MULTIPLE QUENCHING SOLID SOLUTION INFLUENCE ON THE MECHANICAL AND STRUCTURAL CHARACTERISTICS OF 7175 ALUMINUM ALLOY SHEETS

Ion-Daniel DIȚOIU [1], Brândușa GHIBAN [2 *], Laura Nicoleta NEDELOIU [3], Alexandru STREZA [4.]

This paper presents the results of industrial testing conducted on 7175 type aluminum alloy. The study focused on how the application of multiple solution heat treatments influences the potential improvement of mechanical properties. Test specimens in the form of plates with thicknesses of 15mm and 100mm were used. Successive applications of one to five solution heat treatments were performed, and tensile strength, yield strength, and elongation at break were determined. Structural characterization highlighted the phase composition of the alloy and determined the grain size. Fractographic analysis of the tensile specimens revealed the main features of the alloy's fracture behavior for the selected thicknesses. The conclusion is that the application of multiple solution heat treatments does not substantially influence the mechanical properties, with a single heat treatment being sufficient

Keywords: aluminum alloy, solid solution quenching, stereomacroscopy, mechanical characteristics (fracture strength, yield strength, elongation)

1. Introduction

A massive wave of novel materials has emerged as a result of the advancement of contemporary technologies, particularly in the automotive, medical, and aerospace industries [1–5]. In-depth research on new high-strength aluminum alloys has drawn the attention of numerous nations and organizations. These alloys are anticipated to replace conventional materials by minimizing material weight while preserving mechanical stability, corrosion resistance, and surface characteristics of the entire structure [6–11]. Because of their exceptional performance, aluminum alloys from the 7XXX family have undergone and are still undergoing significant development [12–15]. According to statistics, high-

[1] PhD student, Department of Metallic Materials Science and Physical Metallurgy, NUST POLITEHNICA Bucharest, Romania, ion_daniel.ditoiu@stud.sim.upb.ro,
[2] Professor, Department of Metallic Materials Science and Physical Metallurgy, NUST POLITEHNICA Bucharest, Romania, corresponding author, brandusa.ghiban@upb.ro
[3] PhD student, Department of Metallic Materials Science and Physical Metallurgy, NUST POLITEHNICA Bucharest, Romania, laura.nedeloiu@stud.sim.upb.ro
[4] PhD Eng., Department of Metallic Materials Science and Physical Metallurgy, NUST POLITEHNICA Bucharest, Romania, alexandru.streza@upb.ro

performance alloys from both the 2XXX and 7XXX series are still mainly used in over 70% of aircraft structural materials. As the main components of high-strength and high-toughness aluminum alloys, 7XXX series alloys have high specific strength, high specific rigidity, high toughness, excellent machining and welding performance. They are widely used in the manufacture of aircraft chassis, spars and spars as load-bearing components and have become one of the most important structural materials in this field [16-18]. The purpose of heat treatment for 7XXX series aluminum alloys is to optimize the three microstructure parameters of matrix precipitates (MPt), grain boundary precipitates (GBP) and precipitate-free zone (PFZ), so that the alloys have good comprehensive properties. The heat treatment process of 7XXX series aluminum alloys mainly includes homogenization/solution annealing, quenching solid solution and aging. Like other types of aluminum alloys, 7XXX series alloys are used in both cast and deformed states after applying specific heat treatments. Thick aluminum and aluminum alloy plates are obtained by hot plastic deformation, which can significantly increase mechanical properties.

7175 aluminum is a specialized, high-purity version of the widely used 7075 alloy, offering superior fracture toughness and fatigue resistance for critical aerospace applications. It is primarily engineered for premium forging, featuring lower iron and silicon impurities, which creates a more refined microstructure and higher-strength structural components compared to standard 7075. In flat products made of 7175 aluminum alloys obtained by hot plastic deformation and structural hardening to the T7351 condition, the material characteristics are obtained through specific heat treatments, namely solution hardening, quenching and artificial aging.

Solution hardening and quenching was carried out in ALRO with 2 OTrO JUNKER Furnaces and aging in the Seco Warwick Furnace, these equiptments being qualified for obtaining special products. In the heat treatment of solution hardening and aging the most important parameters are the holding temperature in the bearing and the holding period, the temperature of the cooling water and the flow rates of the water pumps that provide the quenching agent. In aging, the holding temperature and time are also very important. Quenching is a critical heat treatment step for 7175 aluminum alloys—typically used in aerospace forgings - to achieve high strength and superior stress corrosion cracking resistance. It involves rapidly cooling the alloy from the solution heat treatment temperature to "lock" alloying elements (Zn, Mg, Cu) in a metastable supersaturated solid solution, preventing premature, coarse precipitation that reduces mechanical properties

Transformations take place both during the process stages and in the intervals between operations in the technological process of producing flat items from aluminum alloys. Because of this, specific technological requirements are set that limit the delay between specific phases of the manufacturing cycle, in addition to the parameters with which the actual activities are carried out. The maximum allowable interval between quenching and controlled stretching for stress reduction, which is set at two hours, is one of the most crucial requirements. In practice, various situations may arise in which the period between quenching and stretching is exceeded and the plates can no longer be stretched. The particular standards offer technological solutions, such as repeating the solution hardening heat treatment, for unique circumstances when the interval between quenching and stretching is surpassed. From the perspective of mechanical properties, this approach clearly has an impact on the final product's features, therefore circumstances where repeating solution hardening is required should be avoided as much as possible owing to the accumulation of additional expenses.This paper aims to highlight the influence of applying multiple quenching solid solution on hot-deformed sheets made of 7175 aluminum alloy, which constitute the top of the range in the aerospace product portfolio, products recently qualified with partners with a tradition in this highly technical field.

2. Research material and methodology

The 7175 aluminum alloy samples come from ALRO Slatina, having the average chemical compositions over time of chemical elements indicated in Table 1.

Table 1

Chemical composition of alloy 7175 from the investigations of this work

Standard	limits	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Ni**	**Zn**	**Ti**	**Others**	
											Each	**Al**
AIMS 03-02-008; EN 573-3	min.			1,2		2,1	0,18		5,1			rest
	max.	0,15	0,20	2,0	0,10	2,9	0,28	-	6,1	0,10	0,05	
Internal (operating limits)	min.			1,3		2,4	0,18		5,6			rest
	max.	0,08	0,14	1,7	0,03	2,8	0,22	0,03	6,0	0,05	0,05	
	target	0,06	0,12	1,6		2,5	0,19		5,8			

Microstructural analysis of 15 mm and 100 mm thick specimens, after applying a single solution quenching, was performed on a BX53M optical microscope, Stream Essentials 2.1 image analysis system, and the grain size was in accordance with ASTM E3-11, ASTM E 407-23, ASTM E 112-24, PO-043, PO-042, PO-044, using 0.5% HF, Barker reagent.

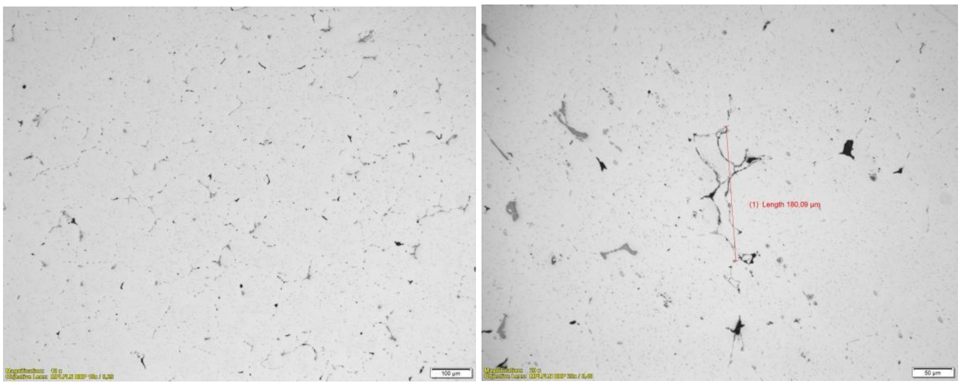
To highlight the influence of applying multiple hardening on the mechanical characteristics of aerospace aluminum plates, alloy 7175 was selected, whose chemical composition is shown in Table 1. From alloy 7175, 2 products were selected, represented by the thickness limits of the aerospace product portfolio, namely rolled plates with G = 15mm and 100mm, taken in the LT direction, blank, longitudinal specimens, which were subjected to repeated heat treatments of solution hardening (from one to five) at 470°/ 2 hours and aging at 108°/8 hours + 169/ 16 hours, corresponding to the T7351 condition.

To verify the condition of the surfaces subjected to tests to determine mechanical characteristics, fractographic aspects were evaluated, through analysis on the OLYMPUS SZX stereomicroscope, equipped with QuickMicroPhoto 2.2 image processing software.

3. Experimental results and their interpretation

3.1 Microstructural analysis

The microstructural analysis of representative specimens of alloy 7175 is shown in the images in Fig. 1, Fig. 2 and Fig. 3. Regardless of the thickness of the specimens, the microstructure of the alloy is similar, consisting of solid solution α based on Cu, Zn and Mg in aluminum and the main intermetallic compounds of the $Al_{12}Mg_2Cu$ and $MgZn_2$ type with uniform distribution.



a b

Fig. 1. Microstructural appearance of 7175 aluminum alloy specimens, 15mm thick:
a- x100; b- x200

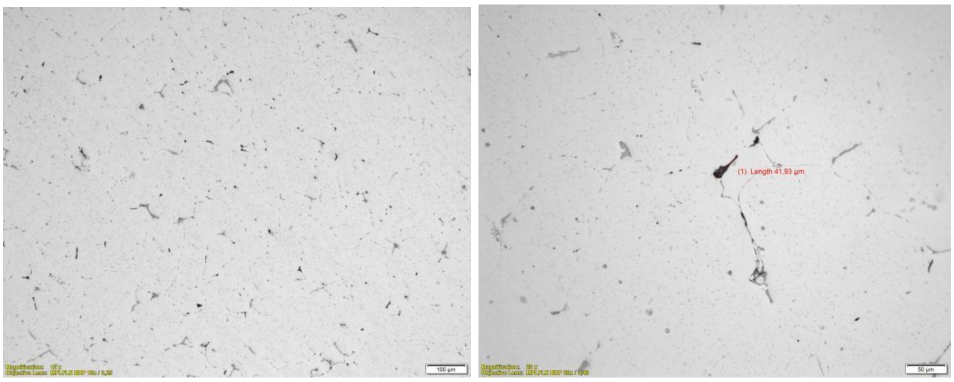


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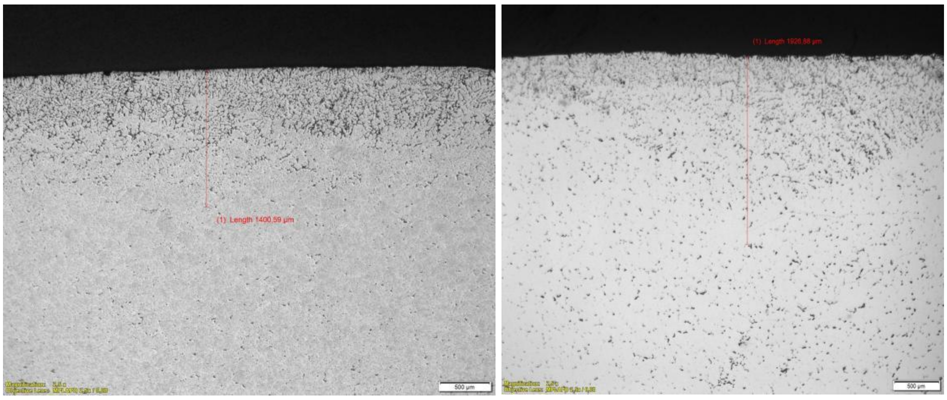
Fig. 2. Microstructural appearance of 7175 aluminum alloy specimens, 100mm thick: a- x100; b- x200



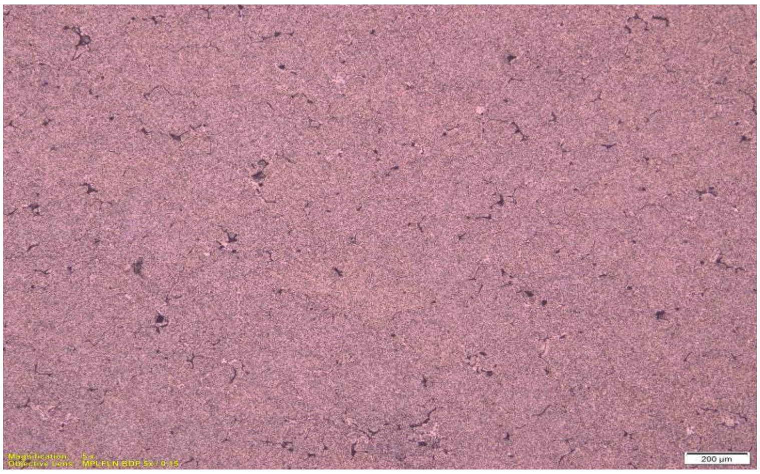
a b

Fig. 3. Microstructural appearance of 7175 aluminum alloy specimens, thickness 15mm (a) and 100mm (b) in the central area

In the microstructurally analysed samples from 15mm thick specimens (Fig. 1a), pores and oxide film with a size of 180.09 µm were identified µm (Fig. 1b). The maximum pore size in the quarter zone was 36.05 µm. In the microstructurally analysed samples from the 100mm thick specimens (Fig. 2a), pores were identified, and the maximum pore size in the middle zone was 41.93µm (Fig. 2b). The maximum size of the central zone for 15 mm thick samples is 1400.59 µm (Fig. 3a) and, respectively, 1926.88 µm (Fig. 3b) for 100 mm thick samples.

3.2. Determination of average grain size

The determination of the average grain size was performed on the samples from the middle areas of the slab sample, after electrolytic attack. The statistical analysis of the grain size values for the 15 mm thick specimens is shown in Fig. 4b, and for the 100 mm thick samples in Fig. 5b.



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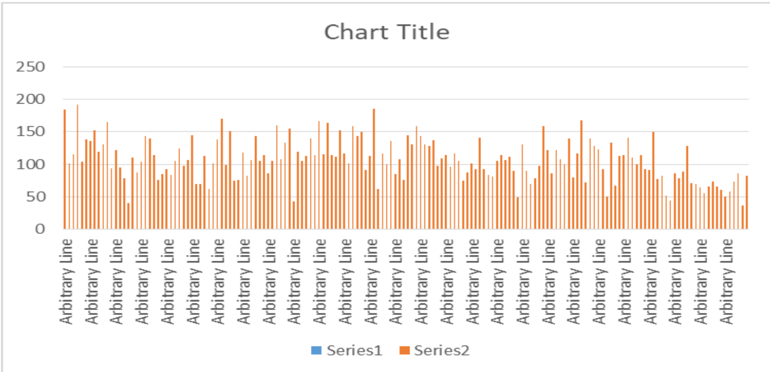
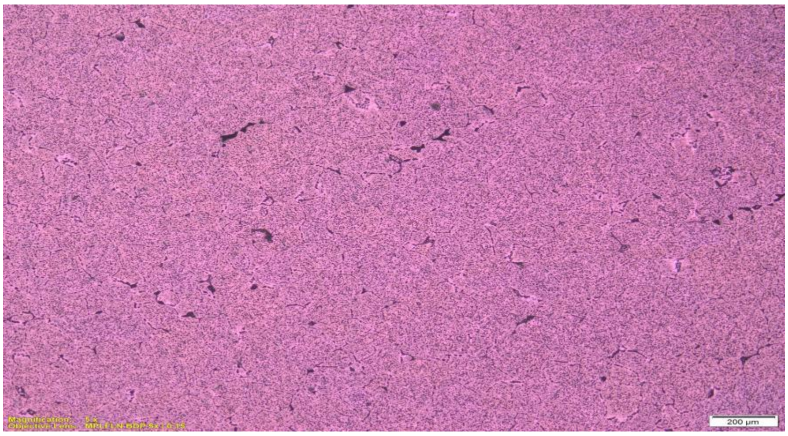


b

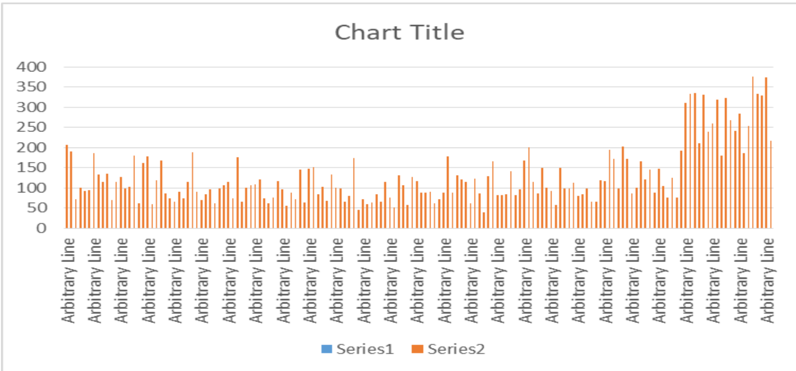
Minimum	36.248 µm
Maximum	192.658 µm
Mean	106.806 µm
Std dev	32.176 µm
Object count	162

Fig. 4. Determination of the grain size of 15mm thick 7175 alloy specimens:
a- captured image; b- statistical analysis

Statistical analysis of grain size values indicates that at a thickness of 15mm the average grain size is 106.81 µm (class 3.5, ASTM E 112) (Fig. 4.a), and at a thickness of 100mm the average grain size is 129.44 µm (class 3.0, ASTM E 112) (Fig. 5.b)



a



Minimum	38.431µm
Maximum	377.006µm
Mean	129.441µm
Std Dev	72.953µm
Object count	158

b

Fig. 5. Determination of the grain size of 100mm thick 7175 alloy specimens:
a- captured image; b- statistical analysis

3.3. Determination of mechanical characteristics

The results obtained from mechanical tests on specimens taken from the 2 batches of plates, without quenching and with multiple quenching's, are highlighted in Table 2 and graphically represented in comparison by number of solution quenching's in Fig. 6. The analysis of the values in Table 2, but especially the evolution of these mechanical characteristics shown in Fig. 6, expresses very clearly the fact that only the first solution hardening influences the increase in mechanical properties, when repeating the operation several times, no transformations of the previous structure occur that affect the mechanical characteristics.

Table 2

Values of mechanical characteristics of sheets of different thicknesses of 7175 aluminum alloy after applying multiple quenching solid solution heat treatment

Plate thickness	Quenching solid solution + aging number	Mechanical characteristics					
		Fracture strength		Yield strength, MPa		Elongation at break,	
		Average value, MPa	Standard deviation, %	Average value, MPa	Standard deviation, %	Average value, %	Standard deviation, %
15 mm	0	249	±7.15	153	±6.25	19.5	±0.25
	1	466	±8.65	389	±7.15	12.5	±0.45
	2	518	±6.95	450	±9.45	12.0	±0.35
	3	512	±9.28	440	±7.13	14.0	±0.52
	4	512	±8.13	444	±8.17	12.0	±0.15
	5	526	±9.14	460	±6.18	12.5	±0.55
100 mm	0	259	±6.17	141	±7.19	21.5	±0.25
	1	455	±6.19	371	±9.16	12.5	±0.45
	2	521	±7.15	445	±6.14	11.5	±0.35
	3	510	±8.16	432	±7.13	12.0	±0.52
	4	515	±7.13	438	±8.15	12.0	±0.15
	5	523	±9.12	451	±9.11	11.5	±0.55

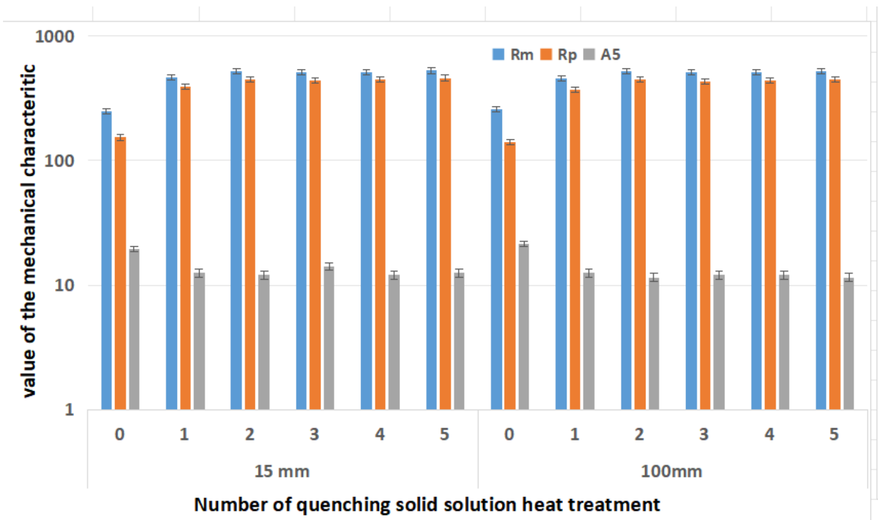


Fig. 6. Evolution of fracture strength, yield strength and elongation after applying multiple quenching solid solution of sheets with different thicknesses from 7175 aluminum alloy (15mm and 100mm)

3.4 Fractographic analysis of tensile specimens

Fractographic analysis provides valuable information on the condition of the fracture surfaces, the nature and morphology of the fracture, the propagation direction of the fracture front, and finally on the type of fracture: ductile-brittle-mixed.

The fracture surfaces were analyzed after the application of a single solution hardening, based on the observation that the subsequent application of solution hardening treatments did not substantially modify either the behavior or the final values of the mechanical characteristics.

The fractographic aspects of the fracture surfaces, in cross-section for 15 mm thick specimens, are shown in Fig. 6, and the fractographic aspects for 100 mm thick specimens are shown in Fig. 7.

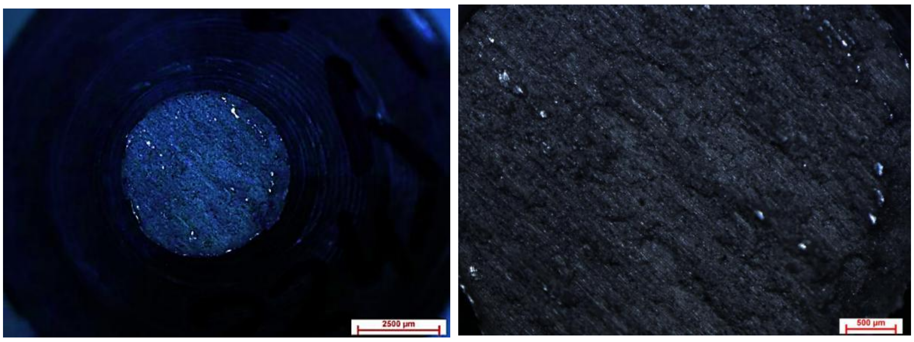


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Fig. 6. Macrostructural appearance of 15mm thick tensile specimens, in cross section, at different magnifications: a- x10; b- x30

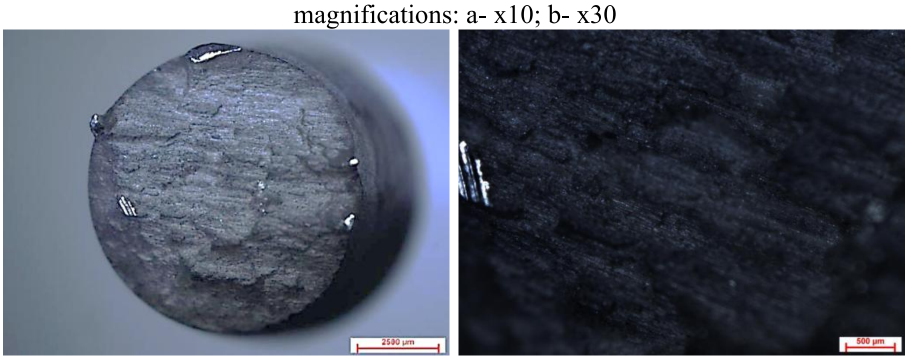

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Fig. 7. Macrostructural appearance of 100mm thick tensile specimens, in cross section, at different magnifications: a- x10; b- x30

In the 15mm thick specimens, at a magnification of 10 hours (Fig.6a), a rough surface with parallel wrinkles was observed. When increasing the magnification power to 30 hours (Fig.6b) the parallel wrinkles were identified with fine grooves, fringed by secondary cracks on the bottom of the groove. The white, shiny particles are non-metallic compounds and alloys. Similar aspects were also identified on the fracture surfaces of the 100mm thick specimens, Fig. 7, with the mention that the parallel grooves are deeper and the presence of secondary cracks is more pronounced. These fractographs are representative of products plastically deformed at high temperatures and subsequently subjected to quenching solid solution. They are very different from the fracture surfaces of products that have been merely homogenized, where ductile fractures occur, with the formation of a cone-cup pair [17,18].

4. Conclusions

This paper analyzes how the application of multiple solution hardening influences the mechanical behavior of 7175 aluminum alloy sheets, for AERO applications. In special industrial situations, where it is considered that the optimal parameters of the mechanical characteristics have not been obtained, repeated solution hardening heat treatments can be applied. The analysis of the microstructural characteristics and mechanical characteristics of the specimens after the application of multiple quenching solid solution heat treatment led to the following conclusions:

Regardless of the number of quenching solid solution, after applying the quenching solid solution heat treatments on both types of sheets with thicknesses of 15 mm and 100 mm, a uniform distribution of phases was evident, without the presence of non-metallic inclusions.

In the 100 mm thick samples, pores were identified in the quarter and middle areas and an oxide film with a size of 180.09µm. The maximum pore size in the quarter zone was 36.48µm, and the maximum pore size in the middle zone was 41.93µm.

The grain sizes were statistically measured, which were 106.81µm (class 3.5, ASTM E 112) for 15mm sheet metal and the average grain size is 129.44µm (class 3.0, ASTM E 112) for 100mm sheet.

The analysis of the degree of influence of multiple quenching solid solution applied to 7175 aluminum alloy plates for AERO purposes on the mechanical properties resulted in that only the first hardening causes a certain increase in mechanical properties, when repeating the operation several times, no transformations of the previous structure occur that affect the mechanical characteristics.

The stereomacrostructural fractographic analysis revealed the presence of parallel grooves, with numerous secondary cracks on the bottom of the grooves in the single quenched solid solution specimens, regardless of the thickness of the plates investigated, respectively 15mm or 100. The hardening particles appear white, located at the top of the grooves. The fractographic aspects are representative of the hot-deformed and quenching solid solutioned products, being differentiated from those of the only homogenized products, in which the formation of the con-cup pair corresponding to ductile fracture is observed.

Aknowledgement

The authors acknowledge the ALRO Slatina for granting access to its company and laboratories.

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