Investigation on some factors affecting crack formation in high resistance aluminum alloys

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ABSTRACT. Aluminum alloys having good mechanical properties are Al-Zn-Mg alloys (7xxx) and Al-Cu-Li alloys (Weldalite®). These alloys may be subjected to stress corrosion cracking. In order to overcome this problem the Al 7050 alloy has been developed and it is widely used for aerospace applications. Despite that, some components made of this alloy cracked during the manufacturing process including machining and chemical anodization. In a previous work cracked Al 7050 components have been analyzed in order to identify possible causes of crack formation. In this work the susceptibility of this alloy to intergranular corrosion has been analysed and compared with that of other high resistance aluminum alloys.

KEYWORDS. Aluminum alloys; Al 7050; Fracture; Intergranular corrosion.

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INTRODUCTION

Al 7XXX alloys find useful applications in the field of aerospace engineering due to their attractive properties, such as low density, high strength, toughness and resistance to fatigue [1, 2]. Despite that Al–Zn–Mg–Cu alloys can be subjected to local corrosion, like inter-granular corrosion (IGC), and stress corrosion cracking (SCC) [3]. Many studies have been carried out in order to study the effect of the alloy microstructure on the material strength [4]. Mg and Cu form precipitates after solution heat treatment and aging. The strengthening effects of these precipitates depend on their size, spacing and distribution. In these alloys strength can be further increased by means of solid solution strengthening and work hardening.

In Al 7050 and 7055 alloys Cr, Zr and Mn that have low solubility in the aluminum matrix, form intermetallic compounds. They are dispersoids that pin grain boundaries and avoid grain growth during heat treatments.

Considering that the low corrosion resistance of many alloys limit their application, many efforts have been done to improve it. In the studies reported in the literature, two mechanisms have been proposed: anodic dissolution and hydrogen embrittlement [5]. Several studies highlighted that over-aging treatments could significantly reduce the corrosion susceptibility, but this determines a reduction of about 10-15% of the alloy strength [7]. Because of that, a retrogression and re-ageing (RRA) treatment was studied with the aim of obtaining both high strength and good corrosion resistance [8,

9]. RRA consists of performing on the alloy in the T6 temper a two-stage thermal treatment: re-ageing follows a retrogression carried out at high temperature.
More recently a non-isothermal ageing (NIA) has been developed with the aim of improving mechanical properties. The variations of mechanical properties and corrosion resistance during NIA were associated with the size, quantity and distribution of intra-grain and grain boundary precipitates [10, 11].
In a previous work [12] a cracked component made of an Al 7050 alloy was analyzed in order to identify possible causes of crack formation. The results highlighted that both the intermetallic phases and the associated microvoids, formed in the alloy during solidification and hot rolling process, probably determine crack formation during the material-removal processes. Considering that the studied Al 7050 component was subjected to anodization during the production process, it is interesting to highlight the susceptibility of this alloy to intergranular corrosion and to compare it with that of other high resistance alloys such as Al7075 T6, Al 7075 T7351 and Al 2195 T8 (Weldalite®).

EXPERIMENTAL

In this work four different high resistance aluminum alloys have been analyzed. These alloys differ by composition, heat treatment and manufacturing technique. The analysed specimens are described in Tab. 1. The heat treatments parameters are reported in Tab. 2.

	Alloy designation	Heat treatment	Components form	Alloy nominal composition
1	7050	T7451	Hot rolled plate mechanically machined	2.3 Cu - 2.3 Mg - 6.2 Zn - 0.12 Zr and Fe,Si<0.1%
2	2195	T8	Rolled plate	0.94Li-0.39Mg-4.1Cu-0.5Fe-0.02Ti-0.4Ag-0.13 Zr
3	7075	T6	Rolled Plate	1.6 Cu -2.5 Mg - 0.23 Cr - 5.6 Zn
4	7075	T7351	Hot ring rolled	1.6 Cu -2.5 Mg - 0.23 Cr - 5.6 Zn

Table 1: Compositions and heat treatments of the alloys studied in this work.

	Alloy designation	Temper	Heat treatment description	Temperature
1	7050	T7451	-solution treatment -Quenching -double aging treatment: first step second step	476 °C (max. quenching bath T 43 °C) 121 °C for 3-60 hours 161 °C for 24-30hours
2	2195	T8	-solution treatment -Quenching -artificial aging treatment:	460-490 °C 160 °C for 14 hours
3	7075	T6	-solution treatment -Quenching) -artificial aging treatment:	460-498 °C 121 °C for 24 hours
4	7075	T7351	-solution treatment -Quenching -double aging treatment: first step second step	460-498 °C (max. quenching bath T 43 °C) 107 °C for 3-60 hours 163 °C for 24-30hours

Table 2: Heat treatment description of the alloys studied in this work (ASTM B918 Standard Practice for Heat Treatment of Wrought Aluminum Alloys).

From each studied aluminum component, several specimens have been taken in order to fully characterize the metallographic structures of the material, to check the possible presence of microdefects, and to obtain specimens for the intergranular corrosion tests. Each aluminum component has been cut in order to get surfaces in the main metallurgical directions (longitudinal, short and long transverse). Specimens for both metallographic inspection and for intergranular corrosion tests have been ground to a mirror like surface using SiC papers up to 2400 mesh followed by 1 μm alumina. The specimens have been inspected by means of optical and electronic microscopes both before and after chemical etching. The Keller's reagent (water 95 ml, nitric acid 2.5 ml, hydrochloric acid 1.5 ml, hydrofluoric acid 1 ml) has been used in order to evaluate grain size and shape.

Intergranular corrosion tests have been carried out according to the ASTM G110 standard (standard practice for evaluating intergranular corrosion resistance of heat treatable aluminum alloys by immersion in sodium chloride+ hydrogen peroxide solution). The ground surfaces have been chemically polished by immersion at 95°C for 60 seconds in an acidic solution (water 94,5 ml, nitric acid 5 ml, hydrofluoric acid 0,5 ml) followed by immersion in concentrated nitric acid at room temperature for 60 seconds. The chemically polished surfaces have been rinsed with water and then observed by means of optical microscope before the corrosion test. This chemical treatment reveals the grain microstructure. Intergranular corrosion tests have been carried out by immersing for 6 hours the prepared specimens in a solution that contains sodium chloride and hydrogen peroxide (sodium chloride 5.7 g, hydrogen peroxide (30%vol) 1 ml, 100 ml of water). After the test the surfaces have been examined in order to identify the corrosion areas. Then from the attacked specimens one metallographic cross section has been prepared and observed both before and after chemical etching with the keller's reagent.

RESULTS

Microstructure characterization

Fig. 1 shows the optical micrographs of the four etched alloys. The 7050 T7451 alloy (Fig. 1a) is characterized by areas with coarse and elongated grains that coexist with recrystallized bands characterized by a homogeneous distribution of fine grains. 2195 T8 alloy (Fig. 1b) and 7075 T6 alloy (Fig. 1c) have coarse grains elongated in the rolling direction. The 7075 T7351 alloy is characterized by a microstructure quite similar to that of 7050 T7451 alloy: the main difference between the two alloys is that 7075 T7351 alloy elongated grains are smaller.

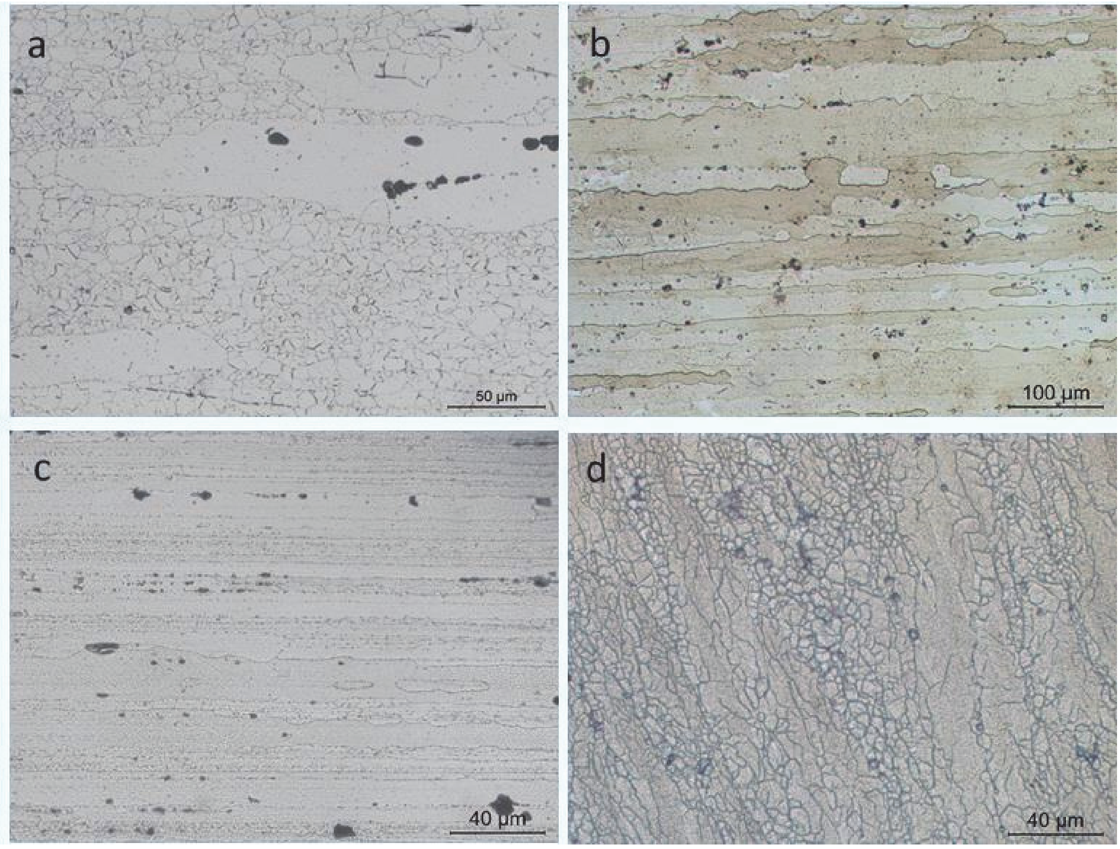

Figure 1: Optical micrograph of the four studied alloys: a) 7050 T7451 rolled and mechanically machined, b) rolled 2195 T8, c) rolled 7075 T6, d) 7075 T7351 hot ring rolled.

Figs. 2-5 show SEM micrographs of the studied alloys. SEM/EDS observation allows to study composition and distribution of secondary phases present in the alloy microstructures. The solubility of almost all elements in solid aluminum is very low. For this reason aluminum alloy microstructures are characterized by the presence of secondary phases (usually intermetallic compounds) dispersed in an aluminum matrix. Generally speaking secondary phases can be divided into three main groups:

- ✓ fine intermetallic compounds like $CuAl_2$, Mg_2Si etc. that are responsible for the heat treatment material hardening. They are finely dispersed in the aluminum grains and cannot be observed by means of SEM.
- ✓ fine dispersoids segregated at the grain boundaries, usually formed by elements added as grain refiners.
- ✓ coarse intermetallic particles that can be easily observed by SEM and analyzed by EDS. They are usually aligned along the deformation direction and they do not dissolve during heat treatment processes.

Fig. 2 shows the 7050 T7451 microstucture. It is characterized by a great quantity of coarse intermetallic compounds aligned along the rolling direction. In the area close to these particles microcavities and microcraks can be often observed. EDS analyses allowed to identify three different types of intermetallic compounds:

a) Al_2CuMg and $CuAl_2$ coarse rounded bright particles
b) Al_7Cu_2Fe elongated bright particles
c) Mg_2Si dark rounded particles

A fine dispersion of bright particles has been observed at the grain boundary. Microvoids and microcraks are usually found close to the b type particles.

Fig. 3 shows the 2195 T8 microstructures. This alloy has a higher quantity of intermetallic particles in comparison with the previous one. Also in this case secondary phases are aligned along the rolling direction. They consist of two different coarse particles identified by means of EDS:

a) Al_7Cu_2Fe compact bright particles
b) AL_2Cu fragmented bright particles.

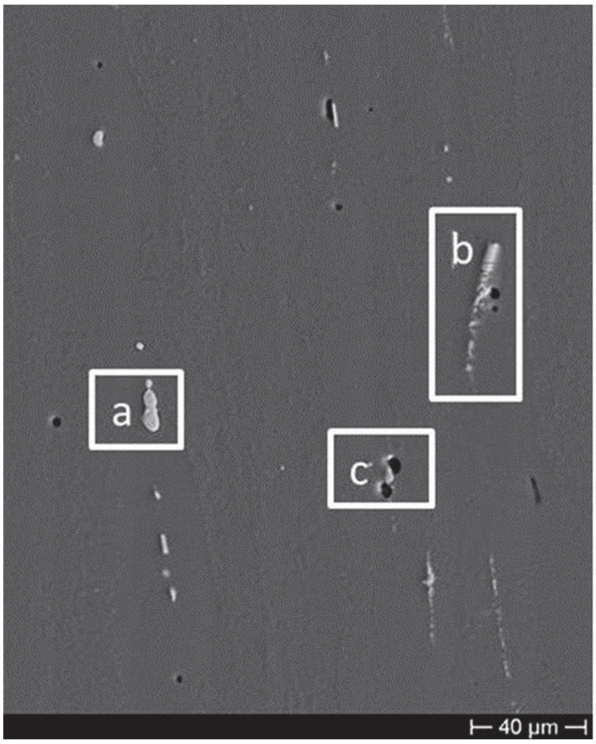

Figure 2: 7050 T7351, distribution of the secondary phases.

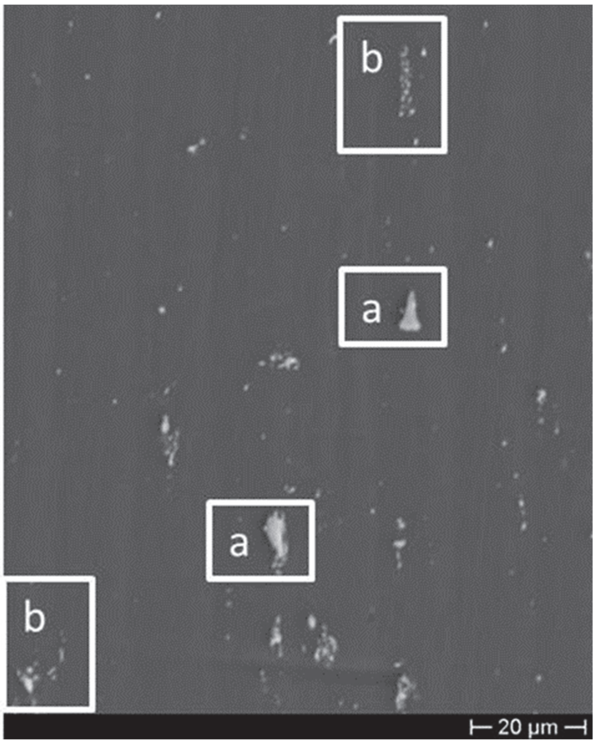

Figure 3: 2195 T8 distribution of the secondary phases.

Fig. 4 shows the 7075 T6 microstructure. A wide variety and quantity of coarse intermetallic phases has been identified:

a) Al_7Cu_2Fe bright and irregular intermetallic phases
b) gray irregular particles containing variable quantities of Al, Fe, Zn and Cu
c) Al_2Cu rounded bright intermetallic phases

d) rounded or elongated dark particles containing variable percentage of Al, Si and Zn
e) biphasic particles characterized by a gray phase that contains Al, Fe and Cu and by a dark phase that contains Al, Si and Zn.
Fig. 5 shows the 7075 T7451 microstructure. Like in the previous case, the base material is a 7075 alloy, but the 7075 T7451 alloy has been subjected to a different thermal treatment. SEM/EDS analyses highlighted that in the 7075 T7451 alloy, secondary phases are more homogeneously distributed in the matrix. Considering that heat treatments do not affect type and distribution of secondary phases, differences are due to the manufacturing process.

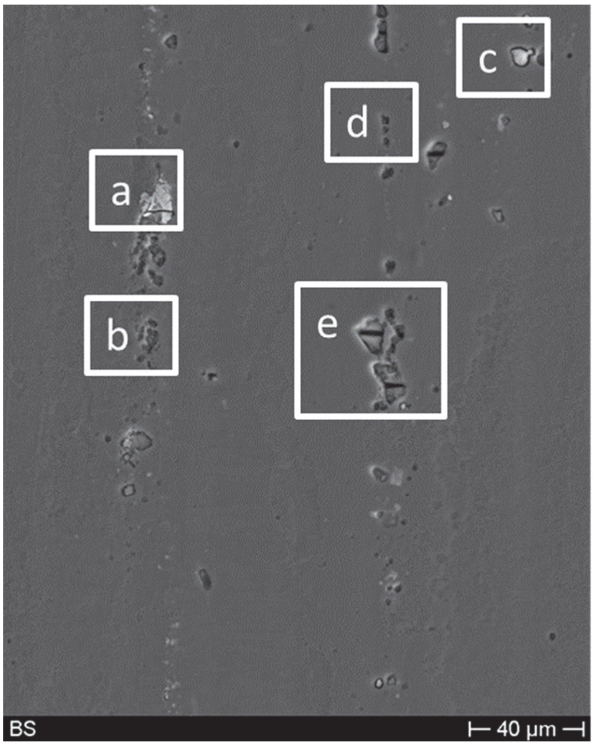

Figure 4: 7075 T6 distribution of the secondary phases.

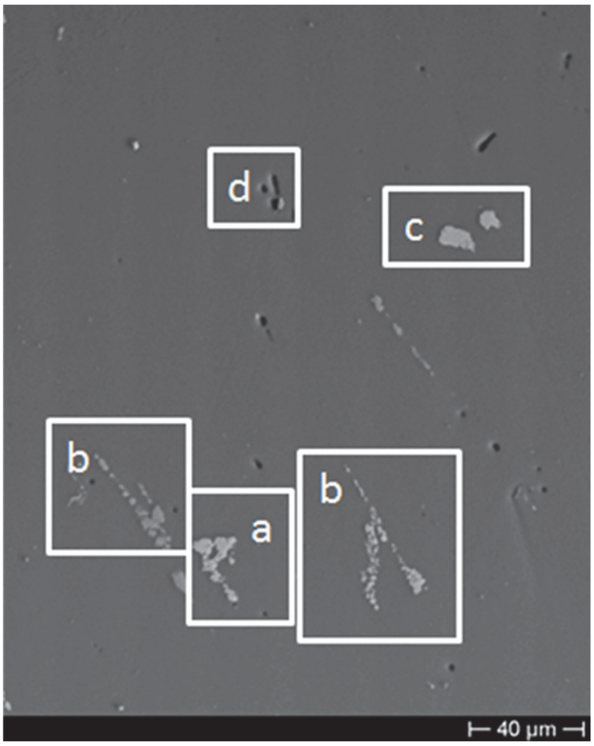

Figure 5: 7075 T7351 distribution of the secondary phases.

Intergranular corrosion test
A careful analysis of the specimens after the intergranular corrosion tests (ASTM G110 standard) highlighted that the different materials behave in different ways. The 7050 T7451 alloy shows only random pitting (Fig. 6). Fig. 7 shows the deep intergranular corrosion occurring in 2195 T8 alloy. Fig. 8 shows severe intergranular corrosion in 7075 T6 alloy: by comparing this corrosive attack with the previous one it can be seen that in this case there is a more diffused corrosion, but corrosion attack is less deep. 7075 T7351 alloy shows a scattered pitting corrosion.

DISCUSSION

The fracture of high resistance aluminum alloys can be due to different causes. A cracked component made of an Al 7050 alloy was analyzed in a previous research in order to identify possible causes of crack formation during the manufacturing process. This process was constituted by a material-removal operation followed by a chemical anodization treatment. For that reason it is interesting to highlight the susceptibility of this alloy to intergranular corrosion and to compare it with that of other high resistance alloys subjected to different production processes.
From a corrosion point of view it is important to evaluate grain size and distribution as well as distribution of second phases such as intermetallics, precipitates and dispersoids. It is well known in literature that dispersoids and precipitates are characterized by an electrochemical potential that is different from that of the bulk material and then they can be responsible for localized corrosion. Intergranular corrosion is affected also by grain size and distribution: corrosion activity may develop because of some heterogeneity in the grain boundary structure. The study of the specimens after

corrosion tests highlighted that severe intergranular corrosion develops mainly in the two alloys having a microstructure characterized by oriented and recrystallized grains (Figs. 1b and 1c) where the corrosion attack can develop faster along the recrystallized bands. The analysis of corrosion pits and cracks revealed only a limited influence of second phases on their formation.

The results confirmed that 7050 alloy is the less sensitive to intergranular corrosion and to stress corrosion cracking. This is due to the fact that this alloy is less prone to recrystallization and that its grains are not oriented. On the ground of these results it can be inferred that crack formed in the 7050 alloy are predominantly due to microvoids usually present close to second phases (Fig. 10). These voids, which are defects characterizing this alloy batch, determine stress intensification and can cause crack formation and propagation during the manufacturing process. This assumption is confirmed by the analyses of the fracture surfaces that highlighted the presence of pit having a particular morphology. These pits can form on fracture surfaces by means of acidic solution etching [13-15]: in the considered case they formed during anodization on the existing fracture surface. Usually the morphology of pits originated on fracture surfaces by an ad hoc etching give information about the fracture propagation plane. In our study pits are generated during anodization and do not have a well defined geometry (Fig. 11).

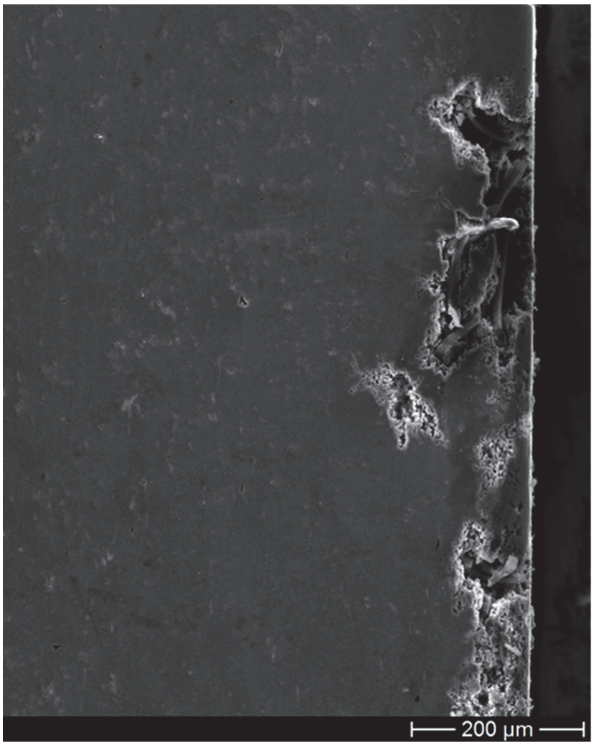

Figure 6: Random pitting in 7050 T7451 alloy.

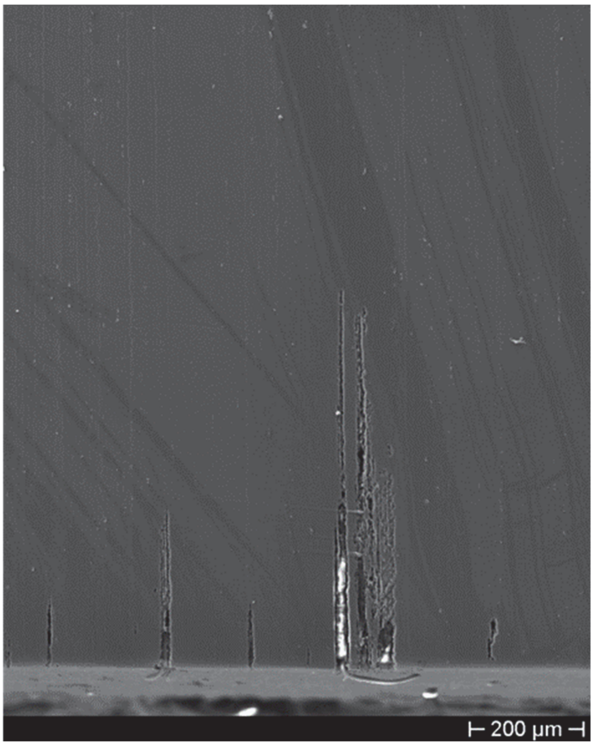

Figure 7: Deep intergranular corrosion in 2195 T8 alloy.

CONCLUSIONS

The study carried out in this research showed that:

✓ Al 7050 alloy has a low susceptibility to intergranular corrosion in comparison with Al 7075 T6 and 2195 T8 alloys.
✓ susceptibility to intergranular corrosion is affected by grain orientation and recrystallization due to shaping process and thermal treatment
✓ crack formation in Al 7050 alloy is predominantly due to the presence of several microvoids present close to the second phases. These microvoids initiate cracks that propagate during the material removal process
✓ chemical etching during anodization process seem to happen on the fracture surfaces already formed.

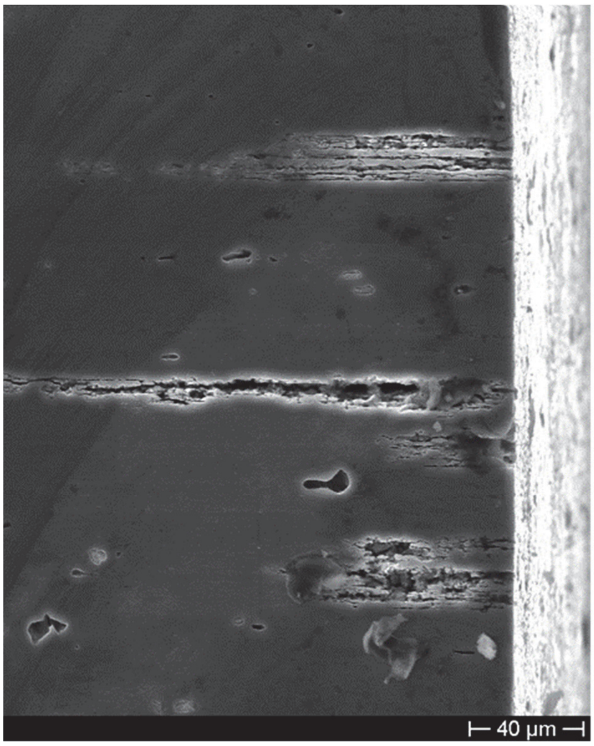

Figure 8: Severe intergranular corrosion in 7075 T6 alloy.

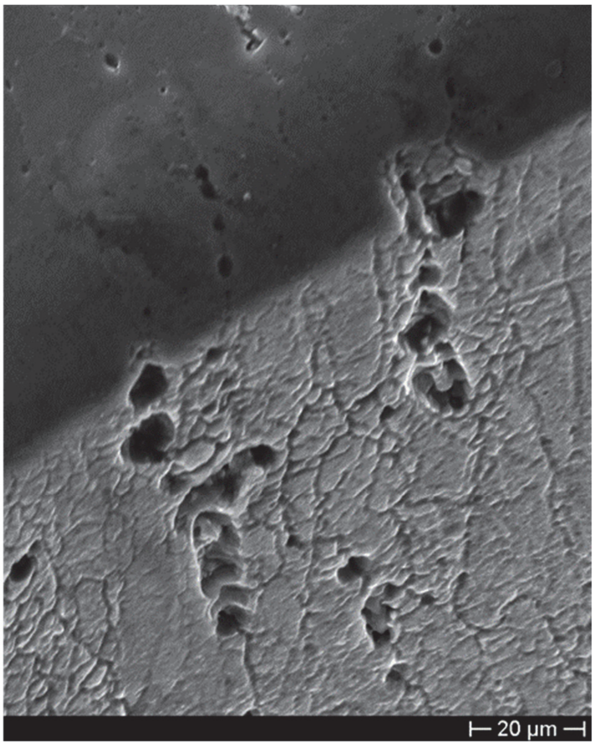

Figure 9: Scattered pitting corrosion in 7075 T7351 alloy.

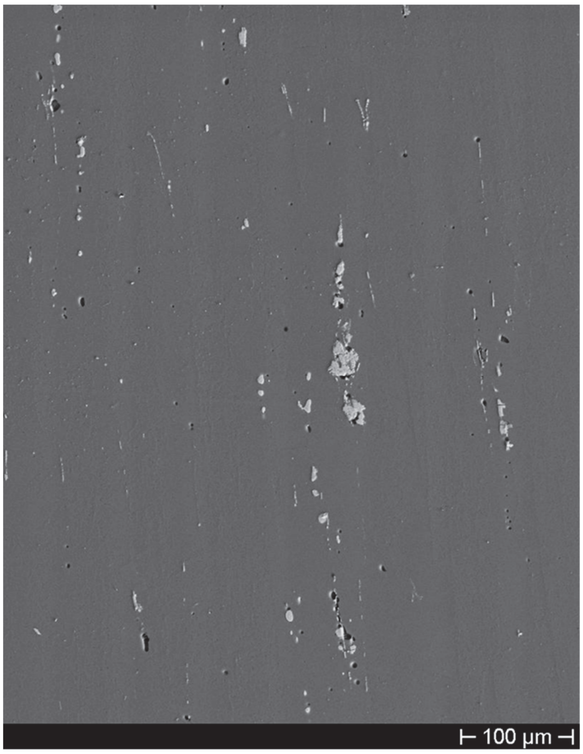

Figure 10: Microvoids formed in the 7050 T7451 alloy close to intermetallics.

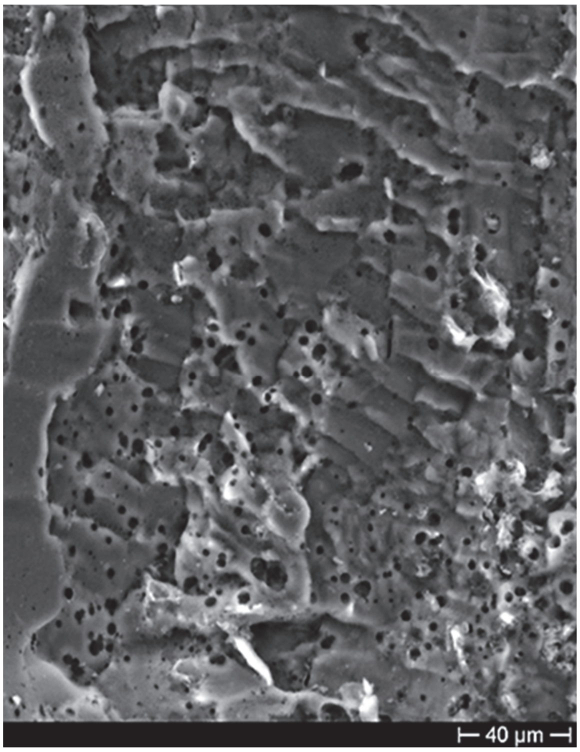

Figure 11: Pits formed on the fracture surface of 7050 T7451 alloy.

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