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ANALYSIS OF THE INFLUENCE OF Zr ON EC ALUMINUM USED IN TRANSMISSION LINES AND ELECTRICAL ENERGY DISTRIBUTION

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Abstract. *This work objectives developing an analysis of Zr influence in important characteristics for application as transmission and distribution conductor of electrical energy in Al-EC, targeting thermal resistance properties through tensile tests and electrical conductivity. The alloys were obtained by direct casting from Al-EC varying different contents of Zr. The solidification was done in a "U" shaped mold and then cold-rolled to 4 mm in a MENAC electrical rolling mill of circular cross-section of different diameters to be after drawn in [3.6, 3.18 and 2.89] mm diameters, generating wires that will be used in all tests. In the step of characterization the alloys were submitted to mechanical tests with KRATOS machine and electrical tests with a MEGABRAS kelvin bridge MPK-2000 model. The characterization of wires sample of each alloy comparing with thermal resistance followed the COPEL ("Paranaense Company of Energy") exigency being submitted to 230ºC temperature for an hour and the heat treatment was done in a NEVONE oven, NV-1.3 model. The stress verified values of specimens with and without heat treatment tend to grow with the amount of solute added. The IACS values suggest a minimum variation with the growth of Zr content, and with the application of heat treatment these values goes down. The produced alloys shown a good performance in several realized tests, generating encouraging prospects to its application, since the requirements for the thermal resistance analyzed were achieved.*

Keywords*: heat-resistant, electrical conductivity, tensile test, aluminium alloy.*

1. INTRODUCTION

The Industrial Revolution has brought for the industrials a preoccupation with production and productivity of goods and services, which is closely linked to qualified products. A necessity with the quality brought to the scientists of Science and of Material Engineering a preoccupation with performance in service. In another call attention, in this time, was referred to quality and performance, happened during the Second World War, when vessels of fuel transport, of the allied troops, berthed in ports have eventually fractured. This last fact brought a preoccupation of the studious with internal structure of the materials and how to control the materials to show the desired behavior in project, without prejudice.

The modern man organizes more in large urban complexes with crescent energetic appetite. Produce and transport this energy to the consumers is an important task and strategic imprint for social progress and human industrial.

Aluminum occupies the third position in abundance on Earth crust and is one of its main constituents and is inclusively the eighth more abundant element in the planet. This peculiarity associated to its excellent primary characteristics as low density and high electrical and thermal conductivity, puts it in an utilization index on metallurgical industry only worse than steel. In despite, as all pure metal, needs addition of alloy elements to improve its mechanical characteristics.

Major applications of zinc are: nuclear reactors, lamps for photographic flash, alloys with niobium forming magnetic superconductors, in glasses and ceramics, on chemical industry where corrosive agents are applied, vacuum tubes and constituent agents of metallic alloys, but besides the applications in engineering, Zr found space on jewelry industry as semiprecious gem on silicate form as much as oxide and also exists the artificial zirconium which is cubic structure unlike the natural, which is monoclinic, known by being the most perfect imitation of diamond obtained.

In vanguard of alloys for transmission and distribution are the heat-resistant alloys (TAL) which has a major application in countries with tropical climate, for example Brazil, where the wires reach higher operation temperatures. Al with addition of small quantities of Zr, tends to form alloys with heat-resistant characteristics.

A heat-resistance alloy is one that supports higher operation temperatures without deteriorating its mechanical properties, consequently will have an increase on ampacity of the cable, whereas supporting higher temperature can support a larger JOULE effect and the project suffer significant increase on reliability, because the wire will have a higher capacity to support variations of electric current by demand peak or undesired atmospheric phenomenon as electric discharge.

A heat-resistant conductor can transport until 50% more energy than CAA (Aluminum Cable with Steel Core) traditional cables, ideal for recapacitation of overloaded wires utilizing the existent infra-structure as well as attending the environmental security in relation to elapsing risks of the electromagnetic field effects and increase on operational security conditions, the recapacitation of a wire can be done with partial shutdown of only one of the circuits, not occasioning interruption on energy supply (Domingues, 2005).

The heat-resistant cables appear as an alternative for that ambient question and difficulties for constitution of new passage bands and obtaining licenses for these work, because it can recuperate the wire with the same infra-structure. Reconduction that will not have problems on stability and drop of tension may be more efficient and economic whether applied the heat-resistant cable (Júnior, 1999).

The application of TAL alloy in tropical climates is perfectly adaptable, since the values of cable elongation can be amplified to compensate the bend increase in high temperature of project, without loss on reliability of the wire. An increase on transmission capacity, proportioned by utilizing the TAL alloy, is economically viable, once the conditions and restrictions of project are attended, are utilized the same structures and bend of Al-1350 cable. The total cost of TAL cable is 10% higher however the increase in loading by 60% justifies its application (Nascimento, 1999).

The expectancy of electrical companies and of Ministry of Mines and Energy is that 100% Al cables will earn space of cables with steel core as well as the Al substituted the Cu due the advance in alloy development of ever stronger alloys with higher transmission capacity than the traditional cables as well as not possess a constituent of deterioration faster, which is the steel. The Brazilian production of Al cables has grew a lot last year and the perspectives are encouraging, this reality has manifested in Para state with the production expansion of factories linked to the sector.

Encouraged by this regional context, in this work we will develop a study based on Al-1350 alloy that is basically Al pure, which will be modified with different content of Zr and constant Fe on search for an alloy with heat-resistant characteristics, involving laboratory analyzes fundamental to characterize important properties to the conductors of transmission and distribution as tension (Stress), elongation, electrical conductivity (%IACS) and heat treatment.

2. MATERIALS AND METHODS

The alloys were obtained by direct melting in Sub-Laboratory of Metallography and Heat Treatment of UFPa from Al-EC (electro conductor aluminum or Al-1350). The five alloys were identified as A(0.0238)%; B(0.0251)%; C(0.0289)%; D(0.0345)% and E(0.038)% of Zr. The content of iron was maintained as advised by specialized literature (0.25%) in all alloys.

A digital balance with 0.01g precision, band saw, bars of Electro conductor Al and Al-10%Zr pre-alloy were utilized on development of the desired alloys, on quantity and needed sizes and the furnace which were executed all the operations of melting.

The alloys were melted initially in 850°C temperature to reach 750°C on pouring moment, with injection of Argon to eliminate impurity and Hydrogen gas.

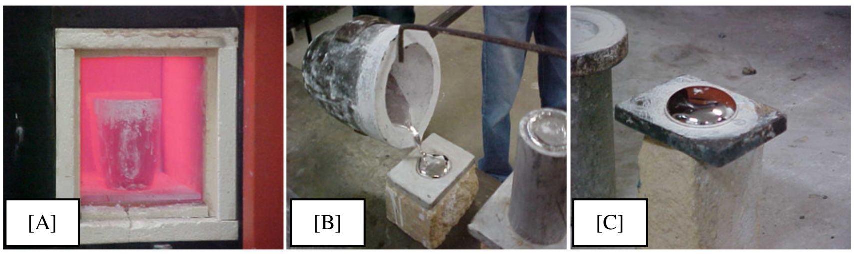


Figure 1. Photos illustrating a crucible in the oven; the collection of samples for chemical analysis and sample collected.

On Fig. 1 can be seen the crucible in the oven, which ruby-red coloration is a temperature indicative around 850°C, then comes the pouring to obtain the sample for chemical analysis and the sample itself.

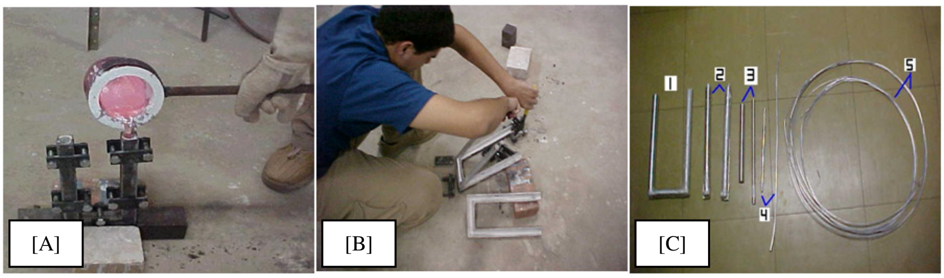


Figure 2. Operational sequence for obtaining the "U" profile.

The "U" profiles obtained as illustrated on Fig. 2, after that, were dismolded and passed for operations sequence of shape change until the wire with the final diameter wanted: 1- Casted, 2- "Legs" of casted, 3- Machined "legs" (Ø=11mm), 4- Rolled (Ø=4mm) test specimen (Ts), 5- Drawn Ts.

The "U" profiles are initially disassembled in its "legs", with 250mm length to be machined for 22mm diameter to 11mm diameter and cold-rolled until 4mm in a MENAC rolling mill with circular section of different diameters (which 4mm is the lowest value) to being drawn (3.6; 3.18 e 2.89)mm (Linnet norm for cables of Aluminum alloy), generating wires that will be utilized in all tests. The machining process was executed in a laboratory of machine tools of CEFET-PA, the rolling process on sub laboratory of metallography and heat treatment of UFPa and the drawing in drawing machines of an associated company.

Some cast profiles shown defects on superior extremity deriving from contraction during the solidification process. These regions were removed with a manual saw frame and the rod, without defects were detached in base for being machined. The removed imperfects extremities were identified and conducted to metallography of the cross section.

The macrograph realized in cross section of the cast was realized with Pouton reagent (12ml-HCl concentrated, 6ml-HNO_3 concentrated, 1ml-HF 48%, 1ml-H_2O distilled) (Aluminium Handbook, 1993).

2.1. Characterization

The experimental results of mechanical and electrical characterization were plotted on graphs in the form of points, and made a fit (power function) for analysis of behavior of these points.

2.1.1. Workability

The material, when submitted to a shape change, by machining or cold-worked plastic deformation, is being submitted to a previous macroscopic evaluation, by naked eye, of the superficial integrity of the profile that will be constructed step by step. The utilized rolling mill, which can be seen the detail of the rolling cylinder with different cross sections is shown on Fig. 3, permitted to obtain the wire in 4mm diameter and then was realized the drawing process with Ø=3.6mm, 3.18mm and 2.89mm final steps. Figure 4 illustrates the drawing frame and accessories that were realized the step of this work.

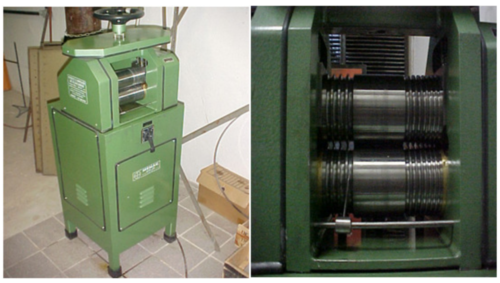


Figure 3. Electrical rolling mill utilized.

Figure 4. Drawing frame, diamond wire gage utilized (Ø=3.6mm 3.18mm e 2.89mm) and the drawing moment.

2.1.2. Electrical

Step of characterization which obtained alloys were submitted to evaluate the electrical conductivity and/or electrical resistivity by the aid of MEGABRÁS kelvin bridge model MPK-2000, illustrated on Fig. 5.

Figure 5. Photos of a component set of Kelvin bridge utilized.

2.1.3. Thermal

Characterization of the wire samples of each alloy relating with Heat-resistant followed the COPEL (Paranaense Company of Energy) suggestion, which the alloys for being framed as Heat-resistant its stress do not have to vary more than 10% when submitted to 230°C temperature by an hour.

2.1.4. Mechanical

In this characterization step of the obtained profiles, in wire shape with desired diameters and after the step of electrical characterization, were submitted to a tensile test according to the norm for electrical cables. The tensile tests generate data which permit characterizing the profiles according to stress; the elongation and toughness were realized in a mechanical tension test machine with KRATOS brand and model IKCL1-USB, illustrated on Fig. 6, coupled to a micro computer with data acquisition system which facilitates the collection of the information. The tensile tests were executed with repetitiveness of [03] three samples for each produced alloy.

Figure 6. KRATOS, model IKCL1-USB and data acquisition system.

These steps of analysis of stress, elongation and electrical conductivity described above were integrally repeated after a 1.5 year period for the first four alloys, due to the 5th alloy have not produced sufficient Ts, allowing to investigate the susceptibility of the produced alloys to natural aging and its effect on heat-resistant test.

3. RESULTS AND DISCUSSIONS

The values of stress found in produced alloys were near to Al-1350 and shown a clear growth on stress due the increasing of Zr content on samples without heat treatment as much as heat treated and after the natural aging of 1.5 year. In the samples where occurred unexpected decreases of stress were probably caused by an internal defect occurred during the confection of Ts, more probably on solidification process.

The loss on stress occasioned by heat treatment occurs due the sensible stress relief deriving from fabrication process of Ts, which generates a great level of mechanical hardening with rolling and drawing processes. This fall is an expected phenomenon and was within the expectation for a heat-resistant alloy, because this one was in 8% order. This treatment was designed based on a test suggested by COPEL, which the heat-resistant aluminum alloys were not show an higher variation than 10% on values of tensile test when submitted to 230ºC temperature for an hour, working as heat-resistant test utilized in this work.

The checked heat-resistant to Al by insertion of Zr should be caused by a special capacity of this element of "breaking" the movement of the discordances and disfavoring the annealing and a possible recrystallization of the structure, increasing the start temperature of these processes, checking an higher reliability to projects of transmission lines and distribution manufactured in this material.

On Tab. 1 are related the experimental values of stress and Elongation obtained, with and without heat-resistant test.

The obtained results and plotted on graphs of Fig. 7 alloy to evaluate the stress behavior and alloy Elongation, before and after heat-resistant test, without 1.5 year natural aging.

On Tab. 2 are related the experimental values of stress and of Elongation obtained, with and without heat-resistant test, with 1.5 year natural aging.

The obtained results and plotted on graphs of Fig. 8 alloy to evaluate the stress behavior and alloy Elongation, before and after heat-resistant test, with natural aging.

Table 1. Stress and elongation of the alloys without heat-resistant test (WTR) and with heat-resistant test (WR), without aging in relation to Zr content.

% Zr	A[0.0238]	B[0.0251]	C[0.0289]	D[0.0345]	E[0.038]
MPa WTR	146.37	152.25	154.40	148.40	156.41
MPa WR	135.73	139.28	135.85	141.42	141.84
ΔMPa	< 10%	< 10%	> 10%	< 10%	<10%
Elong WTR	2.68	2.96	2.95	2.76	3.14
Elong WR	2.42	2.57	2.34	2.38	2.8
Δ%	9.7%	13%	17%	13%	10%

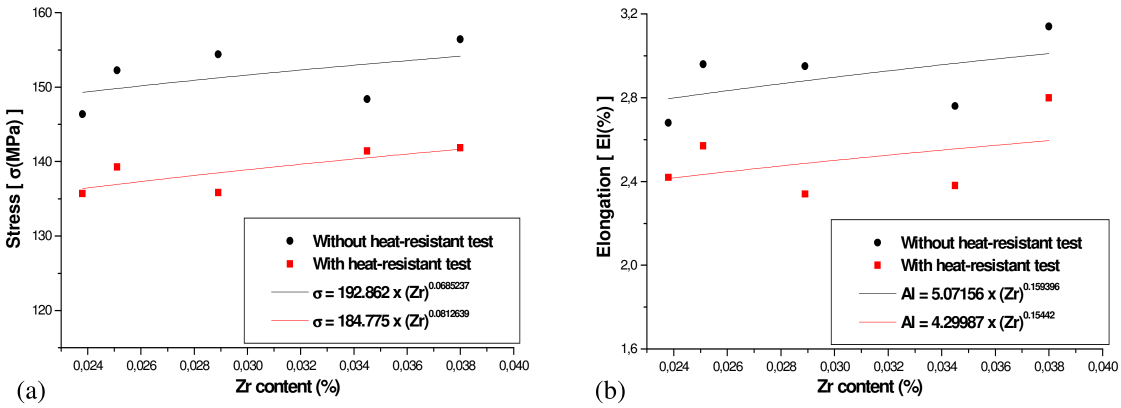
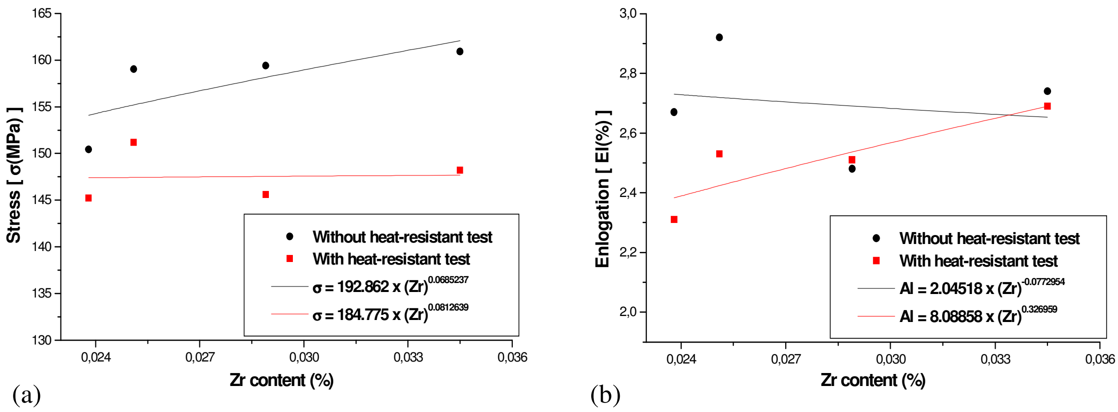


Figure 7. Comparison of results of (a) stress and (b) elongation without and with heat-resistant test, without natural aging.

Table 2. Stress and elongation of the alloys with and without heat-resistant test in relation to Zr content after 1.5 year of natural aging.

% Zr	A[0.0238]	B[0.0251]	C[0.0289]	D[0.0345]
[MPa] WTR	150.43	159.03	159.4	160.9
[MPa] WR	145.2	151.18	145.58	148.19
ΔMPa	< 10%	< 10%	<10%	< 10%
Elong [%] WTR	2.67	2.92	2.48	2.74
Elong [%] WR	2.31	2.53	2.51	2.69
Δ%	13%	13%	0%	2%



(a) (b)

Figure 8. Comparison of results of (a) stress and (b) elongation without and with heat-resistant test, with natural aging of 1.5 year.

The first providence to be done is verifying the reception of COPEL suggestions to be considered heat-resistant should present stress values, before and after the permanence to 230°C for 1h, which differ itself until 10%. A superior difference than 10% observed to stress values for “C” alloy (0.0289%Zr) can be attributed to an execution error, probably in solidification. By this way, these values do not disable the evidence that stress increases with the development of Zr content in these alloys.

The obtained results of stress for submitted alloys to temperature and time effect are inside of the suggested by the norm, being permitted a variation for more or less around the obtained values without temperature and time effect. Thus, all can be considered heat-resistant.

The plotted values show a tendency to growth on stress relating the increase of Zr content in the alloys, for the submitted alloys to the heat-resistant test as much as for those that were not submitted to the test. This performance was expected according to already executed preliminary studies by GPEMAT (Engineering Materials Group Research) in different contents (0.02% e 0.03% Zr).

Small additions of zirconium are realized to increase the resistance of the aluminum alloys worked to control the structures of the grains and inhibition of recrystallization. The zirconium has low solubility, therefore form, before the start of homogenization, precipitated in form of L1 Al3Zr particles. These particles are resistant to decomposition and growth of grains and can control the structure of the grains and sub-grains during the operation, in hot rolling as much as the dissolution on heat treatment (Robson, 2001).

The 1.5 year natural aging brings a discreet increase on stress for its alloys, suggesting a probably formation of a precipitate that result to harden the material. The aged alloys, when submitted to heat-resistant test, shown lower loss on stress than the not-aged, staying around 6%.

The elongation values found for different Zr content remained stable and around 2.83% without heat treatment and 2.42% in treated alloys, showing stability through heat treatment in function of Zr and proximity to elongation of the Al 1350. After 1.5 year, the alloys did not show significant change in the elongation values as well as its answer to the heat-resistant test, presenting good neutrality.

As illustrated on Fig. 7(b) and Fig. 8(b), ductile aspect is present in all alloys and for different conditions of treatment and aging, which agree with elongation found on the tests. Elongation values found in the tests of “C” and “D” aged alloys, without treatment shown an unexpected behavior. It is supposed that some discontinuity of the structure was present in these test specimens, resulting in large distance in the expected values, but not too distant.

It is important to inform that addition of Cu, Mg and Zn accelerate the precipitation kinetic of Al3Zr compared with Al-Zr binary alloy. Changes in magnesium concentrations provoke a great effect on precipitation (Robson, 2001). Thus contaminant elements present on Al utilized to manufacture the TAL alloy need to be treated with attention. The study of other elements present on Al appears as a new frontier to be studied.

On electrical conductivity tests a minimum variation of conductivity through an increase of Zr content was perceived, on heat treated alloys as much as on not-treated alloys. Due to the higher presence of solute atoms which tends to difficult the passage of the electrons trough the decrease of its medium free way (Van Vlack, 1984). The values of conductivity measured in the alloys remained were very close (around 60.2 IACS). Knowing that Al-1350 cables with steel core must have conductivity of 60.6 IACS (NBR 7272/1988) at least, the produced alloys in this work presented very nearly.

Table 3. Electrical conductivity (IACS) of the alloys without and with heat-resistant test, without aging.

% Zr	A[0.0238]	B[0.0251]	C[0.0289]	D[0.0345]	E[0.038]
% IACS WTR	60.28	60.22	59.8	59.8	60.77
% IACS WR	60.63	59.82	60.26	59.76	60.77

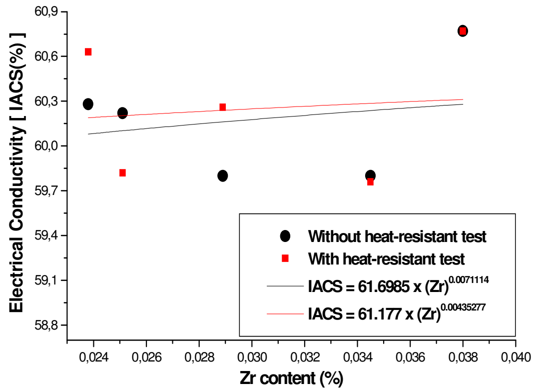


Figure 9. Comparison of IACS results without and with heat-resistant test, without aging.

Table 4. Electrical conductivity (IACS) of the alloys without and with heat-resistant test, with 1.5 year natural aging.

% Zr	A[0.0238]	B[0.0251]	C[0.0289]	D[0.0345]
% IACS WTR	61.69	60.76	60.44	60.16
% IACS WR	61.69	60.76	60.44	60.16

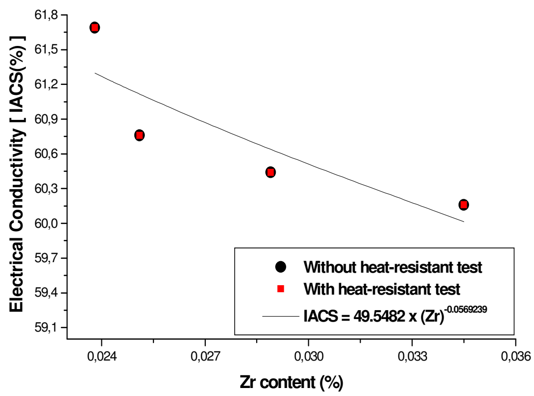


Figure 10. Results of IACS without and with heat-resistant test, with 1.5 year natural aging.

4. CONCLUSIONS

The effect of temperature and time appears to reflect on stress values to accommodate the internal structure, alleviating the internal stresses derived from deformation steps that were submitted to the samples. Even thus, the results indicate that the crescent content of Zr tends to elevate stress of these alloys, which presents acceptable values for application in cables.

Temperature and time effect have not appeared to be felt, with respect to precipitation, since the test under 230°C temperature aims only to inquire the relation of affinity or mobility between Aluminum and Zirconium and its consequences, which provoke possible precipitation tax. The time utilized in test seems to be an indicative that the precipitation test is relatively slow in this system.

The values found in electrical conductivity test suggest a minimum variation on conductivity through increase on Zr content to the studied band, besides maintaining with acceptable values for electrical application. By this way, has an indication that the system did not show a structural change, being with heat-resistant test or natural aging.

The produced alloys shown a good performance in various tests realized, generating encouraging perspectives for its application, due the requisite for heat-resistant analyzed were reached.

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