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RESEARCH ARTICLE OPEN ACCESS

EVALUATION OF ELECTRICAL, MECHANICAL AND THERMORESISTANCE RESISTANCE OF AL- 0.05% CU- [0.25-0.35]% FE-0.5% SI-0.6% MG WITH ADDITION OF (0.13)% NIOBIUM, FOR TRANSPORT AND DISTRIBUTION OF ELECTRICITY

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ABSTRACT

The present work aims to study the influence of the element Niobium, under the alloy Al- 0.05% Cu- [0.25-0.35]% Fe-0.5% Si-0.6% Mg as its mechanical and electrical properties and thermoresistant characterization. The first stage of the work included tensile and resistivity tests for four specimen diameters, 2.8; 3.0; 3.8; and 4.2 mm, these diameters were reproduced cable legs used for transmission and distribution of electric energy and were produced from the casting of aluminum in "U" mold with rods of 22.0 mm in diameter, machining on lathe for 18.5 mm and cold rolling for the four diameters analyzed. The results that the diameter of 3.0mm showed both tensile strength limit (LRT) and conductivity, good performance due to the phenomenon of dynamic recovery, the modified alloy with 0.13% Nb showed good electrical, mechanical and refined grains results. It was noticed that after heat treatment at temperatures of 230 ° C / 1h and 280 ° C / 1h both the base alloy and the alloy modified with% Nb improved its electrical conductivity. The second step evaluated the thermo-resistant characterization of the alloy, following guidelines of the technical standards of COPEL and ASTM. The results allowed the characterization of the modified alloy with 0.13% Nb content, showing a loss above 10% after thermal treatment at 230 ° C / 1h and 280 ° C / 1h.

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INTRODUÇÃO

Aluminum is the most abundant metal in the earth's crust and the second most important metal for industry and commerce. The worldwide production of aluminum is approximately 20 million tons per year and a similar amount is recycled in the same period, with aluminum recycling being important for its industry today (GHALI, 2010). This work makes a study with 6xxx alloys adding small levels of niobium for the manufacture of power cables for high voltage transmission, adopting quality and safety standards established by the national and international standards in force, since our country has the largest reserves of niobium and aluminum in the world. This work investigated the evaluation of LRT, thermoresistance and electrical conductivity of the alloy 0.05% Cu- [0.25-0.35]% Fe-0.5% Si-0.6% Mg with 0.13% of niobium, the alloy presented with% Nb for transport and distribution of electricity.

Objectives: Evaluate the performance of the modified alloy with 0.13% Nb, selected through of experimental methodologies based on mechanical, electrical and thermoresistance tests, for the purpose of transmission and distribution of electrical energy of the elaborated alloys, as molten and as deformed, solidified in a metallic "U" type mold.

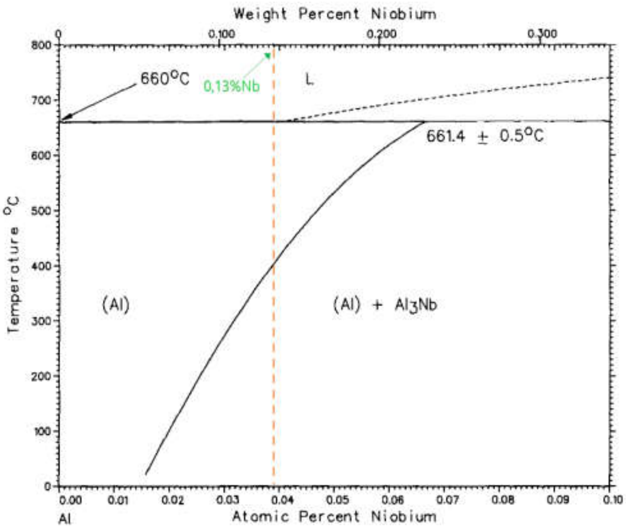
METHODOLOGY

The alloys were made by direct casting at the Metallography and Heat Treatment Laboratory at UFPA from Commercially Pure Aluminum or Electrically Conductive Aluminum (Al - EC), 0.05% Cu- [0.25-0.35]% were added Fe-0.5% Si-0.6% Mg with addition of (0.13)% Nb content, all of which are weight percentages, which could be verified through the chemical composition analysis after obtaining the alloys.

Material Preparation, melting and solidification: The metal fusion was carried out in a MUFLA type furnace, Figure 1, from Atel BRASIMET, with working temperature set at 950 ° C, a temperature that guarantees the fusion of Nb, which in the Al-Nb diagram shows the Al-rich peritética, which I melted at 660 ° C, see Figure 2. After finding the total metal melting, the crucible is removed from the oven and run is the homogenization of molten metal through manual agitation, using a steel spatula painted with kaolin solution.

Source: Author (2020)

Figure 1. Electric Oven and Metal Shaking

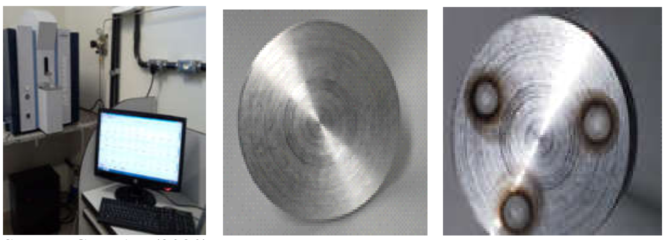


Source: adapted from Elliott and Shunk (1981)

Figure 2. Al-Nb rich degenerated side equilibrium diagram

After homogenization, inert gas (argon) is injected at a flow rate between 0.2 and 0.4 l / s, through a stainless steel tube connected to a 10m 3 cylinder . The injection of argon into the liquid metal is carried out for approximately 1 minute with the intention of removing gases and impurities with low density, forming a layer of slag on the surface of the bath, removed with the painted steel spatula before removing the core sample, the which is made in a steel mold that is prepared (sanded, heated and painted with kaolin solution).

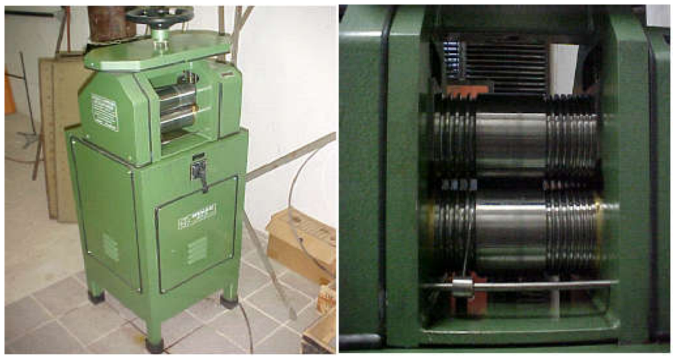
Chemical Composition: With the control sample is made to chemical analysis to confirm the final compositions of alloying elements presenting their percentage amounts by weight, the procedure was carried out using the optical spectrometer shown Brucker brand, model Q4 Tasman Figure 2.



Source: GPMAT (2020).

Figure 2. (a) Core sample (b) Optical mass spectrometer (c) Sample after chemical analysis

Preparation of the Proof Bodies: The "U" profile obtained is initially split into two parts (legs), with 250 mm in length, to be machined from 22 mm in diameter to 18.5 mm in diameter and then cold rolled to the desired diameter [4.2; 3.8; 3.0 and 2.7] mm in a MENAC electric laminator with circular cross-section of different iameters, generating the wires that will be used in all tests, in the obtainewires the electrical conductivity and tensile tests wereperformed.



Source: GPMAT (2020).

Figure 3. Electric laminators

From the lamination, the specimens of the "U" mold can reach up to 1300 mm in length.

Electrical Characterization: To measure the electrical properties, NBR-6814 was adopted as a reference, which describes the method of measuring the electrical resistivity of the conductor in direct current, for electrical wires and cables. To perform the test, a Kelvin MEGABRÁS model MPK-2000 bridge was used, illustrated in Figure 4.

Figure 4. Photos of the Kelvin bridge components used to measure the electrical resistance

The electrical resistances of the wires were measured at a temperature of not less than 10 ° C nor more than 30 ° C and corrected to a temperature of 20 ° C as the NBR 5118 standard recommends.

Mechanical Characterization: In this step the mechanical characterization of the materials applied to the specimens, two equipments were used for the tensile test. First, for PCs as a gross melting structure (without deformation) with a diameter of 14.5 mm, 3 (three) were machined specimens in order to obtain average data as responses to the mechanical properties of the material. The test was carried out at a speed of 0.5 mm / min, on the universal *servo-thruster shimadzu* testing machine model EHF-EM100KN-20L, which has a maximum loading capacity of 100 kN.

Source: Author (2020)

Figure 5. KRATOS traction machine model IKCL1

In sequence, the tensile test applied to the laminated PCs with a diameter of 3 mm (with deformation) used the universal testing machine, from the manufacturer *Kratos*, model KE 3000MP, and for each type of specimen it obeys the specific technical standard: i) for castings, dimensions comply with the ASTM E8M - 95 standard, ii) laminated and drawn, complying with the NBR 6810 and NBR ISO 6892/02 standards, for Electrical Wires and Cables. The distances between claws of 150 mm were respected. Thus, the test was performed with samples of 200 mm in length made for each specimen. The results are acquired by averaging the number of samples tested. After the test, the fracture bases are sanded in an electric polisher, Figure 6 sample was wrapped with epoxy resin for sanding and then polished to make the macro structure test. In polishing, the polisher of the UFPA metallography laboratory was used, as shown in Figure 6.

RESULTS AND DISCUSSION

Of the study participants, 93% are female and 18.4% are CHEMICAL ANALYSIS After the casting of the alloys, the results of the chemical compositions of the materials produced, as shown in Table 1, indicating that all stoichiometric calculation procedures were performed correctly, given the proof by analysis in an optical spectrometer. Therefore, the chemical compositions obtained are in accordance with the scope of this work. The chemical composition refers to Al alloys - 0.13% Nb.

analysis allowed to evaluate the effect of the addition of niobium on the structural modification of the alloy, as shown in Figure 7.

Electrical Conductivity: Figure 8 shows graphically that the results obtained for the values of electrical conductivity for the alloy with the addition of 0.13% Nb are greater for all diameters and in particular for the 3mm diameter. It is observed that in the graph of Figure 8, the highest value was for the diameter of 3.0mm, very good conductivity in IACS%, in general the presence of Nb improved the conductivity, this is due to the grain refining of the crystalline structure, easier hardening and good electron transfer in the structure.

Stretching: Figure 9 shows results that show that the two alloys had a very similar behavior, maintaining the deformability characteristics of the base alloy despite clearly modifying the macrostructure. Note in the graph of Figure 9, the comparison with the samples is possible that the occurrence of the relative dispersion of the second phase particles contributes to the formation of coalescence and, therefore, small variations in the values for the elongation.

Mechanical Characterization Comparison Base and Modified Alloy: Figure 10 makes a comparison of the base alloy LRT with the modified one, realizing that in all alloy diameters with addition of 0.13% Nb the LRT value is higher.

Source: Author (2020)

Figure 6. Polisher

Table 1. Composition of alloys with mass variation of base and modified alloys

League Number	Alloy Element in Weight%								
6101	Si 0,3-0,7	Fe < 0,5	Cu < 0,1	Mn < 0,03	Mg 0,35-0,8	Zn < 0,1	Cr < 0,03	Nb	Al Swing
BASE LEAGUE	0,411	0,27	0,04	0,03	0,531	0,085	0,02		98,67
BASE ALLOY + 0.13% Nb	0,305	0,25	0,03	0,02	0,404	0,06	0,018	0,13	98,78

Alloy elements with a concentration less than three decimal places: Mn; Cr; Ni; Zn; You; B; PB; Sn; V
Source: Author (2020)

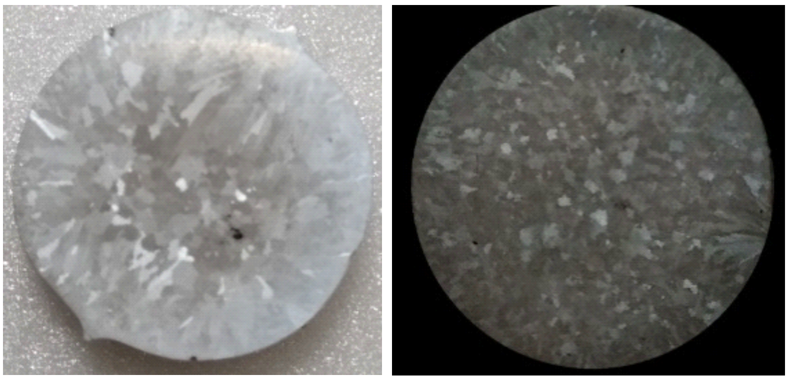
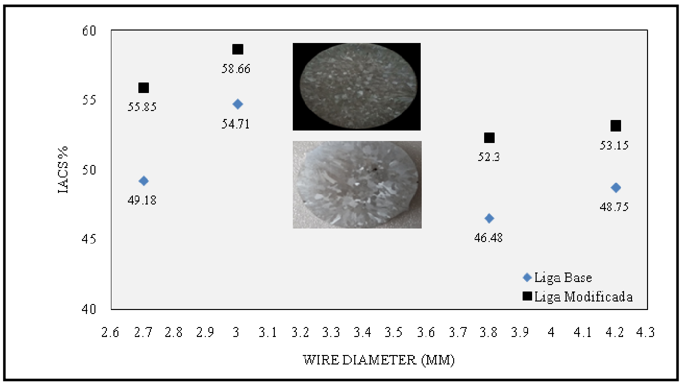


Figure 8. Macro of Al-0.05% Cu- [0.25-0.35]% Fe-0.5% Si-0.6% Mg alloys with addition of (0.13)% Niobium content : a. Alloy 6101; B. Alloy 6101 modified with 0.13% Nb

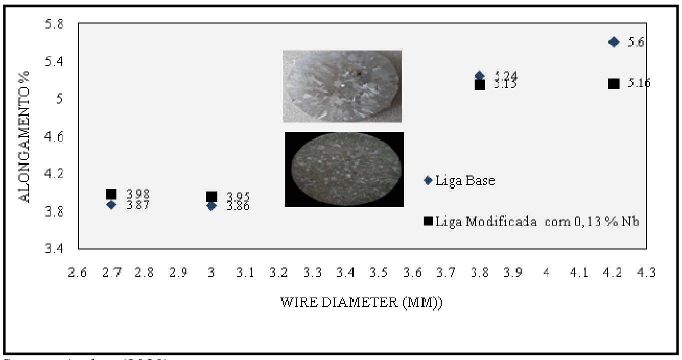
Macro Structure of the Alloys: Grain refinement is an important technique for improving products made from aluminum. Equiaxial structures make the mechanical properties of the material uniform, improving machinability and surface aspects. The metallographic

The graph in Figure 10 shows the highest LRT for both base and modified alloys with% Nb, the diameter of 3.00mm with the highest mechanical performance (LRT) stands out, this behavior may be associated with the greater accumulation of cold work that causes an internal heating of the material causing a dynamic recovery, where hardness and area reduction are killed, decreasing the electrical resistivity of the wire.



Source: Author (2020).

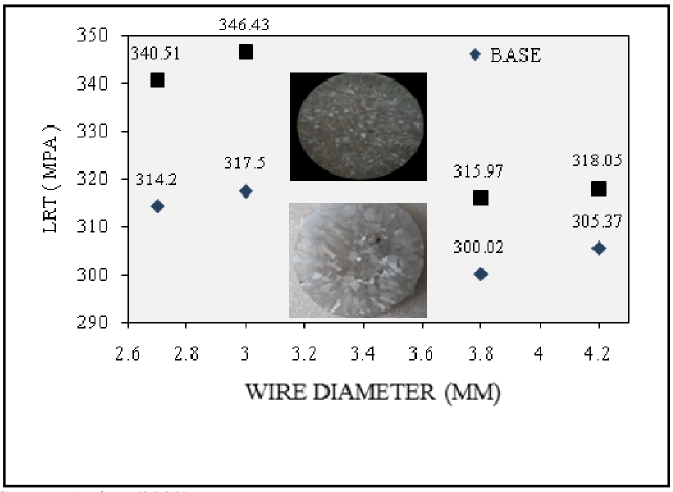
Figure 9. Comparisons between Electrical Conductivity of Base and ModifiedAl-0.05% Cu- [0.25-0.35]% Fe- 0.5% Si-0.6% Mg + 0.13% Nb)



Source: Author (2020).

Figure 10. Elongation of Baseand Modified Alloys Al-0.05%Cu-[0.25-0.35]%Fe-0.5%Si-0.6%Mg+(0.13% Nb)

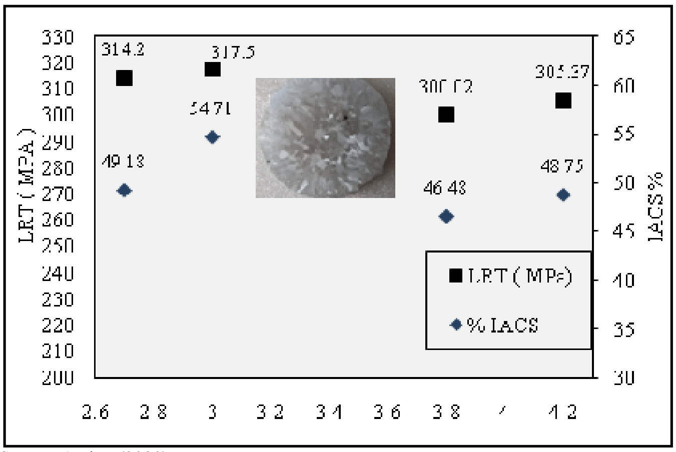
Comparison of thermal resistance in diameters of 2.7 mm and 3.0 mm A comparison of the term resistance in the diameters of 2.7 mm and 3.0 mm, of the base alloy and modified alloy with 0.13% Nb, shown in Figure 11.



Source: Author (2020)

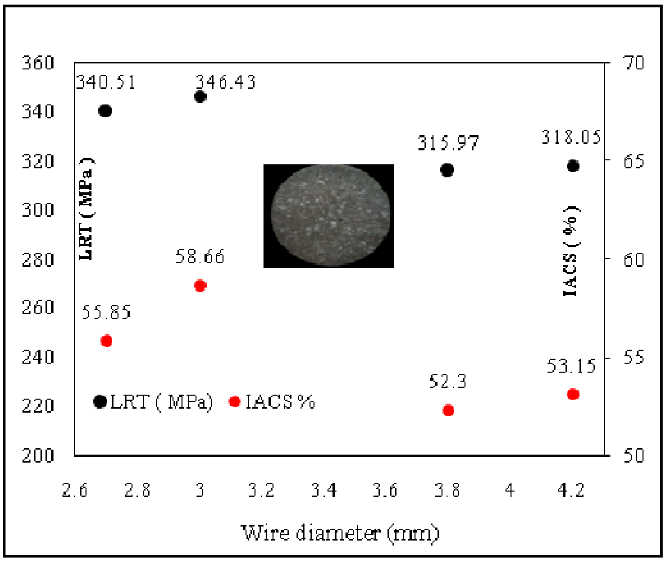
Figure 11. Thermoresistance values for the base and modified alloys Al-0.05% Cu- [0.25-0.35]% Fe- 0.5% Si-0.6% Mg + 0.13% Nb, before and after heat treatments for COPEL standard tests for.

The comparison of the test can be seen when evaluating the sample that underwent static recovery at 230 ° C / 1h, there is considerable loss in the LRT, perceived in the samples, after the heat treatment. The microstructural arrangement undergoes major changes, due to the movement of disagreements in a medium with low atomic incoherence that can, of course, lead to their annihilation. Thus, the results may be reflecting both the static recovery stage and the recrystallization stage. Especially for modified alloys, we had the grain refining in its crystalline structure, which makes the addition of niobium facilitating hardening, high temperatures increasing the agitation of the molecules of its structures and thus having a lot of LRT loss, we classify it as non-heat resistant alloys, according to protocol Copel. Analysis of the behavior of the alloy and selection of the best diameter With the mechanical behavior obtained, the next step is to investigate phenomenology which led to the electrical and mechanical behavior of the base and modified alloy having increased its values, then performing the selection of the best diameter. In order to facilitate the analysis, the graph shown in Figure 12 was constructed, it shows the results of electrical conductivity and tensile strength limit made for four test specimen diameters. Then the macrostructure of the two alloys was analyzed.



Source: Author (2020).

Figure 12. Graphs ofElectrical Conductivity (blue) and LRT (black) for the modified alloyAl-0.05% Cu- [0.25- 0.35]% Fe-0.5% Si-0.6% Mg



Source: Author (2020).

Figure 13. Graphs ofElectrical Conductivity (red) and LRT (black) for the modified alloyAl-0.05% Cu- [0.25- 0.35]% Fe-0.5% Si-0.6% Mg + 0.13 Nb

The evaluation from the point of view of the property when there is good mechanical performance associated with the electrical, in the latter the results suggest that it did not act in a marked way for the electrical conductivity (% IACS), the values being very close and the mechanical performance, very similar behavior, which may be associated with the same degree of cold work imposed on the base alloy profile, with a slightly better performance for the 3.0mm diameter, as can be seen in Figure 12, where there is an elevation of the LRT. This behavior can be associated with the possibility of formation of second phase particles capable of making it difficult to walk with disagreements, by anchoring them, when the alloys are deformed to obtain the wires with different diameters. The graph in Figure 13 shows the LRT and conductivity of the alloy modified with% Nb, so it was noticed that the values of electrical conductivity and LRT obtained in the tests of the specimens. Through these results it can be observed that when the diameters of the specimens are reduced , the values of both the electrical conductivity and the LRT of the modified alloy increase. However, the values of these properties for the 3 mm diameter stand out for being larger. Figure 6- Graphs of Electrical Conductivity (blue) and LRT (black) for the modified alloy Al-0.05% Cu- [0.25- 0.35]% Fe-0.5% Si-0.6% Mg + 0.13 Nb. You can see in the graph the presence of Nb in the alloy, increase in both conductivity and LRT and refine the grain.

This leads to better conductivity due to the ease of electron transfer, thus allowing less electrical resistance, facilitating the passage of electric current in its structure. Use of niobium improves the properties of metal alloys, and when treated shows precipitates increasing its resistance, it is shown that the fixation of niobium produces advantages such as, improvement in the microstructure making it an alloy element that produces improvements for it. The grain improvement benefits include the size, the reinforcement precipitation, promoting the desired microstructure and, therefore, obtaining combinations that increase the resistance (Mizia, 2013).In this way the diameters underwent an intense process of dynamic recovery, which made the same in addition to the good mechanical properties resulting from the intense degree of cold work. For having the highest limit values of tensile strength and electrical conductivity, the diameters of 2.7 mm and 3.0 mm were the diameters with the best performance.

Conclusions

From the discussions carried out on the results obtained from the tests on the alloy Al- 0.05% Cu- [0.25-0.35]% Fe-0.5% Si-0.6% Mg + [0.13 Nb] , it was possible to materialize the conclusions according to the specific objectives proposed in the scope of the present work.

- Evaluate the grain refining capacity for the 0.13 Nb content of the alloy under study. Macro-structural analysis revealed that the alloy has a grain refining capacity. The surface finish improved its mechanical properties.
- Evaluate the variation of the elongation ([δ]), with the electrical conductivity and the limit of tensile strength.
-

The correlation with the electrical characterization showed that the increasing values of the elongation [δ]. However, the correlation with the mechanical characterization showed that the increasing values of elongation [δ] are related to structures of superior mechanical resistance. In the studied diameters, the 3.0 mm wire stood out, which presented the highest values for the limit of tensile strength [LRT] and for the electrical conductivity for the alloy with the addition of niobiumcontent.

Evaluate the ductility of the alloy through the correlation between the elongation [δ]: He found that the increasing behavior of stretching [δ], confirming that the alloy gained ductility with the application of heat treatment [TT 230C / 1h].

Assess the thermoresistance of the alloy after heat treatment: None of the alloys had a good thermal resistivity, according to the national standard COPEL, all leagues lost more than 10%.

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