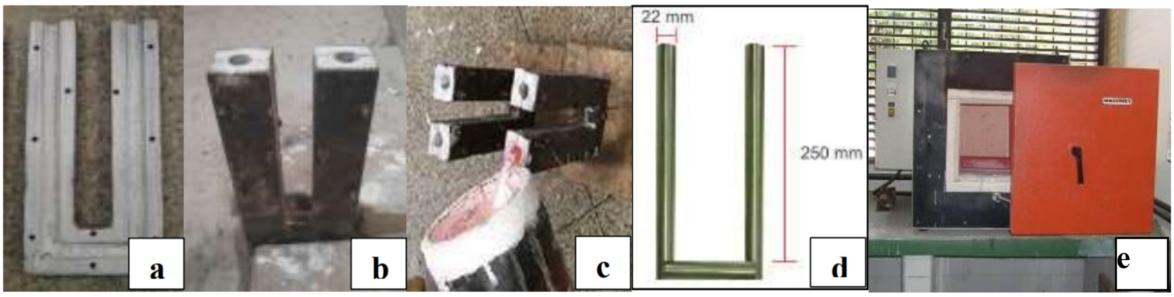

Figure 2. Kaolin-coated U-type mold (a), assembled (b), U-shape mold casting (c), ingot dimensions (d) and muffle furnace used in process (e).

The liquid metal is cast into the U-shape (Figure 2.A) in a conventional manner (Figure 2.C) and the cavity is filled by gravity. After the part solidifies the mold is opened and the part is removed with the dimensions shown in Figure 2.D.

After removal of the already solidified alloys, the cold rolled step begins after heat treatment. Two ingot samples were each sectioned, each 250.0 mm long and then machined from 22.0 mm diameter to 18.5 mm diameter. The machining step is necessary to improve the surface finish of the specimens, avoiding the appearance of rolled defects. Electrical characterization was performed on cold-deformed specimens using two reversible duo electric rolling mills, Figure 3, from MENAC. These rolling mills have different circular sections in their rolling rolls, and in this study the diameters studied were [2,7; 3.0; 3.8; 4.0] mm.

Figure 3. Rolling mills used in the cold plastic deformation process.

With the aid of the muffle furnace different heat treatments were performed in the studied alloy, part of the specimens were heat treated at 230 ° C and 280 ° C, both for 1 hour time and cooled to room temperature.

For electrical characterization a MEGABRÁS model MPK-2000 multiohmmeter was used, the electrical resistances of the wires were measured at a temperature above 10ºC and below 30ºC and corrected to a temperature of 20ºC as recommended by NBR 5118. After obtaining the results from the reading of the resistances of the specimens for each study diameter, we used the equations provided by NBR 6814 to obtain the electrical conductivity (IACS).

3. RESULTS

3.1 Chemical analysis

Table 1 indicates that all stoichiometric calculation procedures were performed correctly and the chemical compositions obtained are in accordance with the purpose of this work. The chemical composition refers to Al-0.05% Cu-0.26% Fe-0.6% Mg-0.03% Ni alloy.

Table 1. Chemical compositions of ingot manufactured.

Alloy	Elements (in% by weight)			
	Fe	Cu	Mg	Ni
Al-Mg-0.030%Ni	0.274	0.054	0.583	0.030

3.2 Electrical characterization of the alloy Al-0.05% Cu-0.26% Fe-0.6% Mg-0.03% Ni

Table 2 presents the results of the electrical conductivity tests for Al-0.05% Cu-0.26% Fe-0.60% Mg-0.03% Ni alloy.

Table 2 - Electrical conductivity tests.

Diameter (mm)	Al – Cu – Fe - Mg - Ni Electrical conductivity (% IACS)
2.7	51.35
3.0	57.12
3.8	49.31
4.0	51.7

Based on the results presented in Table 2, it was possible to elaborate the electrical conductivity graphs according to the diameters studied for Al-0.05% Cu-0.26% Fe-0.60% Mg-0.03% Ni alloy, shown in Figures 4.A and the Figure 4.B shows the nickel content of the alloy in the Al-Ni phase diagram. .

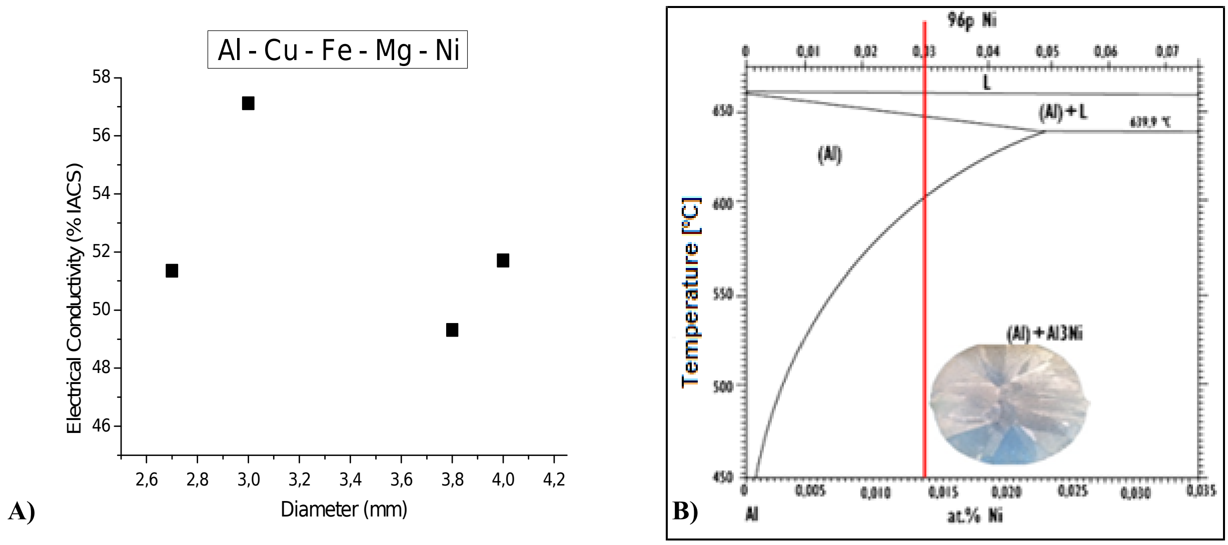

Figure 4. Electrical conductivity with respect to the diameter for alloy Al-0.05%Cu-0.26%Fe-0.60%Mg-0.03%Ni.

In Figure 4, the cylindrical specimen with diameter of 2.7 mm presented the value 51.35% IACS of electrical conductivity, for sample with 3.0 mm the value was 57.1% IACS, whereas with 3.8 mm the value was 49.31. Finally, with 4.0 mm diameter, the conductivity was 51.7% IACS. It is observed that, despite the higher degree of cold working, the wire with a diameter of 3.0 mm presents the highest value for the electrical conductivity. It is probable that this behavior is associated to the efficient phenomenon of dynamic recovery of the material (disentangling and rearrangement of discordance during the dissipation of the temperatures generated in the cold deformation of metals) (LIMA, 2014; FREITAS, 2009; SANTOS, 2010).

3.3 Level termorresistivity test Al-0.05%Cu-0.26%Fe-0.60%Mg-0.03%Ni

As the 3.0mm diameter specimens had better values for electrical conductivity, conductivity analyzes after heat treatments were focused on this specimen diameter, the Table 3 presents the results of electrical conductivity for diameter of 3.0mm and the different temperatures of heat treatments performed for Al-0.05% Cu-0.26% Fe-0.60% Mg-0.03% Ni alloy.

Table 3 - Electrical conductivity data (% IACS) of alloy Al-0.05% Cu-0.26% Fe-0.60% Mg-0.03% Ni without heat treatment (STT) and heat treated (TT) .

Heat treatment	Al-0.05% Cu-0.26% Fe-0.60% Mg-0.03% Ni
	Electrical conductivity (% IACS)
STT	57.14
TT (230°C)	57.82
TT (280°C)	57.51

Based on the values in Table 3 it was possible to plot the graphs of Figure 5 where the values of electrical conductivity are presented with the losses and gains, respectively.

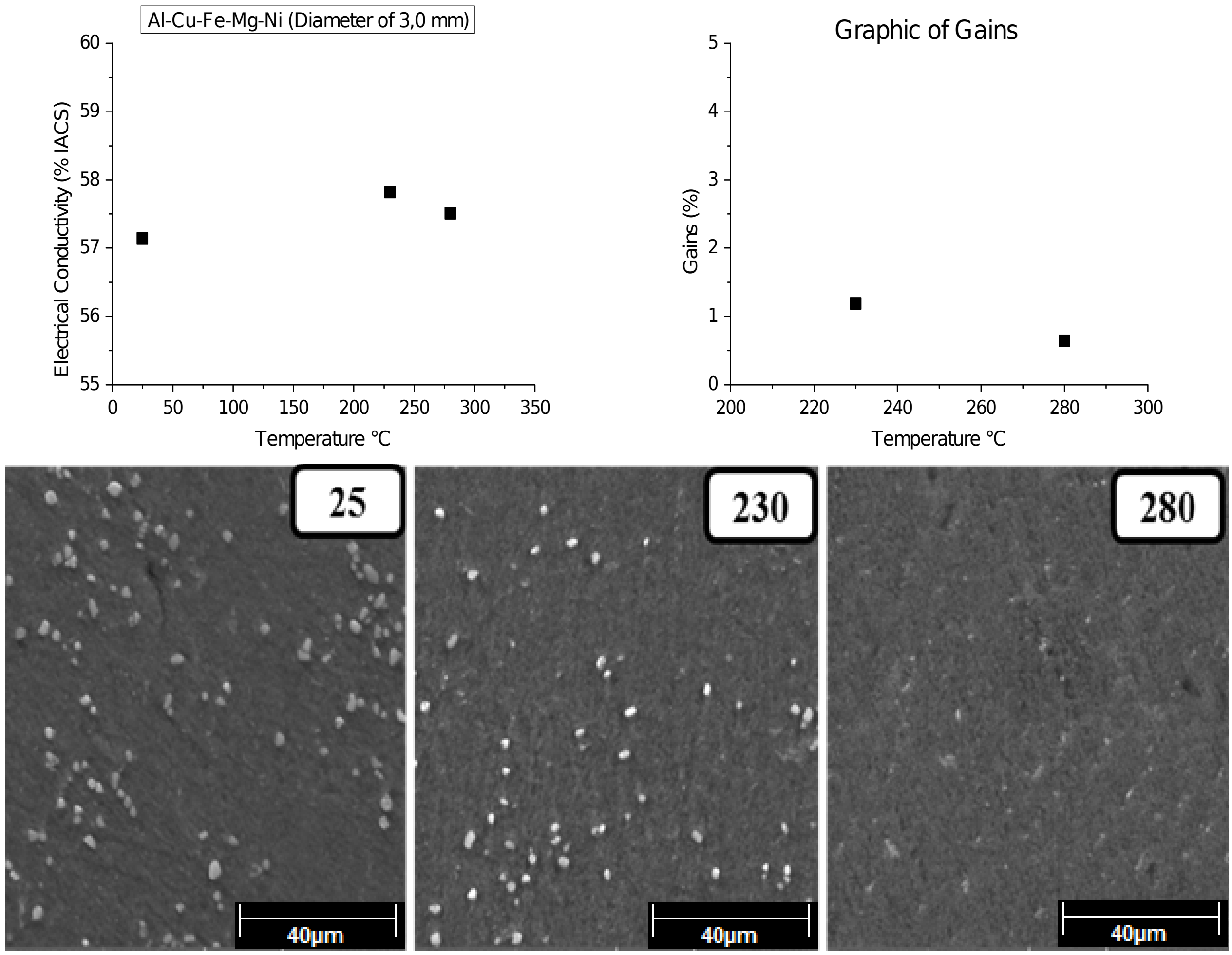

Figure 5. Electric conductivity graph, with gains and microstructures.

According to Figure 5, there was an increase in the electrical conductivity values when the alloy was subjected to heat treatments of 230ºC and 280ºC, the increases in the electrical conductivity of the heat treated specimens at 230 ° C and 280 ° C for the untreated alloy were 1.19% and 0.64%, respectively. It is also possible to observe distinct patterns in the distribution of nickel tri aluminides (Al3Ni) in the matrix of untreated and heat treated specimens, it is noticed that the higher dispersion of the second phase particles in the aluminum matrix with the heat treatment may have contributed to the maintenance of the electrical conductivity of the alloy.

4. CONCLUSION

Considering the methodology developed in the present study to observe the electric characterization of the alloy, we conclude:

• The diameter of the wire that presented the best electric performance was 3.0 mm.

• The alloy showed gains of electrical conductivity with the heat treatment, being that the alloy maintained an electrical conductivity close to 60% IACS.

• After the heat treatment, the possible formation of the intermetallic compound (Al_3Ni) was observed, which may have contributed to the maintenance of the electrical conductivity of the alloy even after the heat treatment.

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6. RESPONSIBILITY NOTICE

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