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## **CHARACTERIZATION OF AL-6%MG MODIFIED WITH 0.15% OF ZR ALLOY AND SUBMITTED STRAIN RELIEF THE 400°C/1H**

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**Abstract.** *The work aims to analyze the mechanical and electrical characteristics of Al-6% Mg alloy with the addition of 0.15% of Zr and the influence of the thermal stress relief treatment. The alloys were cast and cast in Cu (section of the Properzi wheel section) cooled in water. Cross sections of the ingot were obtained for metallographic characterization. It was divided into two groups: the CTT and the STT, the heat treatment was at 400 ° C for 1 hour. The tensile and electrical resistance tests were performed for mechanical and electrical characterization, respectively. The results showed that the addition of Zr generated grain refining in the structure. Through the electrical conductivity test, an average value of 30.34% IACS was obtained. The limit of tensile strength and the elongation of the alloys before and after the heat treatment were evaluated. The treatment resulted in loss of LRT and real deformation gain of the samples. In the curves resulting from the tensile tests, it was noted that the alloys were in the plastic zone. For the STT alloys the addition of Zr decreased the occurrence of this phenomenon. However, the CTT alloys had their plastic zones extended and the serrations were more evident.*

**Keywords:** *aluminum alloys, strain relief, mechanical and electrical characterization.*

### **1. INTRODUCTION**

Among the various aluminum alloys, one of the most resistant are those of the Aluminum Magnesium series, being very used in the manufacture of blades, plates, profiles, tubes and wires. In general, increasing Mg contents tend to increase resistance. Aluminum alloys also have good corrosion resistance and are therefore widely used in vessels. They are also easily produced and have good weldability (ABAL, 2007).

Lately, in several engineering fields, there has been an increase in interest in thermoresistant alloys, that is, those that are able to maintain their properties, especially the mechanical ones, under high temperatures. Studies of aluminum alloys with zirconium additions were presented as a promising way to raise the recrystallization temperature of such alloys (DIAS, 2016).

This work aims at obtaining the electrical and mechanical characteristics of the Al-6% Mg base alloy, modified with the content of 0.15% Zr and the influence of the tension relief on them.

## 2. MATERIALS AND METHODS

The samples were divided into two groups: STT and CTT. From the stoichiometric calculation, for the alloying elements, the casting was performed and then the cast ingots for each alloy composition were sectioned. From the ingots were obtained chemical composition, macrostructure and microstructure. The material obtained from the slicing of the ingots was machined to the diameter of 9 mm. In the second step the material was cold rolled gradually to the 3 mm diameter where two groups of samples were divided, the CTT and STT samples. The heat treatment was 400 ° C for 1 h in the 3 mm wire. The two groups of samples then passed the electrical conductivity and tensile tests.

### 2.1 Casting and solidification

As The alloys were obtained by direct casting where an aluminum conductor (Al-EC) was fused. The magnesium element was used in its pure form. The zirconium element was used from an Al-10% Zr alloy. The masses of each element were determined by stoichiometric calculations, considering their respective percentages in each alloy. In the cutting of the Al-EC the band saw was used. Subsequently all the elements were weighed in the digital scale and then melted in the muffle furnace.

After confirmation of the complete melting of the metals, the crucible was removed from the furnace, the molten metal was homogenized by hand shaking with a steel spatula painted with kaolin solution ( $\text{Al}_2\text{O}_3 + 2\text{SiO}_2 + 2\text{H}_2\text{O}$ ). And it applied the injection of inert gas (argon) in the molten alloy through a stainless steel tube connected to a 10m<sup>3</sup> cylinder, to remove gases and low density impurities, which are segregated forming a layer of slag on the surface of the bath, which was immediately removed by steel spatula. The leak has started.

The solidification stage of the alloys was through a copper mold corresponding to the segment of the Properzi wheel provided by the company ALUBAR, is explained in Figure 1. After this step, each ingot was cut into small segments. Six prismatic sections [12x12x160mm] were obtained, which were then machined to a diameter of 9.5mm and a length of 160mm.

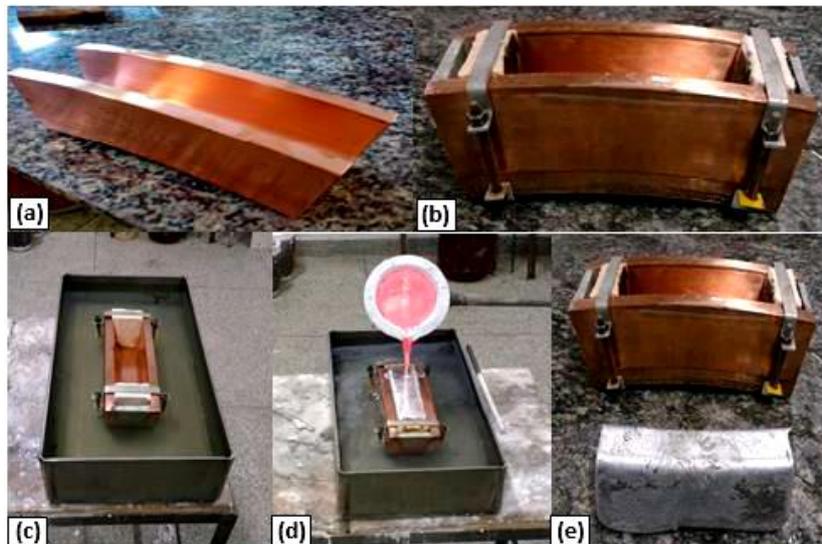


Figure 1. Properzi wheel mold for solidification of ingot. (a) segment of the properzi wheel, (b) a suitably sealed shell, (c) shell immersed in water, (d) casting and (e) solidified alloy. Source: GPENat file.

### 2.2 Metallographic characterization

The macrostructures of the alloys were developed according to standard techniques in metallography following the sanding and polishing steps. The chemical attack was performed by immersion with Keller metallographic reagent (2ml HF + 3ml HCl + 5ml HNO<sub>3</sub> + 190ml H<sub>2</sub>O) for macrostructure. The micrographs were obtained in the scanning electron microscope (SEM) of the brand TESCAN of model Mira 3.

### 2.3 Electrical and mechanical characterization

The electrical and mechanical tests were carried out on 3 mm diameter wires obtained after the machining and rolling of the specimen obtained in the solidification process. In the electrical characterization, the test bodies were submitted to the tests with the objective of evaluating the electrical resistivity with the aid of a multi-ohmmeter (kelvin

bridge) of the manufacturer MEGABRÁS. The electrical resistivity tests were performed according to the norms NBR 5118 (2007), NBR 6810 and NBR 6815 (1981b). After the electrical characterization, the specimens were submitted to the mechanical test, in a KRATOS traction test machine, model IKCL1 - USB. The tensile tests were performed according to the norms for electric cables, NBR 6810, and metallic materials, NBR 6892, running them in three samples with 20 cm for each diameter.

### 3. RESULTS AND DISCUSSIONS

#### 3.1 Macrostructure of cast alloys

The macrostructure of the Al-6%Mg base alloy (Figure 2.a), is compared with the addition of 0.15% Zr (Figure 2.b).

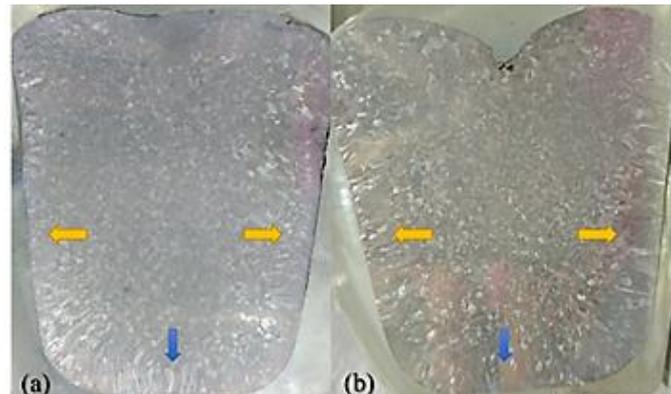


Figure 2. Macrostructure of the solidified alloy in copper mold. (a) Al-6% Mg; and (b) Al-6% Mg-0.15% Zr.

In the Al-6% Mg base alloy shown in Figure 2.a, a grain region with columnar tendencies near the metal / mold interface (yellow and blue arrows) is observed, however, inside the material the presence of equiaxial grains is observed. In Figure 2.b, the base alloy with 0.15% of zirconium showed slight macrostructural changes. The magnesium content added to the alloys was responsible for the refining of grains observed, with the addition of zirconium assisted in this process. This behavior of grain refining when added in a single aluminum ingot, the elements Mg and Zr has already been observed in the work of Santos (2010).

The structure of Al-0.18% Zr alloy obtained by Silva (2017) is observed in Figure 3.a, while the macrostructure of Al-6% Mg-0.15% Zr alloy is shown in Figure 3.b.

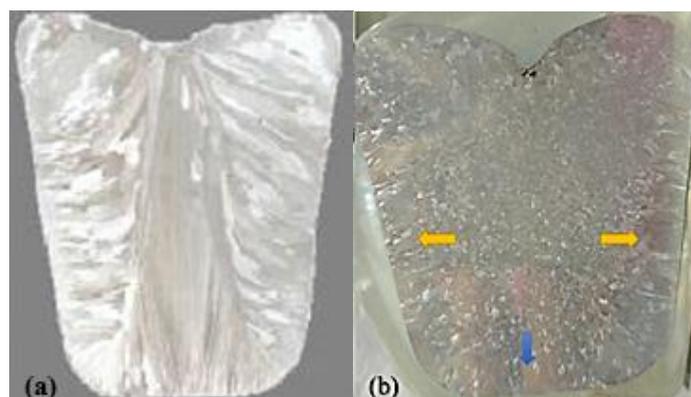


Figure 3. Macrostructures of solidified alloys in copper mold. (a) Al-0.18% Zr Alloy, obtained by Silva, 2017; (b) Al-6% Mg-0.15% Zr.

In the Al-0.18% Zr alloy obtained by Silva (2017), shown in Figure 3.a, we can observe the macrostructure of the alloy with the predominance of columnar grains. In the alloy Al-6% Mg-0.15% Zr is shown in Figure 3.b the macrostructure with predominance of equiaxed grains. These results indicate that the modification generated by the addition of 6% Mg in the alloy caused grain refining.

#### 3.2 Electric conductivity

### 3.2.1 Sample STT

The electrical conductivity of the modified Al-6% Mg alloy with a content of 0.15% Zr is presented in Table 1.

Tabela 1. Resultado do ensaio de condutividade elétrica das ligas.

League	Ambient Temp. (°C)	Resistance (mΩ)	Resistance corrected to 20°C (mΩ)	Electrical Resistiv. (Ωmm <sup>2</sup> /m)	Electrical Conduct. (%IACS)
Al-6%Mg	26,3	2,48	2,42	0,05718	30,15
Al-6%Mg-0,15%Zr	26,2	2,46	2,40	0,05674	30,39

The three alloys had low values of electrical conductivity due to the amount of solute inserted in the alloy. The Mg element may have attributed to the alloys the low values of electrical conductivity when compared to electroconductive alloys, thus not being favorable for the application as conductors of energy. The addition of zirconium did not cause significant variations in the electrical properties of the material.

### 3.2.2 Sample CTT

The samples were submitted to a temperature of 400 ° C for one hour. The results can be observed in Table 2, where we have the conductivity values for the alloys studied in this work.

Table 2. Results of the electrical conductivity test of the alloys.

League	Ambient Temp. (°C)	Resistance (mΩ)	Resistance corrected to 20°C (mΩ)	Electrical Resistiv. (Ωmm <sup>2</sup> /m)	Electrical Conduct. (%IACS)
Al-6%Mg	26,1	2,39	2,38	0,05515	31,26
Al-6%Mg-0,15%Zr	26	2,44	2,40	0,05632	30,61

The CTT alloys presented low conductivity values, so they can not be characterized as alloys with good conducting properties. Due to the addition of zirconium the alloys obtained small gain with the treatment, however, it is probable that due to the amount of Mg, it was not possible to obtain satisfactory values of electrical conductivity..

### 3.2.3 Influence of heat treatment

A comparison between the conductivity results of each of the CTT and STT alloys is shown in Figure 4.

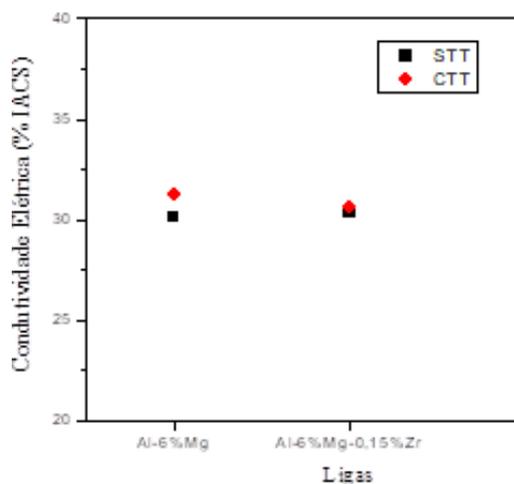


Figure 4. Comparison of conductivity results for CTT and STT alloys.

All the alloys had low values of electrical conductivity and the heat treatment did not generate changes in these results. The Al-6% Mg alloy obtained a gain of 1.11% IACS with the heat treatment that can be considered an unimpressive gain. The electrical conductivity of Al-6% Mg-0.15% Zr alloy was not altered with the heat treatment. The low conductivity can be related to the fact that the alloys have a great presence of solute, in this case, the Mg, being thus detrimental the electrical characteristics of the alloys.

### 3.3 Limit of tensile strength

#### 3.3.1 Sample STT

The Figure 5 shows the strain x strain graph for the two alloys studied in this work, from which the STT alloys presented values of tensile strength similar to those obtained for the CTT alloys. However, the alloy without addition of Zr obtained a similar percentage deformation to that of the alloy with addition of 0.15% Zr. In the results presented in Figure 5, the effect of Portevin-Le Chatelier during the plastic deformation zone of the material can be observed. In the alloy without Zr addition, the band where the effect occurs is much more extensive and the addition of Zr tends to inhibit the effect.

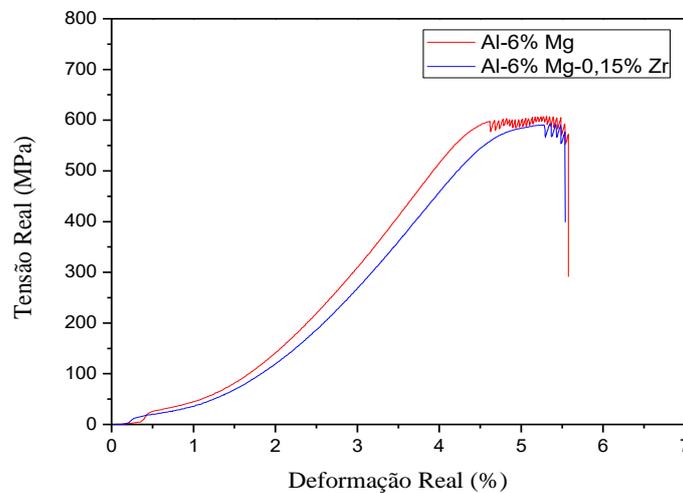


Figure 5. Real voltage x real deformation graph of the STT alloys.

#### 3.3.2 Sample CTT

The CTT strain relief alloys were subjected to the same test performed on the STT alloys under the same conditions. Figure 6 shows the strain x strain plot for CTT alloys. All treated alloys had similar maximum stress values. The alloy with addition of 0.15% Zr obtained the lowest values of real deformation.

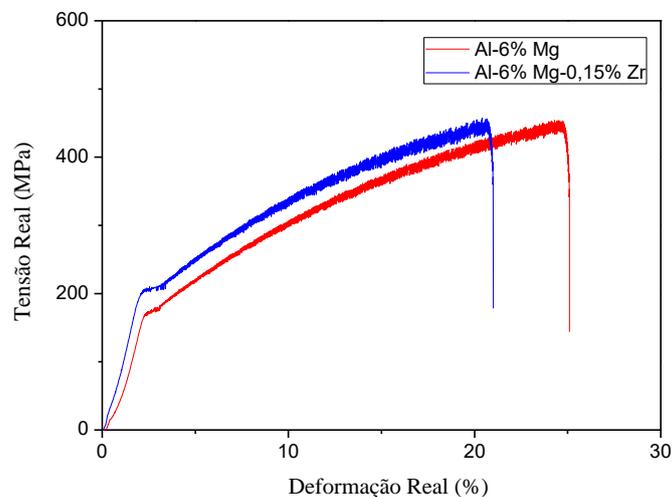


Figure 6. Real voltage x real deformation graph of CTT alloys.

The yield limit of the alloy with 0.15% Zr is higher than that observed for the alloy without addition of Zr. This fact can be justified, due to the composition of 0.15% Zr being within the region of precipitation and due to the occurrence of this hardening mechanism, from which an increase in the yield limit was registered. The effect of Portevin-LeChatelier was observed in the CTT and STT alloys, but the heat treatment generated an extension in the region of plastic deformation, region of occurrence of the effect.

### 3.3.3 Influence of heat treatment on alloys

In Figure 7 the tensile strength and elongation limit results for Al-6% Mg, Al-6% Mg-0.15% Zr CTT and STT alloys are seen. The STT alloys presented values of tensile strength equivalent to each other, since the maximum variation of 2.5% can be neglected. The CTT alloys also presented results equivalent to each other, with a maximum variation of 4.1% in the values.

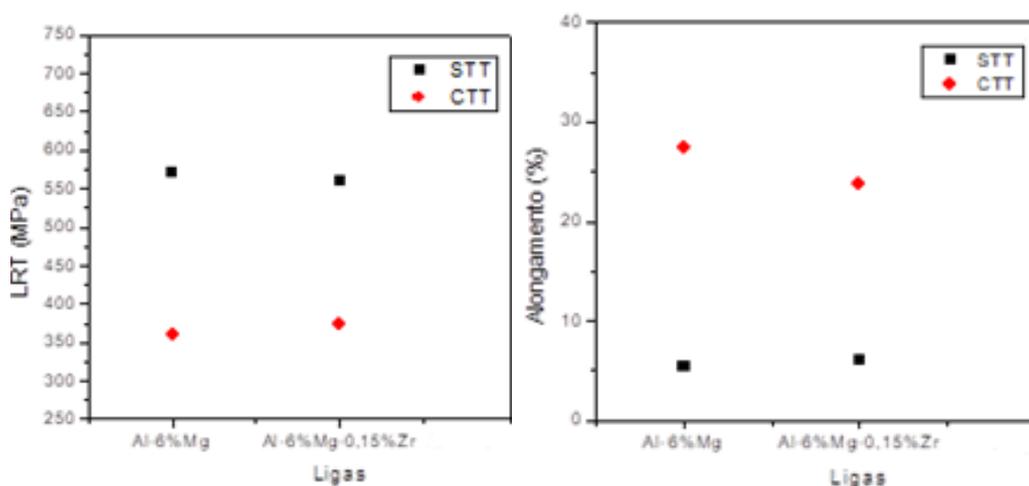


Figure 7. Comparative graph between LRT and elongation results for CTT and STT alloys.

It is observed that the STT alloys obtained better values of tensile strength when compared to the CTT alloys of tension relief, in which the heat treatment generated a mean loss of tensile strength of 36.48%. The elongation of the alloys was little influenced by the addition of zirconium, but with great influence of the thermal treatment. The CTT alloy elongations obtained an average gain of 21.22% in real deformation. Both results may be related to the fact that the heat treatment has undone one of the hardening mechanisms, in this case cold working, and thus damaging the mechanical characteristics of the material.

## 4. CONCLUSION

Considering the methodology developed in the present study to observe the structural characterization for STT alloys and the electrical and mechanical characterization of the CTT or STT alloys, we conclude:

- For macrostructural characterization of alloys Al-6% Mg and Al-6% Mg-0.15% Zr, the macrostructure of the material was refined due to the added magnesium value.

- In the analysis of the electric behavior of the alloys Al-6% Mg and Al-6% Mg-0.15% Zr s CTT and STT, it is noticed that for the STT samples, the modification of the base alloy, Al-6% Mg, with the additions of zirconium did not significantly alter the electrical conductivity values of the alloys. In the case of the CTT samples this generated inexpressive gains of electrical conductivity in all the studied alloys.

- When analyzing the mechanical behavior of the Al-6% Mg and Al-6% Mg-0.15% Zr CTT and STT alloys, it was observed that in the STT samples the addition of zirconium did not produce any noticeable changes in the resistance limit traction and elongation values. However in the CTT samples this generated loss in the limit of tensile strength and gain in the elongation values of all the alloys studied.

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