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INFLUENCE OF SECUNDARY AGEING ON MECHANICAL PROPERTIES OF AN AA7050 ALUMINUM ALLOY

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Abstract: *Aluminum alloys have been the primary material of choice for aircraft industry since 1930. This is due to the high values of strength and low weight. For aircraft structures are used Aluminum, Zinc, Copper and Magnesium alloys, with greater strength, fatigue and corrosion resistances. The particles of η' phase precipitation are responsible to the strength, toughness and fatigue resistance improvement. In this paper, a two-step ageing heat treatment was performed to promote the η' phase precipitation. The condition choose was T614-65, with treatment temperatures of 130ºC and 65ºC. These temperatures were chosen to promote GP zones formation during the first step and then transformation from GP zones to η' particles in the second step. Studies shows that longer ageing heat treatments at lower temperatures results on stronger mechanical properties. The objectives of this paper are to understand and quantify the effects of the second step ageing on an AA7050 Aluminum Alloy. The condition T614-65 was compared to single step ageing treatment T6, and industry produced T7451. Tensile tests were performed to source mainly mechanical properties and structural features while differential calorimetry scanning (DSC) qualify the presence of η' particles.*

Keywords: *Aluminum AA7050, Ageing Heat treatment, DSC, Mechanical properties.*

1. INTRODUCTION

Aluminum alloys are widely applied in aircraft and automobile industries due to their high strength to density ratio. In special, alloys of 7xxx series are applied in the structure components of many commercial airships. Aluminum, zinc, magnesium and copper compose these alloys and their interaction results on a large range of second phase particles, which have great role on the alloy mechanical properties.

All these interactions are related to the thermal history of the alloy, and with the use of ageing heat treatments is possible to improve the mechanical properties of these alloys, inducing the nucleation and growth of second phase particles with high hardness, the most influential among these particles are the η' and η particles.

The sequence of precipitation of η particles are known as the sequence: [1-6]

Aluminum $\alpha \rightarrow \alpha(\text{SSSS}) \rightarrow \alpha + \text{GP}(1, 2)$ zones $\rightarrow \alpha + \eta' \rightarrow \alpha + \eta$.

The sequence starts with a super saturated solid solution (SSSS) formed during solution treatment of the alloy, and then are formed the Guinier Preston zones (GP), which can be two different kinds. GP (1) zones are coherent clusters of solid solution atoms on specific crystalline planes that exhibit generally spherical shape. GP (2) are very alike with GP (1), but are vacancy rich. Particles of second phase η' nucleate from GP zones. [5, 7, 11]

The maximum tensile properties of commercial 7xxx series alloys are associated with formation of a dense dispersion of particles of metastable phase η'. The equilibrium phase η forms by the transformation from the η' phase.

Second phase η, $MgZn_2$, forms hard particles with plates shape. Its crystalline structure is hexagonal with parameters a = 0,521nm and c = 0,860nm and incoherent with the Aluminum matrix. Metastable phase η' has hexagonal crystalline structure, with parameters a = 0,496nm and c = 0,702nm and is semi-coherent with the matrix. Both GP zones and η' are sheared by dislocations and the energy to shear η' is about twice that required to shear GP zones. Particles of phase η can show nine different orientation relationships with aluminum matrix termed – η_1 to η_9, as well several morphologies, the formation of these variants depends on the ageing temperature, time and conditions.

GP zones, η' and η can nucleate and grow in different temperatures, but their nucleation and growth are favored in key temperatures. GP (1) are favored from room temperature to 140ºC, GP (2) are favored above 70ºC. Upon heating, η' particles starts formation at 160ºC, and the stabilization starts at 230ºC. Appling this temperatures to heat treatments, is possible to control which phase will nucleate and growth, and controlling the time, how much these phases will nucleate and growth. [1 – 3]

Commercial 7xxx series alloys have maximum strength levels when aged to T6 temper, however this results in degradation of stress corrosion crack (SCC) resistance and crack growth resistance. The duplex ageing treatments, like

T7451 reduce the susceptibility to SCC, but also reduces the alloys' strength. Ageing heat treatments called 'interrupted ageing' shows great results in simulations for combined strength, fatigue and SCC resistance. In these treatments, an alloy is aged at elevated temperature for a short period and then aged in a reduced temperature, between 25 and 70ºC for a long period of time (T614). [3, 4, 9, 10].

According to BUHA, et. all, ageing treatments with lower temperatures for longer periods, as T614-65, can improve the usage of the solution atoms, optimizing the nucleation and growth of η' phase particles. The result is a fine dispersion of particles that interacts with the crack tip, delaying its propagation, improving the fatigue resistance.

The focus of this study was to propose an alternative ageing heat treatment, T614-65, for a 7050 aluminum alloy and evaluate their effects upon tensile mechanical properties and then compare to two traditional different ageing heat treatments, T6 and T7451.

2. EXPERIMENTAL PROCEDURES

For this work, the material used was a commercial aluminum alloy AA7050 in form of a 3 in. thick block received from EMBRAER- LIEBHERR with T7451 temper, the composition of the alloy is described in table 1. It was performed solution heat treated in two steps, quenched into water and then aged to T7451, T6 and T614-65 tempers as table 2. With increasing treatment time, Vickers hardness was measured with 1kgf load and 12 seconds, ten analysis per specimen as ASTM E 92 – 82 [12].

Table 1. Chemical composition from the AA7050 alloy.

	% Zn	%Mg	% Cu	% Zr	%Mn	% Ti	% Fe	% Cr	% Si
As	5,7	1,9	2,0	0,10	max.	max.	max.	max.	max.
Standard	6,7	2,6	2,6	0,16	0,009	0,06	0,15	0,006	0,12
Valued	6,06	1,90	2,19	0,15	0,10	0,06	0,14	0,04	0,12

Table 2. Description of ageing heat treatments

Ageing Heat treatment	*Solution treatment*	*First step*	*Second step*
T7451	10ºC/min to 485ºC 485ºC for 4h	110ºC for 2h	Ageing at 175ºC
T6		Ageing at 130ºC	None
T614-65		130ºC for 30min	Ageing at 65ºC

The specimens were studied with differential scanning calorimetry (DSC) in a Shimadzu DSC60 equipment, with a high purity aluminum plate as reference. The specimens had plate shape with a 20mg max and polishing finish. The heating rate was 10ºC/min. For measuring the mechanical properties, tensile tests were performed according to ASTM E8M-01 standard [13]. Tests were carried out at a Shimadzu AG-I equipment, at room temperature with speed of 0,5mm/min. There were three tensile specimens for each conditions as shown in table 2, measuring tensile properties were for both transversal (TD) and longitudinal directions (RD) from rolling. Figure 1 shows the geometry of the samples for Vickers hardness and tensile measures.

Table 3. Description of specimens groups for tensile tests

Specimens Group	*First Step*	*Second Step*
T7451	As received	As received
T6	130ºC for 2h	-
T614-65	130ºC for 30min	65ºC for 24h

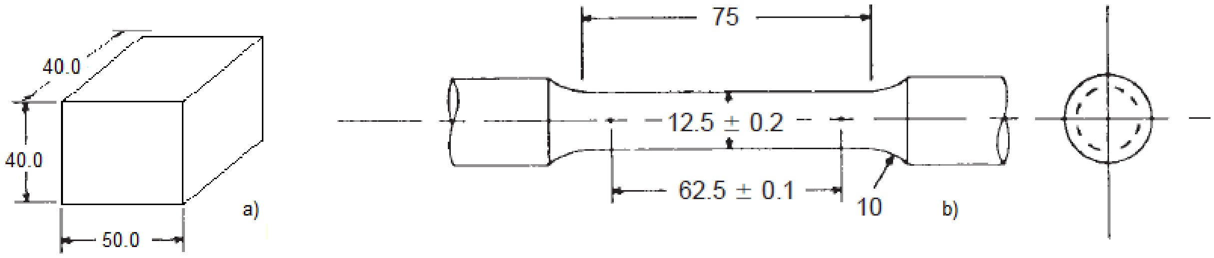

Figure 1. Geometry for the Vickers hardness (a) and tensile (b) specimens. Measurement in mm.

3. RESULTS AND DISCUSSION

3.1 Age hardening

Figure 2 shows the effects of heat treatment increasing time over the hardness of the T7451, T6 and T614-65 specimens.

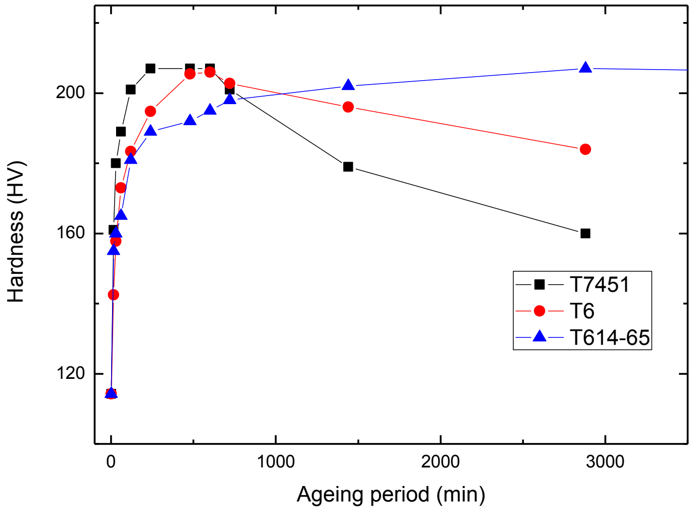

Figure 2. Profile hardness from the specimens of T6, T615-65 and T7451 tempers specimens.

It is possible to notice in Fig. 2 that the T7451 ageing treatment promotes the fastest hardness increase, reaching the maximum hardness within 120 minutes. For T614-65 ageing heat treatment, the peak of hardness occurs after long period but maintain for much longer, more than 160 hours. T6 ageing treatment shows an intermediary behavior.

3.2 DSC study and comparison between microstructures

Fig.3 shows the DSC scans of the specimens from table 2. The T614-65 curve show for two exothermic peak, one at ~230ºC and other at ~250ºC. Similar peaks are present at T6 curve, but less intense. T7451 curve does not show these peaks.

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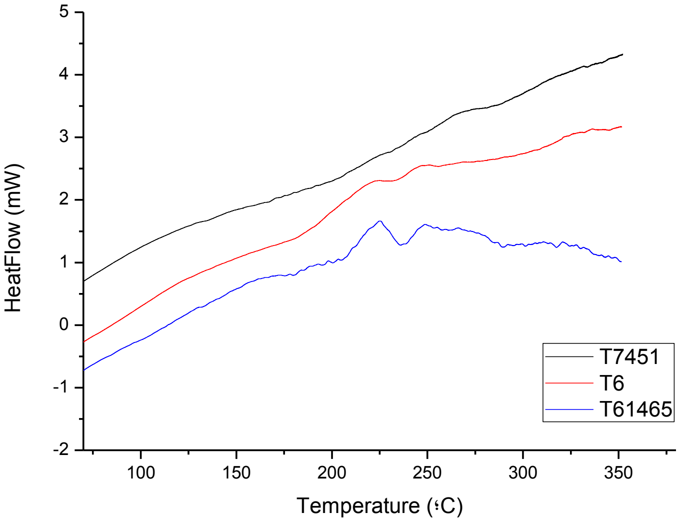

Figure 3. DSC scans for T6, T614-65 and T7451 tempers specimens. The curves had been offset for clarity.

According to BUHA et. all, the reaction responsible for the peak at 230ºC is the transformation of η' particles into η_1 and η_2 particles. Peak at 250ºC is due to reaction from the transformation of η' particles into block shaped clusters of η. The presence of these peaks indicate that the specimens with T6 and T614-65 tempers had particles from the metastable η' particles however T7451 samples doesn't shows these peaks, indicating that all η' has been transformed into η or the residual η' are not detected by the equipment.

Figures 4 and 5 show microstructures from T7451 and T614-65 specimens, comparing both is possible to observe that there are no great difference between the grain size and shape, indicating that the alloy doesn't shows signs of recrystallization even after solution and ageing heat treatments.

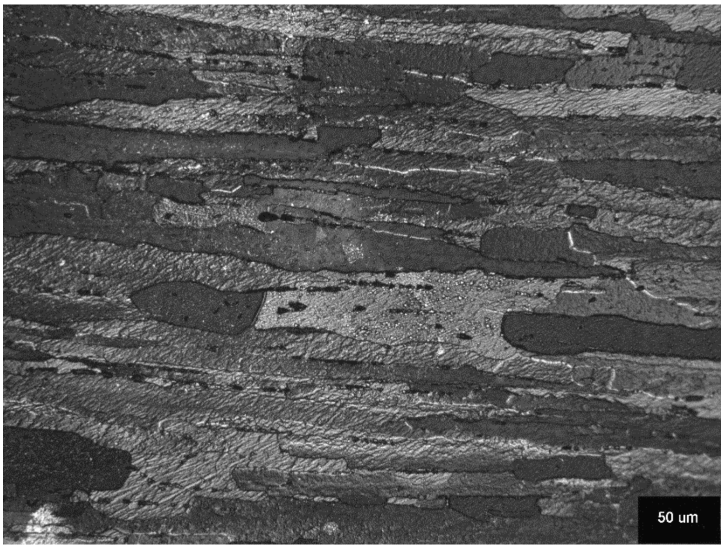

Figure 4. Microstructure from the T7451 specimen as received. Etching: Keller reagent.

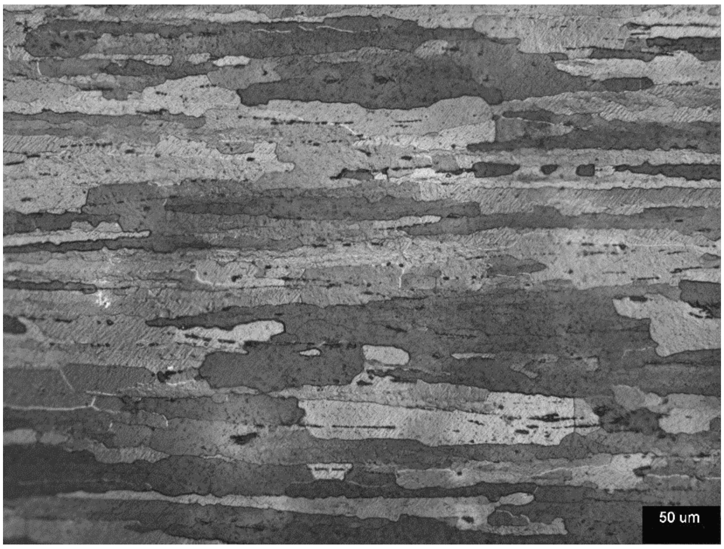

Figure 5. Microstructure from the T614-65 specimen. Etching: Keller reagent.

3.3 Tensile properties

Table 4 shows the tensile tests results for the three groups of specimens, from the rolling direction and transversal direction.

Table 4. Tensile properties from T7451, T6 and T614-65 specimens groups

Properties	*Yield strength RD, MPa*	*Yield strength TD, MPa*	*Tensile strength RD, MPa*	*Tensile strength TD, MPa*	*Ductility RD, % area reduction*	*Ductility TD, % area reduction*
T7451	490,0 ± 10,5	532,1 ± 5,0	588,6 ± 23,1	634,4 ± 5,3	4 ± 1%	3 ± 1%
T6	486,9 ± 11,7	444,0 ± 23,1	541,8 ± 24,1	596,1 ± 14,0	10 ± 4%	4 ± 4%
T614-65	433,4 ±12,9	439,2 ±9,8	538,8 ± 13,8	589,9 ±13,3	17 ± 2%	15 ± 2%

It can be seen in table 4, as expected, strength at rolling direction is lower than in transversal direction, result of anisotropy. Strength resultant of T7451 temper is higher if compared to others conditions. Whereas T6 strengths are superior to duplex temper T614-65. Even they shown similar harness levels.

However, in relation to ductility behavior among three conditions has opposite tendency. It is possible to notice in Table 2 comparing T7451 with T614-65 temper that occurs the reduction of almost 10% in UTS. This can be attributed to the modification on the η' particles size, with lower temperature ageing, the nucleation process can be more effective than growth, resulting in a higher density with reduced size when compared to the T7454 condition.

Figures 6, 7 and 8 show the tensile tests results from T7451, T6 and T614-65 specimens, one from rolling direction and one from transversal direction.

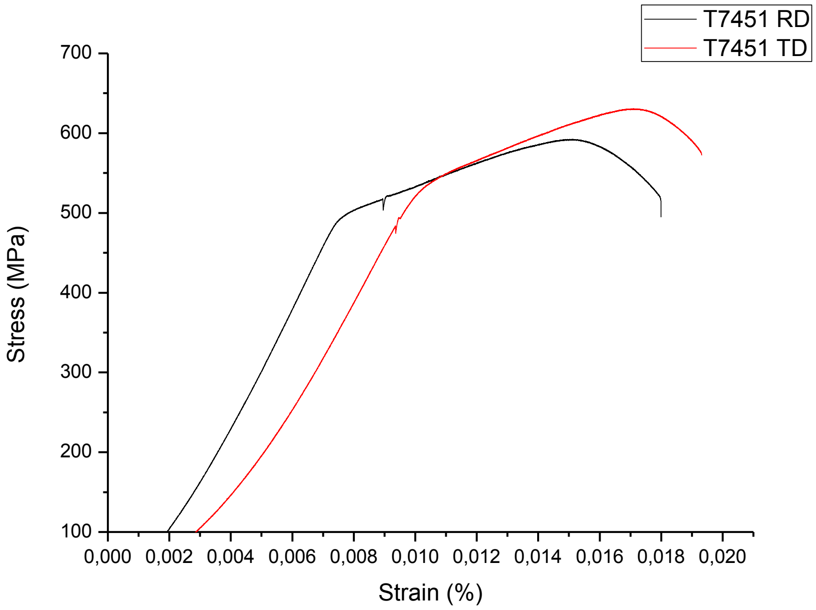

Figure 6. Tensile tests results from T7451 specimens, rolling and transversal directions.

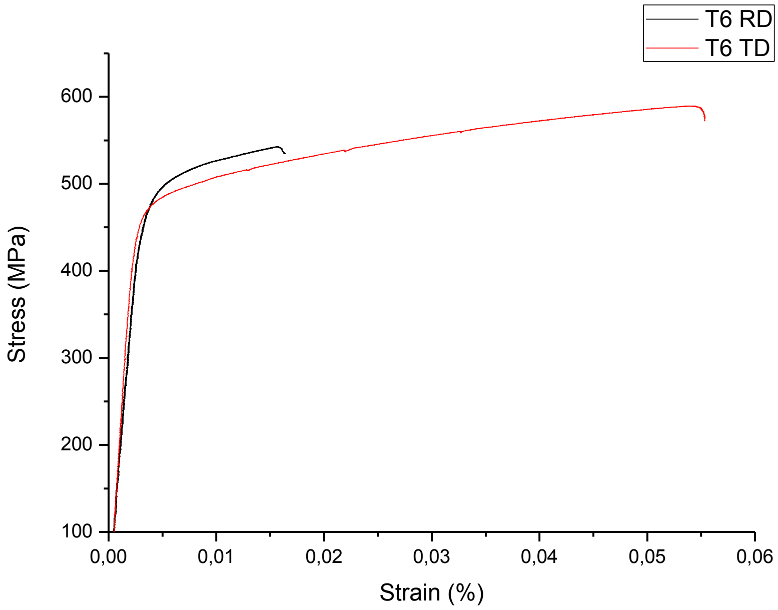

Figure 7. Tensile tests results from T6 specimens, rolling and transversal directions.

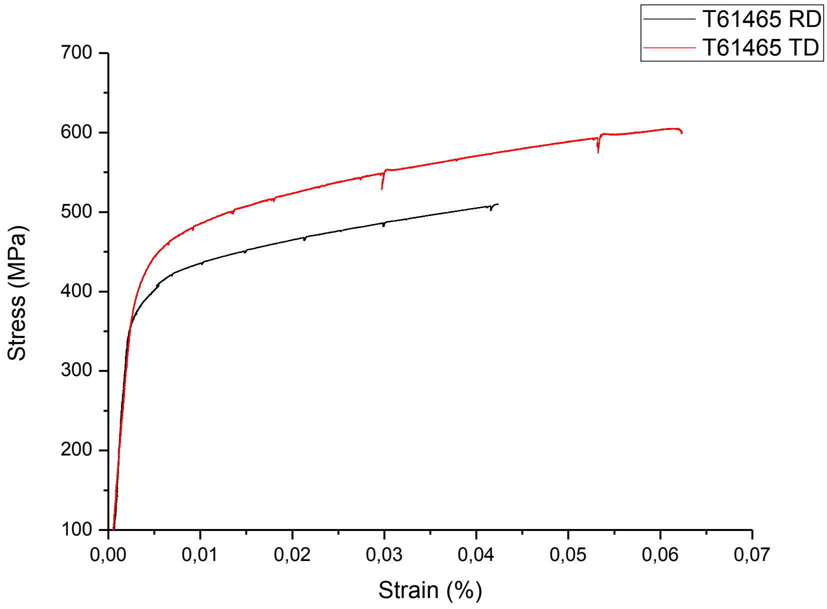

Figure 8. Tensile tests results from T614-65 specimens, rolling and transversal directions.

4. CONCLUSIONS

1. Ageing heat treatment T614-65 is effective in nucleating η' particles and this results in some improvements on the mechanical properties of the alloy.

2. Comparing the properties resulting from T614-65 and T7451 tempers is possible to achieve the same levels for Vickers hardness but the difference of 12% upon ultimate tensile strength but the increase up to almost three times upon elongation.

3. DSC results indicate that η' particles are present in specimens with T6 and T614-65 tempers meanwhile these particles cannot be detected in T7451 temper with this analysis.

4. The changes on mechanical properties are related to effects of the heat treatment, for no cold work was applied and the grain size and distribution was not greatly affected by the heat treatments.

5. Four reactions were observed through DSC scans, GP (1) zones formation (~70ºC), transformation from η' to η phase (~230 and 250ºC) and possibly T phase formation (~255ºC).

Next step for this work is to measure the ageing treatments effect on fatigue properties of the alloy.

5. ACKNOWLEDGEMENTS

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