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ELECTRICAL AND MECHANICAL CHARACTERIZATION OF THE AL-CU-FE-MG-TI ALLOY TO THE HEAT TREATMENT OF 200°C FOR 4H

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Abstract. *The objective of this work was to evaluate the modification of Al-Cu-Fe-Mg-0.15% Ti alloy subjected to the thermal aging treatment at 200 °C for 4h. The study was carried out starting from the aluminum alloy of commercial purity with addition of the contents of Cu, Fe, Mg and Ti. The alloy was obtained by direct solidification in a U-shape metallic mold. After obtaining the material as molten the same passed through the process of chemical analysis and machining to the diameter of 18.5 mm then one of the machined samples was subjected to the heat treatment at 200 °C for 4 hours after that the sample with and without the cold working process until the diameters of 3.0mm were obtained. The alloys were characterized structurally, electrically and mechanically. In addition, part of the samples after deformation, both without and with 200° C treatment, were submitted to the thermoresistance test. As a result of the study, it was observed that the heat treatment favored the electrical properties of the alloy, generated loss of mechanical properties and did not cause significant changes in the macrostructure of the alloys. The thermoresistance test applied to the alloy, improved the electrical properties, but in contrast, it impaired the mechanical properties.*

Keywords: *Electrical Energy, Mechanical Properties, Heat Treatment, Al-Ti Alloy and Thermoresistance Test.*

1. INTRODUCTION

Electricity is an important ingredient for development, which is one of the main aspirations of the populations of the countries of Latin America, Asia and Africa. Energy consumption per capita can be used as an indicator of problems affecting these countries, which are home to 70% of the world's population.

The development of technologies that improve the transmission [Tx] and distribution [Dx] of electricity to meet the demand for energy has become indispensable to the development of any nation; This statement is seen in Inter Academy Council, 2007. In this context, we have been looking for more efficient and less expensive materials to be used in this application.

Given the above, one realizes the importance of studies that generate benefits in the [Tx] and [Dx] of electric power, thus the production of new metal alloys that benefit the electromechanical behavior of electric cables can meet these needs.

For Lima, 2014 thermoresistance aluminum consists of adding some alloying elements to pure aluminum in order to raise the recrystallization temperature of the material. Given this, the alloy studied in this article seeks to present beneficial properties for the use in the manufacture of electric [Tx] and [Dx] cables from the addition of titanium [Ti].

The works of Sena, 2015 show that the iron [Fe] contents in the range of [0.24- 0.28]% and 0.05% Cu are the most indicated to raise the tensile strength limit of the electrically conductive aluminum [Al -EC]. As shown in the studies by Jorge, 2013 the Ti contributes to the elevation of the mechanical properties of aluminum alloys. In addition, according to the studies Prazeres et al., 2017 the AL-0.15% Ti alloy obtained higher mechanical strength than the Al-0.03% Ni alloy, under conditions without heat treatment.

The aging heat treatment, as shown in the work of Garcia, 2015, consists of precipitation from another phase, in the form of extremely small and evenly distributed particles. This new phase hardens the alloy. After aging, the material will have acquired maximum hardness and strength. Aging can be natural, done at room temperature for a long time or artificial, accelerated in a temperature controlled oven.

The objective of this work is to analyze the Al-0.05% Cu-[0.24-0.28]% Fe-0.6%Mg-0.15%Ti alloy on the influence of the aging treatment at 200°C for 4 hours. Thereafter was carried out electrical and mechanical characterization before and after the test of thermo-resistivity of solidified alloys in a U-shape metallic mold.

2. MATERIALS AND METHODS

2.1 Foundry and Sample Preparation

The alloy was made by mold system metal of the type "U" to the solidification, in the elaboration of the alloy was used pure aluminum [Al] or Electro Conductive Aluminum (Al-EC).

This preparation was performed by adjusting the element compositions to achieve 0.05% Cu, 0.6% Mg, 0.15% Ti and [0.24-0.28]% Fe, all by weight, so the elements and the crucible were separated and placed in a 250 ° C oven to remove moisture from the material and foundry crucible.

The foundry crucible is removed from the oven and covered with alumina so that the container wall does not react with the alloy, then the pure Al was cast in the oven at a temperature of 900 ° C and after of the Al complete foundry; Cu, Ti and Fe alloy elements were added to the crucible to be fused

With all the elements homogenized, argon gas [Ar] was injected to remove the possible slag present in the molten material, after removing all the slag, the magnesium [Mg] was added and then the mixture was punched out in the type "U" (Figure 1). After foundry the sample was taken from the obtained ingot for chemical analysis, the purpose of which is to confirm the final compositions of the alloying elements added.

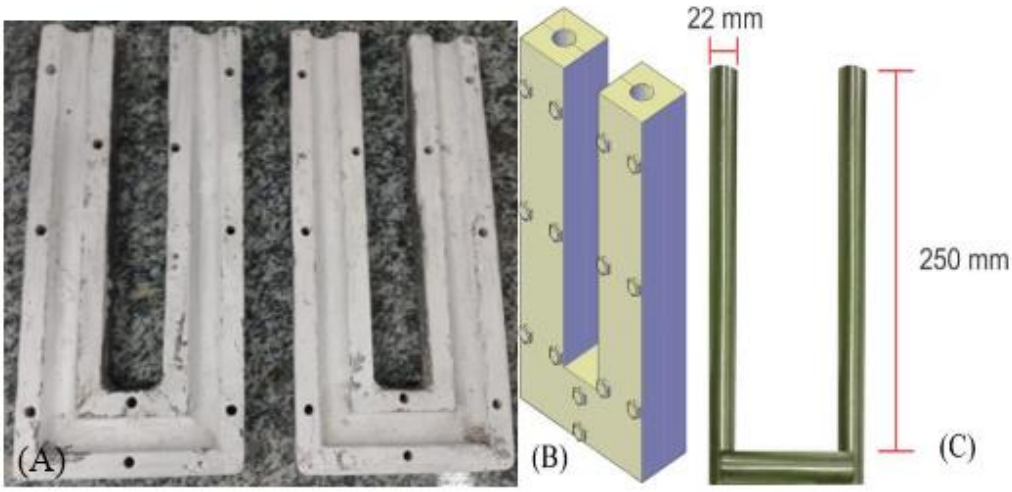

Figure 1. Mold type "U" (a), (b) the scheme of the mold closed and (c) the dimensions of the cast material produced. Available from: GPEMat file.

After getting the alloy in the type of the mold "U", the material was sectioned and machined. The heat treatment of artificial aging was performed for 4 hours at a temperature of 200°C [TT+4h] of one of the machined samples, part of the material was sectioned for macrostructure analysis and another was laminated, as was the sample without heat treatment [STT]. The machined and treated material was inset in resin, sanded onto sandpaper 120, 220, 320, 400, 600, 1000, 1200 to be polished with alumina of 3μm and then chemically attack in Keller reagent (2mL HF, 3mL HCl, 5mL). HNO_3, 190mL H_2O) the attacked parts were washed and dried with hot air, the images of the samples were recorded and compared between images by 4h treated sample and the untreated sample.

2.2 Thermoresistance Test

Part of the samples laminated to 3.0 mm wires was used to perform the Thermoresistance Test [TR] using the oven kept at a constant temperature of 280°C, the samples with and without treatment were subjected to this temperature for 1 (one) hour. and analyzed in accordance with the ASTM B941 standard that describes that electrical conductors characterized as resistant, must not present a loss greater than 10% of the Ultimate Tensile Strength [UTS] , when subjected to the presented conditions.

2.3 Electrical and Mechanical Characterization

The electrical resistances of the wires were measured at a temperature [10 to 30]°C and corrected to the temperature of 20°C as recommended by NBR 5118. To obtain the electrical resistance of the material was used the microhmmeter (Figure 2.a). After obtaining the result from the reading of the resistance of the test bodies in 3 mm diameters (Figure 2.b) was used the equation provided by the norm NBR 6814 for the calculation of electrical conductivity.

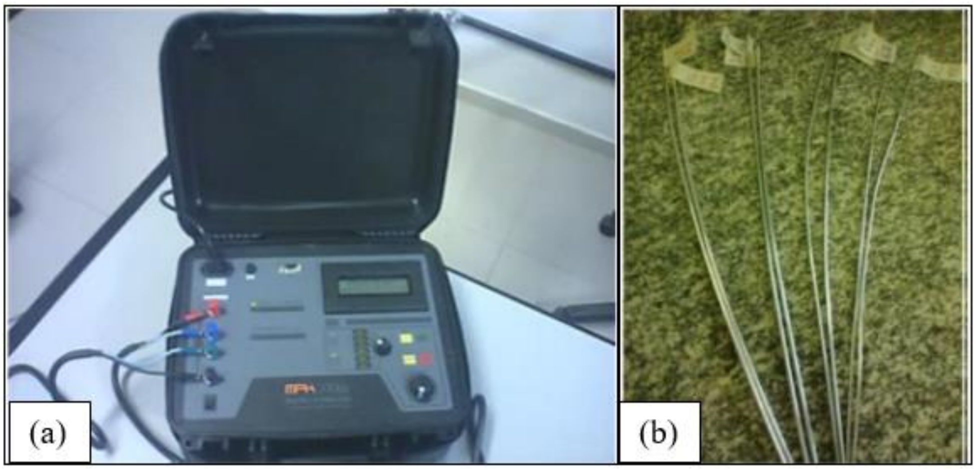

Figure 2. (a) (a) Microhmmeter used for the test and (b) wires for the tensile test. Available from: GPEMat file.

The mechanical testing of the alloy samples was made from the tensile test on the KRATOS machine (Figure 3.a and Figure 3.b) using the NBR 6810 and NBR ISO 6892/02 standards for electrical wires and cables. Thus, the test was performed with 200 mm long samples for each sample, respecting the 150 mm claw distances (Figure 3.c).

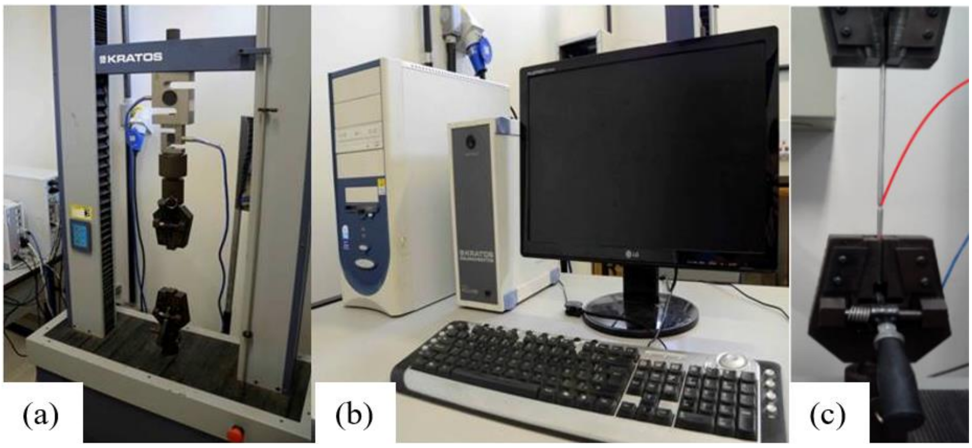

Figure 3. Scheme of representation of the tensile test; (a) tensile testing machine, (b) data receiving equipment and (c) test specimen subjected to the test. Available from: GPEMat file.

3. RESULTS AND DISCUSSIONS

3.1 Chemical Analysis

Table 1 shows that the chemical composition obtained is in accordance with the objective of this work, thus inferring the validity of the stoichiometric calculations performed. The chemical composition refers to Al-0.15%Ti alloys.

Table 1: Chemical compositions of the manufactured ingots.

Alloy	Elements (Wt%)			
	Fe	Cu	Mg	Ti
Al-Cu-Fe-Mg-Ti	0.251	0.048	0.629	0.148

3.2 Macroestructure of Alloys Without and With Heat Treatment

Figure 4 shows the Al-0.15% Ti alloy macrostructure, without deformation, Figure 4.a and Figure 4.b, respectively, refer to the alloy without heat treatment and the alloy subjected to heat treatment of aging at 200°C for 4 hours.

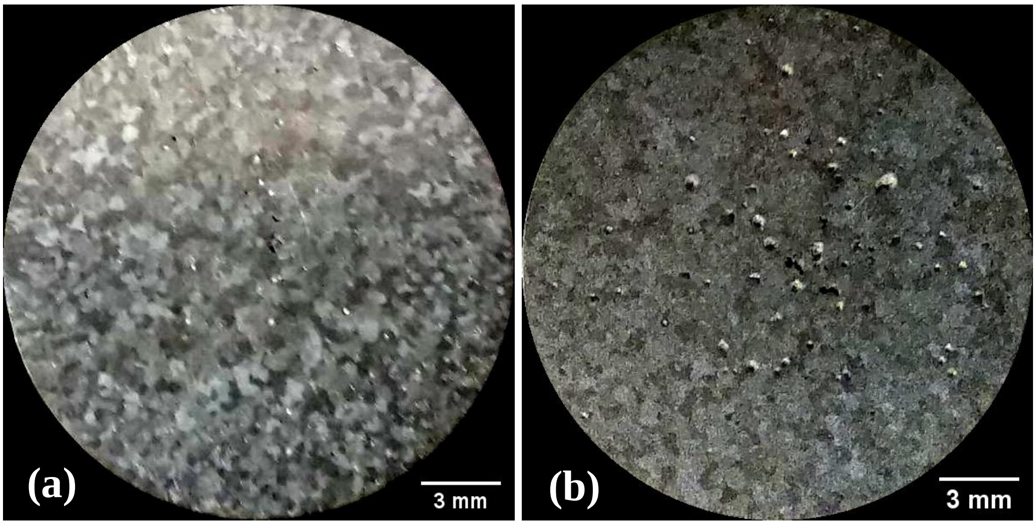

Figure 4. Macrography of the Al-Cu-Fe-Mg-0.15% Ti alloy, (a) without treatment and (b) with treatment. Available from: GPEMat file.

The morphologies of the grain structures of the alloys, without deformation, are predominantly equiaxial due to the refining action of the Ti element. This morphology seen in the alloy macrostructure studied is confirmed by Ferrarini, 2005 which shows that Ti is usually added in contents of 0.05% to 0.2% as a grain refiner for all sand foundry alloys and permanent casting, and dispensable in pressure foundry. Moreover, the aging treatment at 200°C for 4 hours was not sufficient to generate significant changes in the Al-0.15%Ti alloy macrostructure.

Figure 5 shows the Al-Ti phase diagram for alloy, which shows the demarcation (red) of the weight percentage of Ti used in the alloy, this percentage is at the limit of the maximum solubility of Ti in Al, so unable to undergo perithetic transformation.

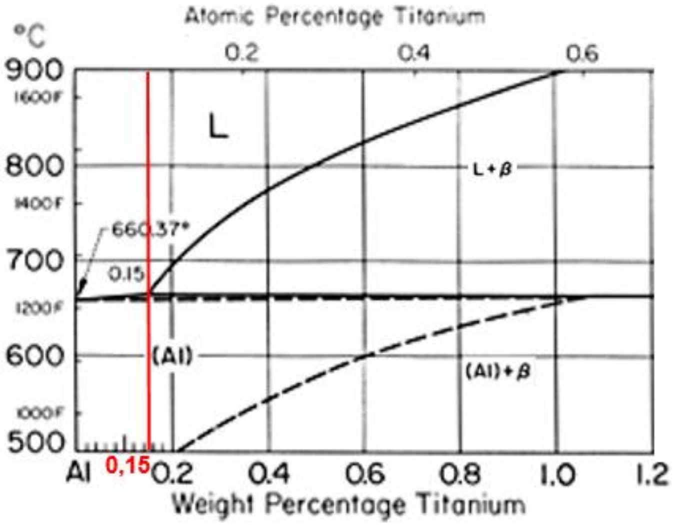

Figure 5. Al-Ti phase diagram. Available from: https://www.infomet.com.br/site/diagrama-de-fases-ver.php?cod=56

3.3 Electrical and Mechanical Comparison between STT and TT4h Sample

Table 2 presents the data on electrical conductivity and Ultimate Tensile Strength [UTS] obtained for Al-0.15% Ti alloy under the condition without heat treatment and with aging treatment of 200°C for 4h, thereafter cold deformation up to 3.0mm diameter. Figure 6 shows the graphs for the data obtained on electrical conductivity and UTS correlated with the curve True Stress vs. True Strain.

Table 2. Electrical conductivity and Ultimate Tensile Strength for STT and TT4h sample.

Heat treatment	Al-Cu-Fe-Mg-0.15%Ti	
	Electrical Conductivities (%IACS)	UTS (1) (MPa)
STT(2)	40.95	279.56
TT4h(3)	41.07	269.85

(1) Ultimate Tensile Strength
(2) Without heat treatment
(3) Heat treatment at 200 ° C for 4 hours

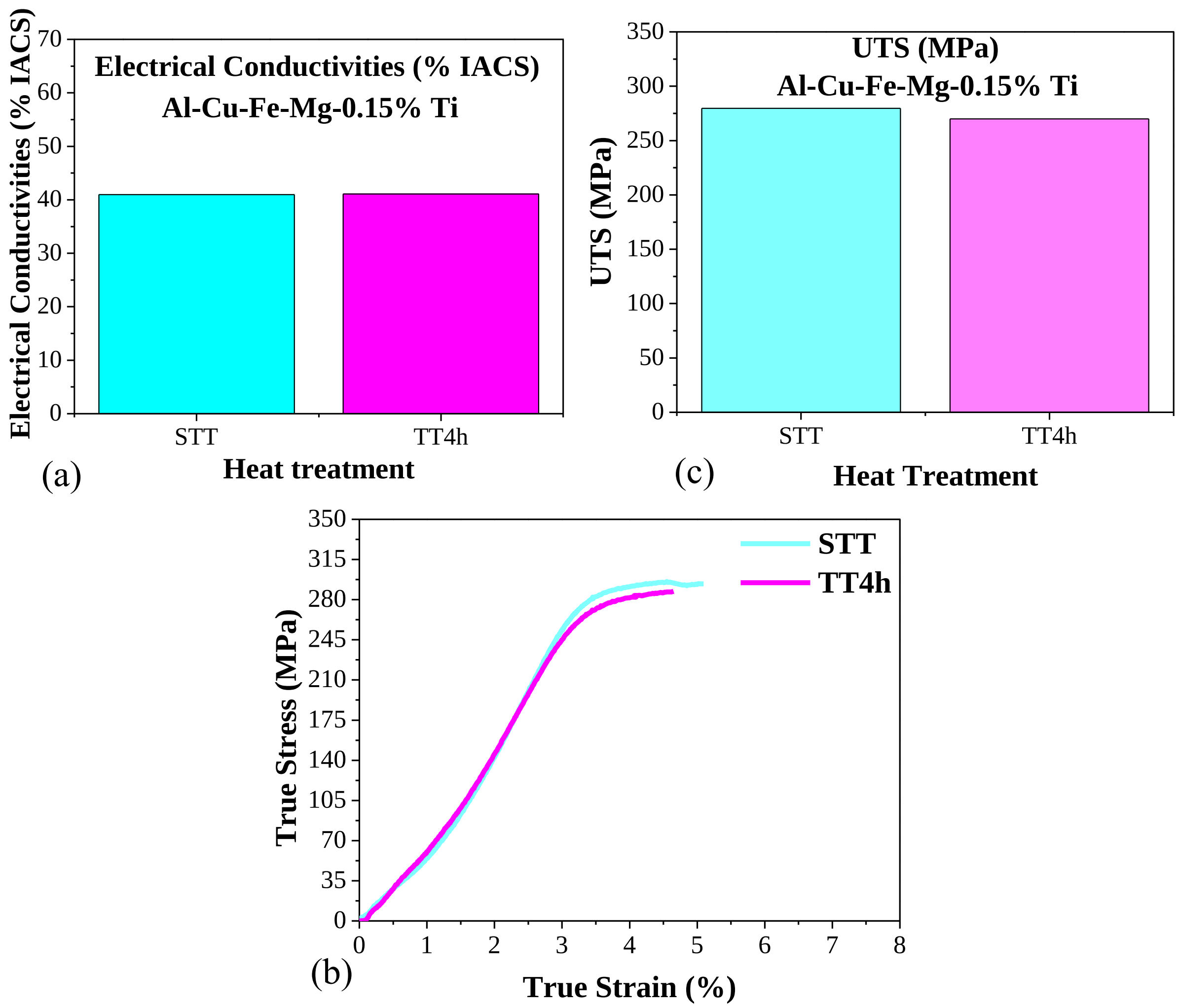

Figure 6. Correlation between (a) Electrical conductivity, (b) True Stress vs True Strain and (c) Ultimate Tensile Strength for STT and TT4h specimen. Available from: GPEMat file.

Observation of the values seen in Table 2 and Figure 6 show that the material as a melt subjected to the operating conditions already described did not change significantly in the electrical and mechanical properties, which may mean that the temperature [200°C] and the time [4h] used the heat treatment were not sufficient to eliminate the mechanical hardening state in which both types of samples were present.

3.4 Electrical and Mechanical Comparison between STT and STT+TR Sample

Table 3 shows the results of electrical conductivity and Ultimate Tensile Strength obtained for Al-0.15% Ti alloy under the condition as melt without heat treatment and cold deformation to the diameter of 3.0mm that was subjected to the thermoresistance test according to ASTM B941. Figure 7 shows the graphs for the data obtained on electrical conductivity and UTS correlated with the curve True Stress vs. True Strain.

Table 3. Electrical Conductivity and Ultimate Tensile Strength for STT samples and with thermoresistance test.

Heat treatment	Al-Cu-Fe-Mg-0.15%Ti	
	Electrical Conductivities (%IACS)	UTS[(1)] (MPa)
STT[(2)]	40.95	279.56
STT+TR[(3)]	52.49	177.72

(1) Ultimate Tensile Strength
(2) Without heat treatment
(3) Without heat treatment and with thermoresistance test

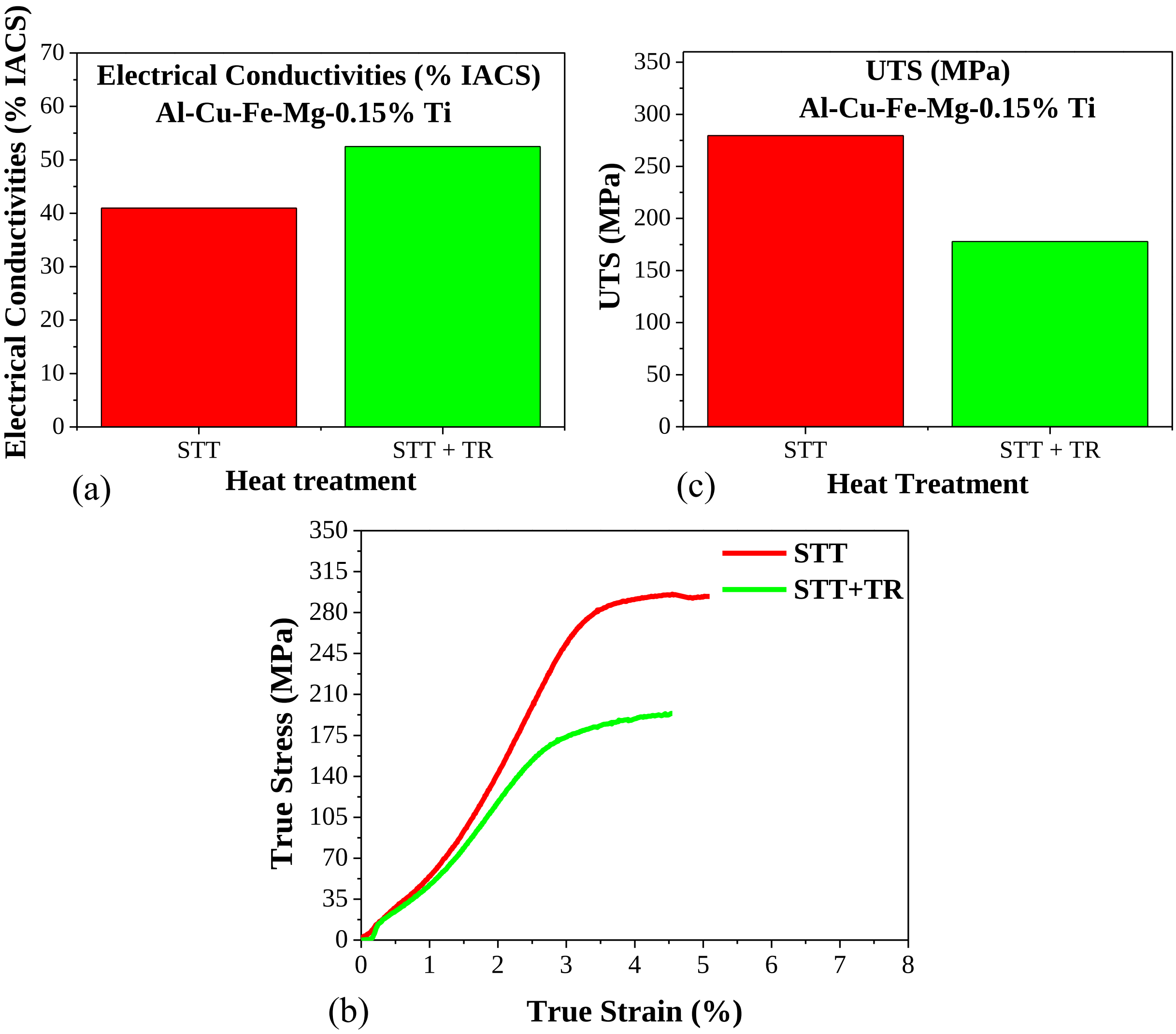

Figure 7. Correlation between (a) Electrical conductivity, (b) True Stress vs True Strain and (c) Ultimate Tensile Strength for STT samples without and with thermoresistance test. Available from: GPEMat file.

According to Horikoshi et al., 2006, the introduction of Ti may contribute to the reduction of the electrical conductivity of [Al]. Observing the data contained in Table 3 and Figure 7, it is noted that the material subjected to the thermoresistance test presents curious performances: i. With regard to electrical conductivity; improvement with gains of approximately 28.2%; ii. As regards the UTSs catastrophic losses of approximately 36.4%.

For Figure 7.b we have the curve True Stress vs. True Strain, which shows that when compared to the STT sample and with thermoresistance it is noticeable the difference in mechanical behavior between both. It is noticed that the term resistivity test according to ASTM B941 norm proved to be harmful to the mechanical properties, since there is a decrease of the UTS followed by the maintenance of the deformation of the sample. sample. In these circumstances it is possible that despite the short treatment time [1h] normally used in static recovery treatment, the temperature used in the test [280°C] is critical to the point of recrystallizing the sample structure rather than only statically recovering it, thus presenting a catastrophic loss of UTS.

Thus, it can be concluded that for the situation shown in Figure 7 under study, no thermoresistance characteristics were presented if subjected to the conditions of ASTM B941 standard.

3.5 Electrical and Mechanical Comparison between TT4h and TT4h+TR Sample

Table 4 shows the Electrical Conductivity and UTS data for the aging treated samples and the TT4h sample submitted to the thermoresistance according to ASTM B941 standard. Figure 8 shows the correlation scheme, for these conditions, between Electrical Conductivity, True Stress vs.True Strain and the UTS.

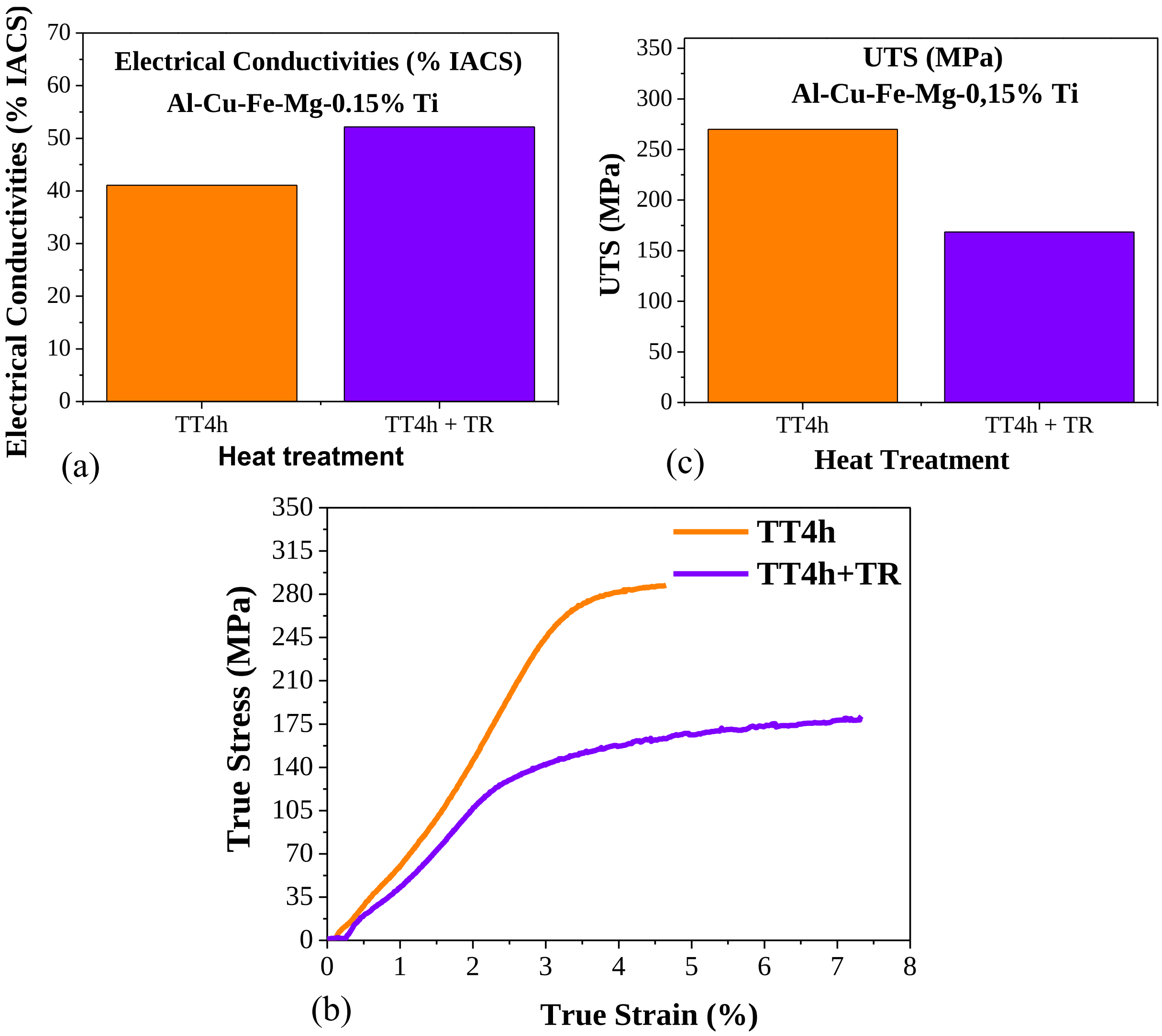

Table 4. Electrical conductivity and Ultimate Tensile Strength for aging samples with and without of thermoresistance test.

Heat treatment	Al-Cu-Fe-Mg-0.15%Ti	
	Electrical Conductivities (%IACS)	UTS (MPa)
TT4h	41.07	269.85
TT4h + TR	52.16	168.36

(1) Ultimate Tensile Strength
(2) Heat treatment at 200 ° C for 4 hours
(3) Heat treatment at 200 ° C for 4 hours and with thermoresistance test

Figure 8. Correlation between (a) Electrical conductivity, (b) True Stress vs True Strain and (c) Ultimate Tensile Strength for aging samples with and without of thermoresistance test. Available from: GPEMat file.

Comparison between TT4h and TT4h + TR samples showed an increase in electrical performance by 27.0% compared to the TT4h sample. This fact may be due to the fact that the temperature used in the thermoresistance test [280°C] acted in reducing the mechanical hardening of the wire, thus improving the mobility of electrons in the material. However the negative consequence is shown in Figure 8.b and Figure 8.c, in which it is possible to notice as effect the catastrophic loss of Ultimate Tensile Strength with 37.6% decline in the TT4h sample. Thus, it is concluded that the alloy subjected to the aging treatment did not have thermoresistant qualities when subjected to the conditions of ASTM B941, since the LRT loss was greater than 10%.

4. CONCLUSION

Based on the tests performed to characterize the alloy Al-0.05%Cu-0.27% Fe-0.6%Mg-0.15% Ti. The STT sample, as well as the TT sample have equiaxic grains, the heat treatment did not generate evident changes in the macrostructure.

Aging treatment for 4 hours at 200°C promoted a slight increase in electrical conductivity and a small decrease in UTS compared to the STT sample. It can be inferred that the heat treatment of aging was not sufficient to improve the mechanical properties of the material studied.

After the heat resistance test, there was a slight increase in electrical conductivity and a high decrease in UTS for samples that did not undergo heat treatment, as well as those that suffered artificial aging. In addition, it is noteworthy that both the STT sample and the TT4h sample are not thermoresistant according to ASTM B941.

The curve True Stress vs. True Strain has similarity between the curves of the specimen [STT] and [TT-4h] and for the samples submitted to the heat resistance test the curves showed divergences while the STT+TR showed fragile behavior, the TT-4h +TR presented growth of the deformability.

5. ACKNOWLEDGEMENTS

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