Analyses of Mg Variation Content on 6101 Alloy Mechanical, Electrical and Microstructural Properties.

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***Abstract**: The power cables market is increasing, mainly of power cables manufactured by aluminum alloys, due a mechanical resistance obtained and reduced weight. The paper objective is show the influence of Mg content on 6101 series alloy, the microstructural development obtained to produce power cable, as well as the mechanical and electrical properties analyses on material. These alloys were casting into "U" mold, to get cylindrical specimens. The silicon content was constant (0.6%) and magnesium was added as following contents: 0.3; 0.5; 0.7; 0.9 and 1.1%. These specimens were machined until 10 mm diameter. After machined the specimens were cold rolled, in a rolling mill with circular canal, where were rolled until 3.98 mm diameter and after, the specimens were submitted to drawing process to it obtain a 3.45 mm diameter. The alloys were characterized by tension test on Wires Kratos Machine, to evaluate the mechanical properties of material (Tensile Strength, Elongation and Tenacity), and by electric resistivity test to evaluate electrical properties in a micro ohmimeter with Mega Bras cross-bridge Kelvin. The results show that when Mg content is increased, mechanical resistance can be elevated and electrical capacity decreased, on the alloys researched.*

***Keywords**: 6101 Alloy, Mechanical Properties, Electrical Resistivity.*

1. INTRODUCTION

The aluminium alloys are used in several applications, as a result of high resistance and solidity characteristics of this material. Due to the high solubility, copper, magnesium and silicon are alloy elements commonly used with aluminum.
The more or less efficiency of solute and alloy applied on casting/solidification process will be associated to affinity between mold and material casting. Although the Al-Si, Al-Mg, Al-Mg-Si and Al-Si-Cu casting alloys are important commercially, the fluidity dates and casting variables influence need to be evaluated. Solidification variables process, as overheating degree, alloy composition and metal/mold affinity can modify the fluidity and the structure obtained needs to be studied.
Studies of Verran et al (2004) show that, kind of elements and content elements, on alloy, as well as casting temperature affect the fluidity of aluminum alloys and on some others alloys.
Kim and Loper (1995) analyzed the Al-Si fluidity with copper variations on 3,5%, to overheating degrees and found that copper small contents affect the binary properties, as can be analyzed on Figure 1 (b).
The Figure 1 (a) shows the aluminium viscosity graphs with usual elements. By graph is possible to see that alloy viscosity decreases with the Si and Mg content and the small Cu content increases this property.

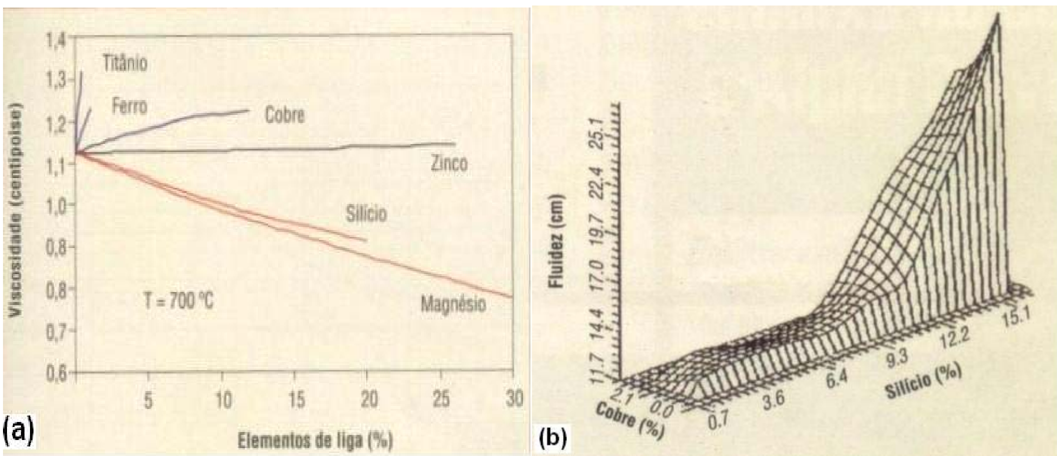


Figure 1 - Influence of alloy elements on aluminium viscosity, Verran, 2004
and on aluminum fluidity variation depending of silicon and copper content, Kim e Loper, 1995.

From graph of Figure 1(a) can be evaluated the Mg influence about the aluminum fluidity and, this fact doesn't occur with copper presence.
However, to understand the fluidity is necessary to know the metals viscosity. Wang (2005) suggests that solidification variation temperature, the viscosity, and metal surface tension and the inclusion presence are the mainly factors that determine the alloy fluidity. Although the Si and Mg temperature fusion in relation the Al is the same, these elements affect the alloy viscosity, which decrease with the elements contents are added.
Studies of Loper (1992), Kin and Loper (1995), show that alloy viscosity behavior has been attributed to influence of high casting temperature of pro eutectic silicon, greater that Al or Mg casting temperature, and this intense heat release during the solidification does the alloys with larger silicon content keeps liquid the metal to along time and then adhere with more efficiency to the mold.
The solidification way can be modified to columnar grain growth with front plane (to dilute alloys) until the columnar dendrites formation which the arms fracture, forming the equiaxial grains (alloys with high solute content) that flows by liquid metal flux.
As example, Mattos (2005) suggested that high heat transfer coefficient (hi) provokes the formation of a thick solid coating, that heats the mold and shrinks itself sweetly, and this coefficient, influenced by metal pressure, form smaller Gap's promoting grain coarse structure (grain columnar), due the low solidification speed and low heat transfer rates that inhibit the intense heat transfer convective on metal, when the solute contents is increased, as on Figure 2, which shows the macrostructure on ingot center with 20x60mm dimension.
On Figure 2, is possible to observe that, when the Mg content increases, the cast structure modifies, of small columnar grains to elongated columnar grains with transition columnar/equiaxial to all alloys, distant 28,9 mm from metal/mold interface as arrows show.

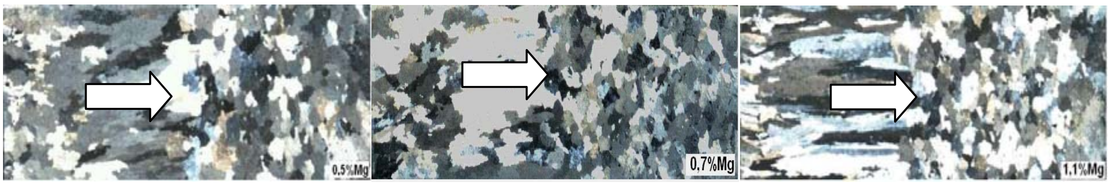


Figure 2 – Macrographs obtained to Al- 0,6%Si-[0,5; 0,7 e 1,1]%Mg alloys, Poulton, 5s.

The metal capacity of adhere on mold can be associated by better metal fluidity or better alloy fluidity, and this aspect can be associated to "mushy zone", or solidification interval, or solidification range, that Garcia (2006) identifies by "Liquidus/Solidus" lines distance to each alloy content.
To alloy with short solidification interval, Figure 3, the mushy zone is refined, and the solid coating formed on the liquid metal when the solidification starts is thick, and the motive power to heat distortion of this solid coating is high and increase with a time.
The motive power to heat distortion plus to the metal pressure, do that only the refined region (which the mechanical resistance is low) of solid coating is pushed to mold wall, forming marks on surface, compromising the ingot workability, mainly, the cold workability.

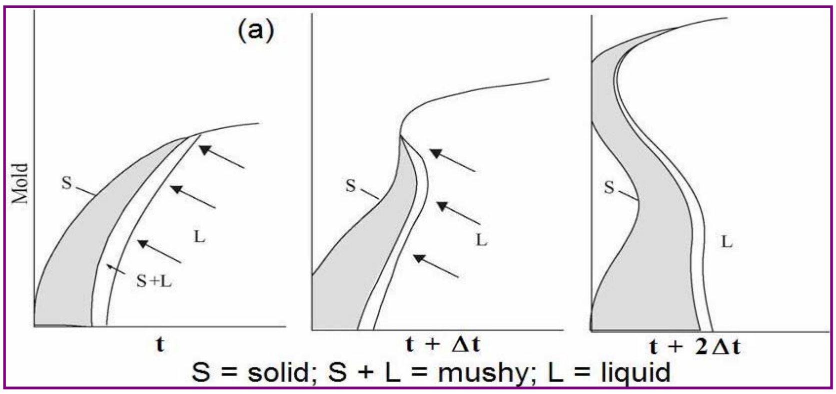


Figure 3 – Illustration of metal pressure and motive power during the alloy solidification with short time solidification or low fluidity.

When the alloy has a larger solidification interval, Figure 4, the "mushy zone" will be thick, that generates a solid coating slimmer, which is not resistant to metal pressure, compressing the solid coating to mold. This fact prevents the heat distortion, inhibition the surface marks, and this contributes to ingot workability.

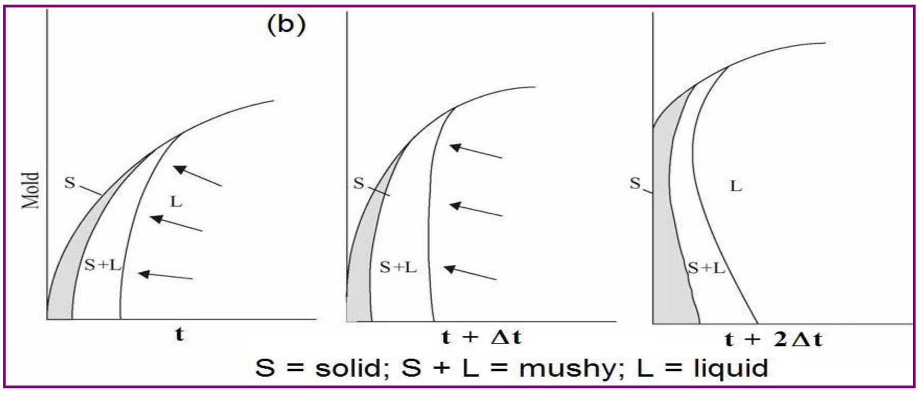


Figure 4 – Action Illustration of metal pressure and motive power during the alloys solidification with larger time solidification or high fluidity.

By this way, it knows that the high fluidity is an attribute that permits the metal or alloy adheres to the mold and as consequence, intervening on generation process of cast structure.

2. MATERIAL AND METHODS

The alloys composition (Table 1) makes possible a larger variation to production and the properties use. The verification of commercial alloy composition of aluminum and alloys, added 0.3 %, 0.5%, 0.7%, 0.9% and 1.1% of Mg were realized on ALUBAR using mass spectrometer and results obtained to a media of three analysis is showed on (Table 2).

Table 1 – Compositions of 6101 and 6201 alloy.

Elements	Si	Fe	Cu	Mn	Mg	Cr	Zn	B
6101	0,3 a 0,7	0,5	0,1	0,03	0,33 a 0,8	0,03	0,03	0,06

Table 2 – Alloy composition (%).

Al-0.3% Mg	Si 0,5935	Fe 0,3841	Cu 0,0492	Cr 0,0053	Mg 0,3036	Zr 0,0012	Ti 0,0005	B 0,0014	Al 98,62
Al-0.5% Mg	Si 0,6235	Fe 0,3373	Cu 0,0496	Cr 0,0010	Mg 0,4922	Zr 0,0013	Ti 0,0022	B 0,0016	Al 98,43
Al-0.7% Mg	Si 0,6152	Fe 0,2895	Cu 0,0490	Cr 0,0016	Mg 0,6804	Zr 0,0013	Ti 0,0009	B 0,0012	Al 98,33
Al-0.9% Mg	Si 0,6039	Fe 0,3761	Cu 0,0504	Cr 0,0006	Mg 0,9632	Zr 0,0012	Ti 0,0011	B 0,0022	Al 97,96
Al-1.1% Mg	Si 0,5749	Fe 0,3559	Cu 0,0463	Cr 0,0042	Mg 1,0197	Zr 0,0012	Ti 0,0008	B 0,0011	Al 97,97

The alloys were casting on graphite crucible, using commercial aluminum, 0.6% Si and Mg contents as following: 0.3; 0.5; 0.7; 0.9; 1.1%. To casting the alloys, was used an electric resistance furnace. All alloys were poured out into mold with "U" shape, to obtain cylindrical specimens.
The specimens were machined until 11 mm diameter, cold-rolled until 3.90 mm diameter and finally were drawn until 3.45 mm diameter.

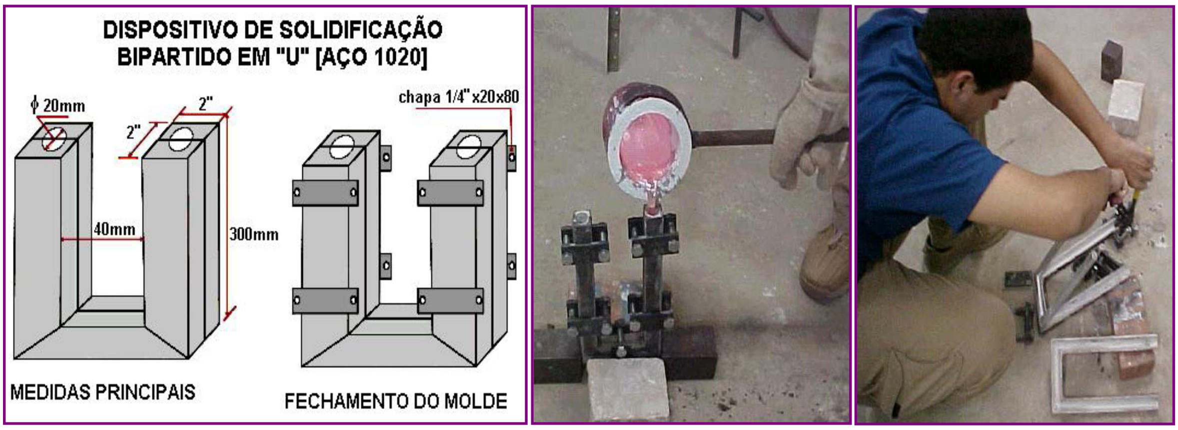


Figure 5 – Sequence of operations to obtaining the "U" specimen.

The specimens obtained, as shown on Figure 5, were submitted to machined and forming sequence (first rolling and after drawing) to obtain wire with 3.45 mm diameter, Figure 6.

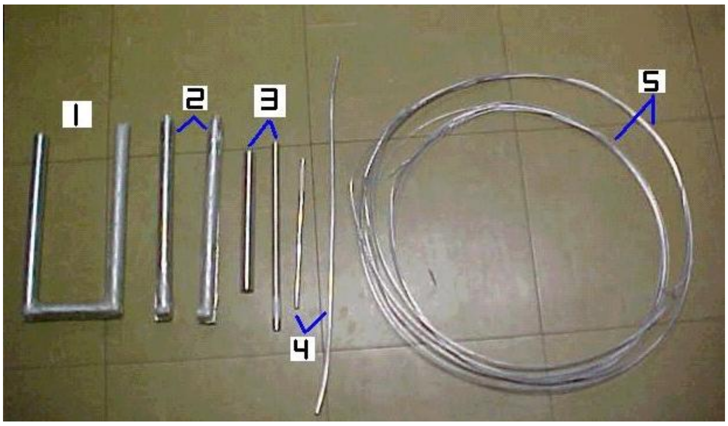
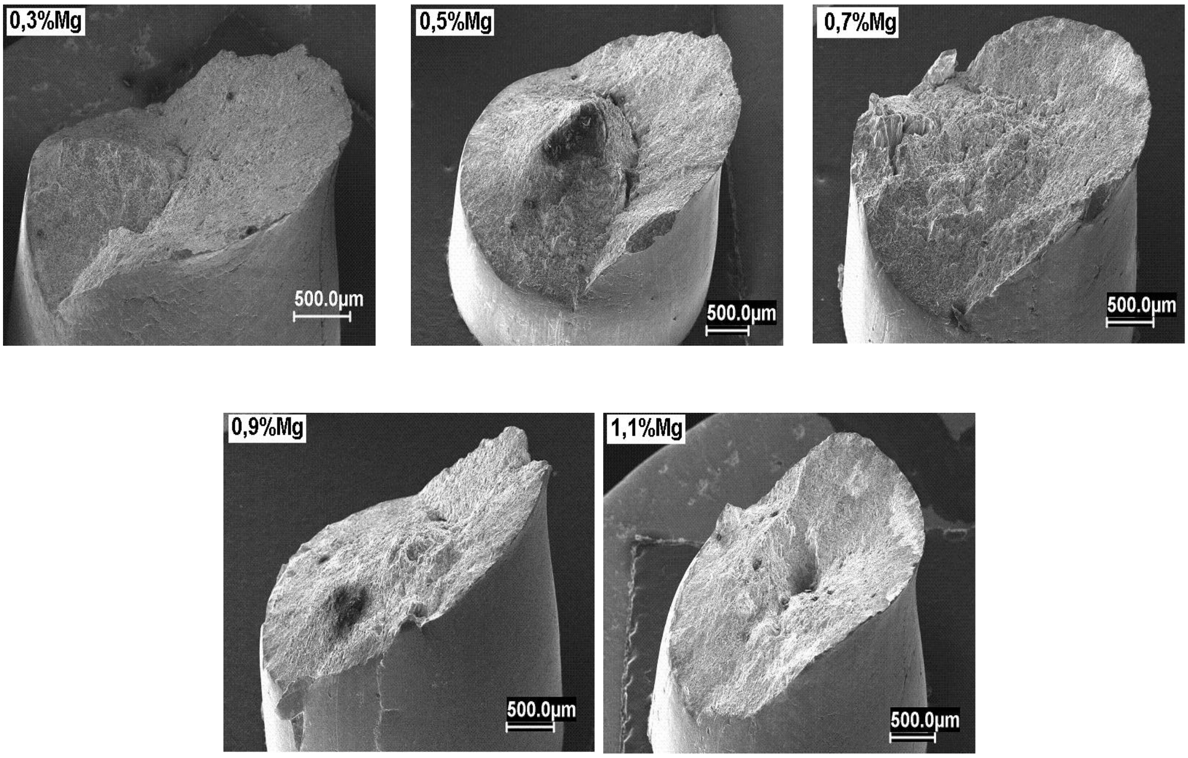


Figure 6 – Sequence of operational stages until diameter 3, 45 mm.

After forming process, the specimens were submitted to Electric Resistance Test and Tension Test, using NBR-5384; NBR 5285 and NBR-6207 standards, respectively.
The fractures obtained by tension test were analyzed on Scanning Electron Microscope (SEM) LEO, 1450P model; the specimens were cleaned up with alcohol + acetone (PA) solution, on ultrasonic cleaner during 10 min. The macrostructures obtained of cast specimens were analyzed on Leica Optical Microscope.

3. RESULTS AND DISCUSSIONS

The usually definition of WORKABILITY, associates a good deformability to without surfaces defects. By observation of this research, workability not depends of surfaces quality only, but depends of hardening without embrittlement too. After the machined process, the specimens didn't show porosity, important characteristic to evaluating qualifiedly the Al alloys. The cold forming starts with cold rolling and after the drawing, to get the ϕ=3.45mm in according NBR 5285 Standard.
In the strength tests were evaluated Elongation, Tension Limit and Toughness values, because the mechanical resistance to cable is more critical.
The fracture characterization of Al-0.6%Si-(0.3; 0.5; 0.7; 0.9; 1.1)%Mg ternary alloy was realized on drawing specimens until ϕ=3.45 mm diameter, with the finality to observe the action Mg in relation to high mechanical properties on percentage studies, and related each other.



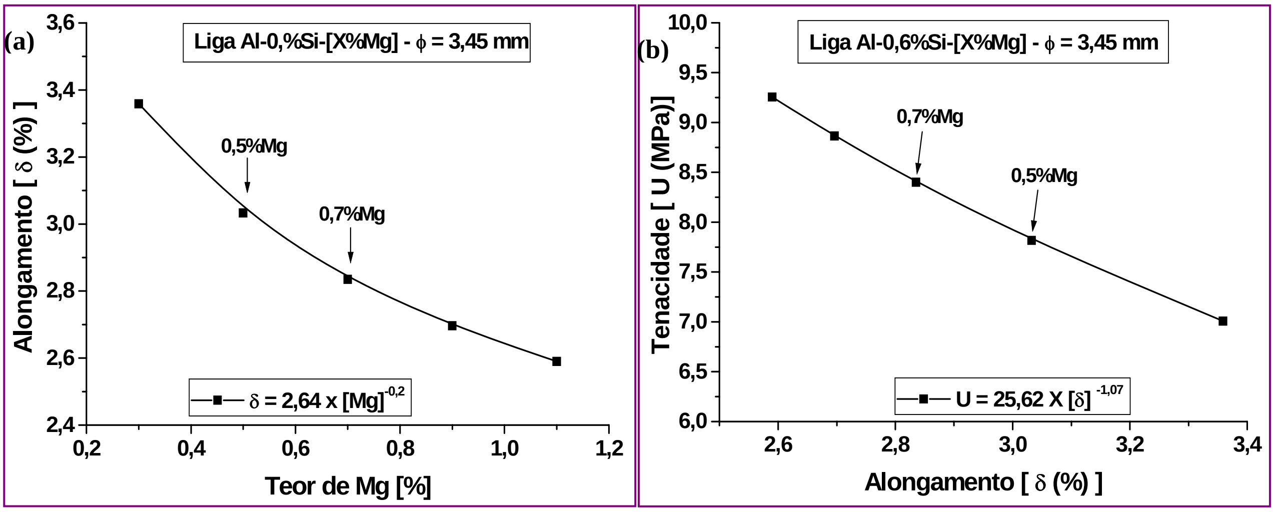


Figure 7 – Elongation in according with Mg content.

The toughness module was calculated to evaluate the absorption of energy for volume unit without rupture of alloy research, which makes possible using the alloys in applications which were submitted, by equation:

$$U = [\frac{\sigma_R + \sigma_E}{2}]\varepsilon_F$$

Where U is toughness; σ_R is a Rupture Tension; σ_E is a Yielding Tension and ε_F Final Deformation.

The Figures 7 (a) and (b) show the evolution of Elongation in function of Mg content and Toughness Module in function of Elongation respectively. The curve of Figure 7(a) shows that, when the Mg content increases the elongation decreases, this contributes to increase the mechanical resistance of alloy increases and toughness too.

The values show that when the Mg increases, the alloy absorbs the energy before the fracture, therefore alloys with high Mg content show a high tension resistance near of some steels (1010 steel, for example). Low elongation associated to high toughness can not in according with NBR 5285 Standard.

By this research, the Mg contents more effective is 0.5% and 0.7%. However, the macro fractures of Figure 7 don't show a significant loss of ductile and therefore, show a small variation on fracture appearance.

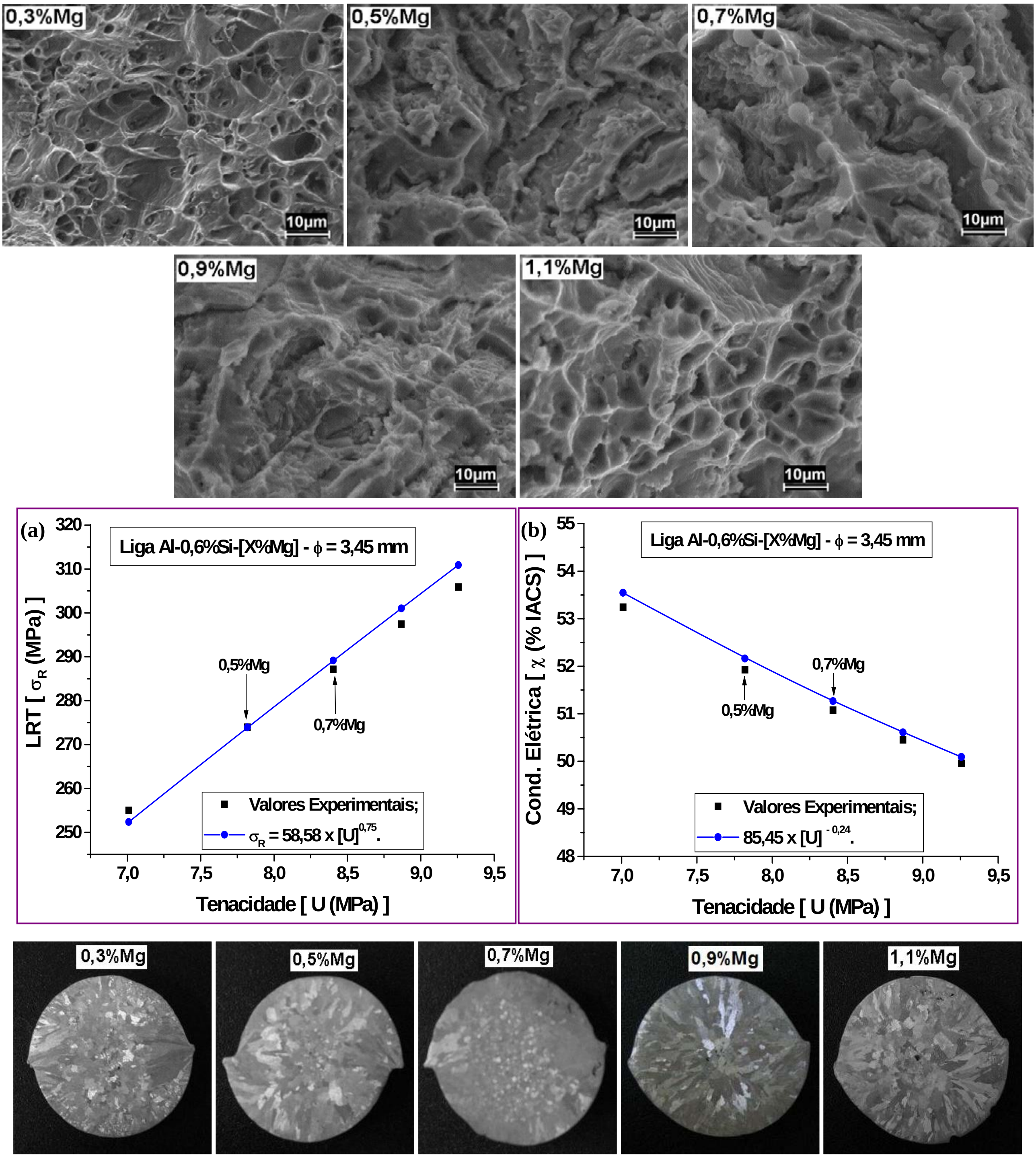


Figure 8 – LRT and Strength in relation to Mg content.

The figures 8 (a) and 8 (b) show the LRT and electrical conductivity values in function to toughness, respectively. These results are associated to macro and micro structures obtained. It observe that, when the Toughness Module increases the LRT values increases too, these results are associated to loss of electrical conductivity in % IACS (International Annealed Copper Standard). The values of Mg contents that show better associated of properties (Mechanic and Electric Properties), by these results are 0.5% and 0.7%.

Other observation is relation to macro structure which shows equiaxial and smaller columnar grains to contents until 0,7% Mg, from this content, the grains increase becoming columnar.

On Figure 8, it can be observed that the fractures show transgranular aspect with dimples perfectly defined.

4. CONCLUSION

The results of mechanical properties (LRT, elongation and toughness) on 6000 series alloy show that, the 0.5% and 0.7% Mg contents as the most promising contents to added on Al-0.6%Si binary alloy. These results indicate a better performance to power transmission and distribution, because it show the grain aspect combined to the Elongation, Toughness and LRT values, in accord with NBR 5285 standard.

5. ACKNOWLEDGEMENTS

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