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Study of defect formation in Al 7050 alloys

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Abstract

The Al 7050 alloy is an Al-Zn-Mg-Cu-Zr alloy having good mechanical properties. This alloy has been developed in order to overcome stress corrosion cracking problems that characterise 7xxx Al alloys. Despite Al 7050 is widely used for aerospace applications, it can be subjected to crack initiation and propagation during the manufacturing process. In this work cracked Al 7050 components have been analysed in order to identify possible causes of crack formation such as coarse intermetallic phase presence, voids or wrong mechanical machining processes.

Keywords: Aluminium alloys, Al 7050, Fracture.

1. Introduction

Over the last decades many efforts have been spent to realise newer aluminium alloys and to improve the performances of the existing ones in order to find, for Al 7XXX alloys, new application fields as said by J.C. Williams et al. (2003). The Al 7XXX mechanical properties are affected by the alloy chemical composition and by the alloy microstructure related to the used production process parameters. Among the different Al alloys we are going to focus on the Al 7050. Aluminium alloy 7050 is an aerospace grade of aluminium characterised by high strength, stress corrosion cracking resistance and toughness as described by M. Dixit et al. (2008). It is particularly suited for heavy plate applications due to its lower quench sensitivity and retention of strength in thicker sections. Al 7050 therefore is the premium choice aerospace aluminium for applications such as fuselage frames, bulkheads and wing skins. Aluminium alloys based on the Al-Zn-Mg composition can be heat treated and age hardened in different

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ways as reported by P. Rometsch et al.(2014): using particular heat treatments, mechanical fracture risks could be reduced drastically. Although aluminium alloys that contain appreciable amounts of soluble alloying elements, primarily copper, magnesium, silicon and zinc, are susceptible to stress corrosion cracking (SCC) as shown by J.Chen et al.(2016), the main characteristics of Al 7050 alloy are high fracture toughness and resistance to SCC. This gives them very useful characteristics, as said above, for aerospace applications. Aim of this work is to analyse Al 7050 defects that could become critical during manufacturing processes. Three are the critical stages: shaping process, heat treatment and mechanical machining processes. During these stages cracks could nucleate and propagate. In this work we examined various types of defects that could be critical for Al 7050 alloy.

2. Experimental.

In this paper we examined an Al 7050 alloy, subjected to shaping and machining processes, having the following nominal composition: Al-2.3Cu-2.3Mg-6.2Zn-0.12Zr, Fe and Si <0.1. In the studied components major cracks were detected after the machining process necessary to obtain the final product. The as-received material was certified as Al 7050 subjected to T7451. This heat treatment, according to the ASTM standard B918, is performed in two steps:

1- solution heat treatment and quenching: solution temperature 476 °C, quenching solution maximum temperature 43 °C;
2- two step precipitation ageing: first step temperature 121 °C for 3-6 hours, second step temperature 165 °C for 24-30 hours.

The metal in this state of preparation was cut with a diamond cutter to consistent size for observation. In order to perform metallographic examinations on the specimen surfaces they were ground to a mirror-like surface using SiC papers up to 1200 followed by 1 μm alumina and then etched in Keller's reagent. Metallographic structure, crack paths and fracture surfaces were inspected by scanning electron microscope (SEM) and microanalyses were carried out by energy dispersion spectroscopy (EDS). Microstructure observations were also performed by means of an optical microscope.

3. Results

Figs. 1-3 show the optical micrographs of the examined components taken in three metallurgical directions (respectively longitudinal L, short S and transverse T). This is the typical microstructure of a rolled and heat treated component characterised by coarse elongated grains together with bands of fine recrystallized grains. It can be also highlighted that coarse second phases particles, which are always present in aluminium alloys, are aligned along the rolling direction.

From the micrographs it can be easily seen that the grains have a preferential orientation due to rolling operation, necessary to obtain a plate to be machined. It can be noticed a great number of coarse intermetallic phases similar to those reported by D. Dumont et al. (2003) and N.M. Han et al. (2011).

Figs. 4-6 show SEM back scattered micrographs of these components. This confirms what observed with the optical microscope and allows to identify the different kinds of coarse particles that are present in the microstructure In Fig. 5 a fine precipitation of bright intermetallics can be observed along the grain boundaries. EDS semi quantitative microanalysis has been carried out in order to identify their chemical composition. Figs. 7a-d show the EDS spectra of these intermetallics. Four different intermetallics have been identified..

- A bright globular intermetallic containing Al, Cu and Mg (probably Al_2CuMg)
- A bright polygonal intermetallic often fragmented by the rolling process composed mainly by Al, Cu and Fe (probably Al_7Cu_2Fe)
- A dark intermetallic whose principal elements are Mg and Si (EDS revealed also the presence of oxygen)
- A bright globular phase composed by Cu, Al and Mg (this phase differs from the first identified intermetallic for the very high content of Cu).

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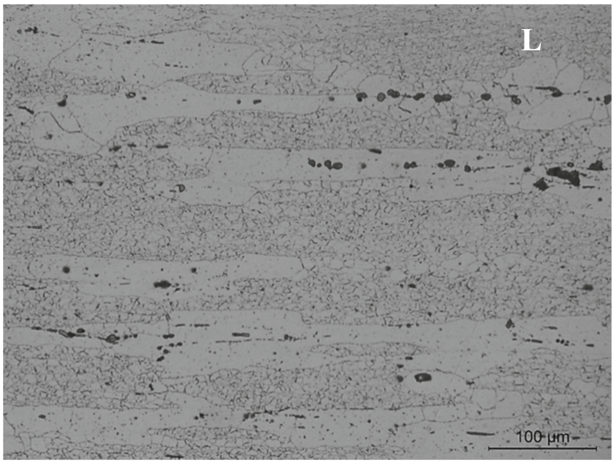

Fig. 1. Optical micrograph showing the alloy structure in the L direction.

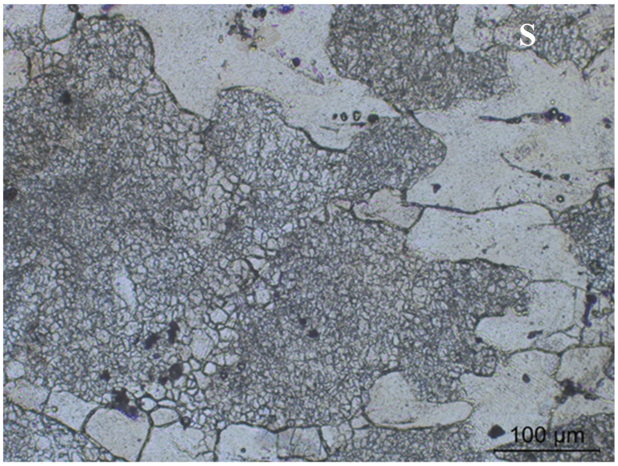

Fig. 2. Optical micrograph showing the alloy structure in the S direction.

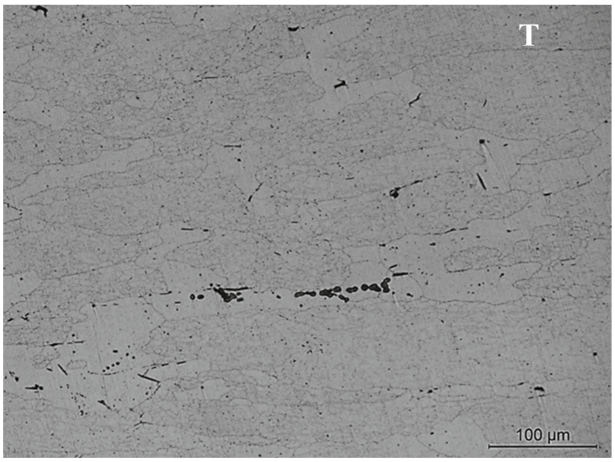

Fig. 3 Optical micrograph showing the alloy structure in the T direction

SEM observation also highlighted the presence several microcavities that tend to align following the rolling direction (L) (Figs. 8-9). These microcavities can often be found in proximity of the polygonal intermetallic phase. Considering that the deformation of hard inclusions do not comply with the overall deformation of the ductile matrix, during rolling hard inclusion presence can cause formation of internal voids.

Observations carried out on components subjected to mechanical machining revealed that cracks develop on the thinner section of the components. Fig. 10 shows the typical crack path. Cracks mainly follow an intergranular path in regions characterized by fine recrystallized grains and they do not seem to interact directly with the coarse intermetallics. In the region with coarser grains cracks follow an transgranular path. All the fracture surfaces are characterized by the presence of cleavage planes. Metallurgical defects, such as deep delamination (Fig. 11) and inclusions (Fig. 12) have been found on them.

In particular several types of inclusions have been found on almost all fracture surfaces. EDS analyses revealed the presence of silicon and iron rich inclusions and an inclusion characterized by a high content of oxygen.

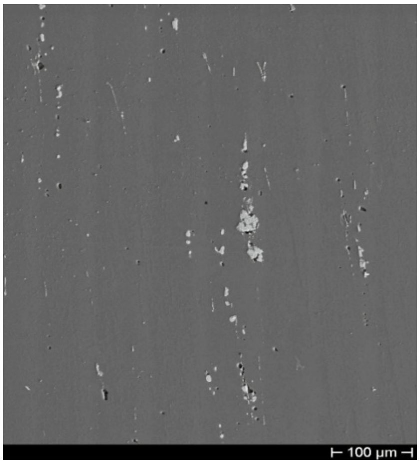

Fig. 4. SEM micrograph showing intermetallic particles

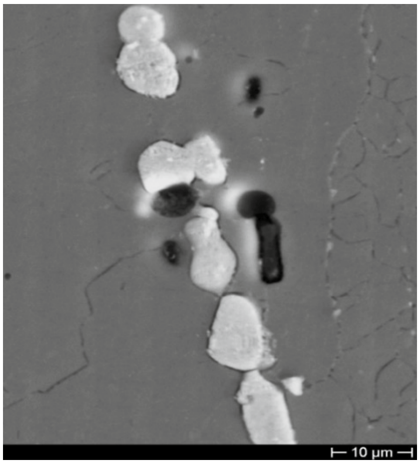

Fig. 5. SEM micrograph showing intermetallic particles

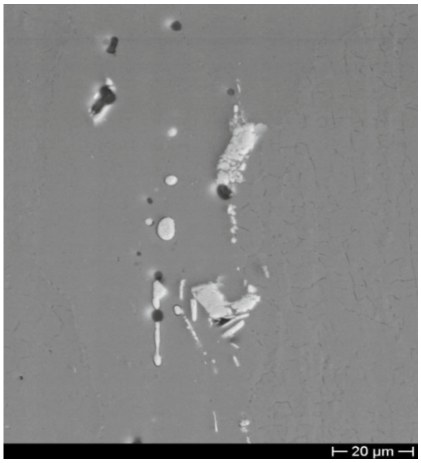

Fig. 6. SEM micrograph showing intermetallic particles

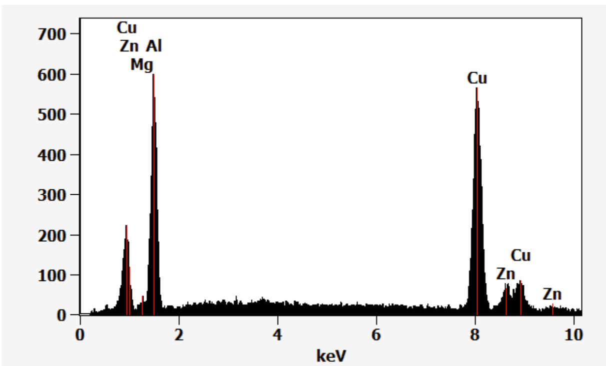

Fig. 7a. EDS spectrum of globular bright intermetallic

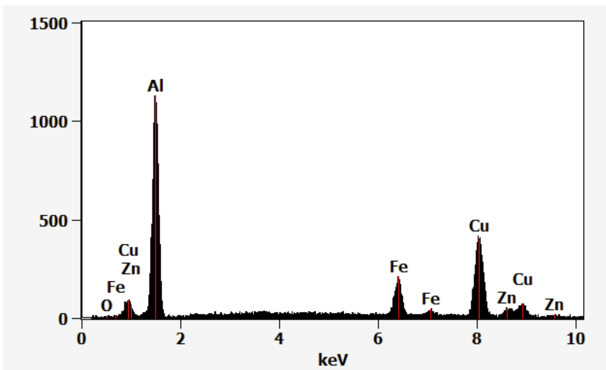

Fig. 7b. EDS spectrum of polygonal bright intermetallic

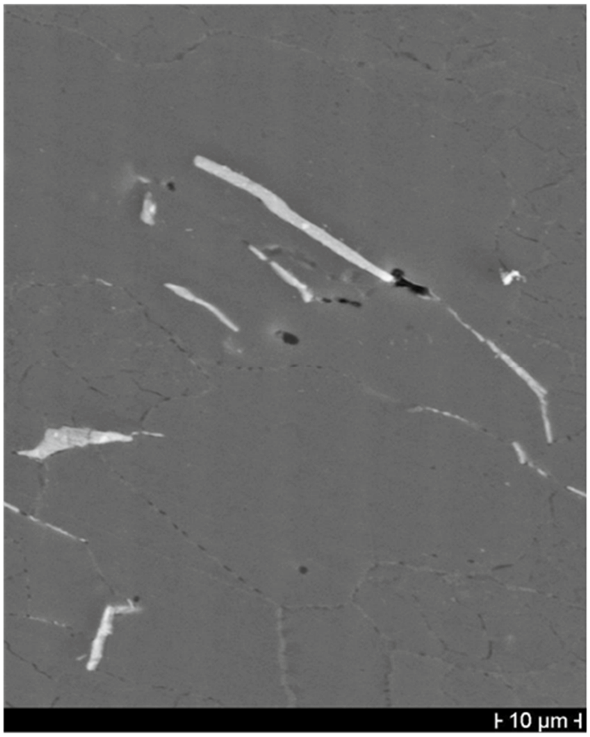

Fig. 8. SEM micrograph showing secondary intermetallic phases and microvoids.

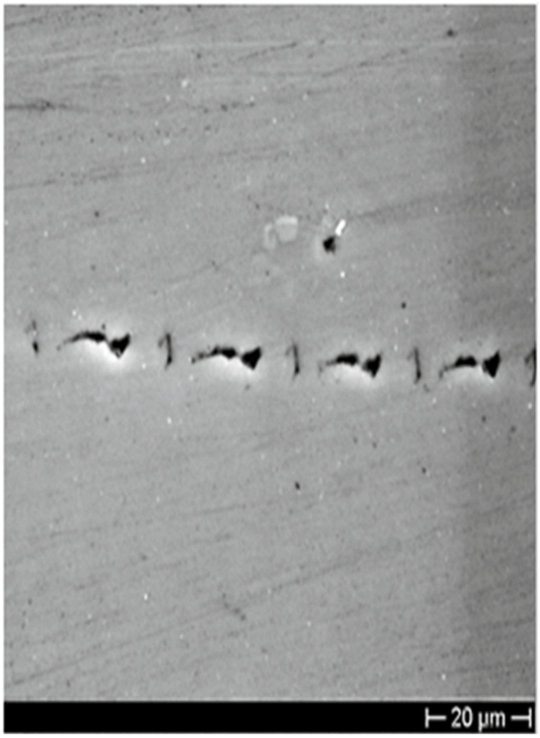

Fig. 9. SEM micrograph showing aligned microvoids.

4. Discussion

Al 7050 alloys are characterised by the presence of five different types of particles: intermetallic particles, dispersoids, that can originate during homogenisation process and hot rolling, coarse precipitates, formed during quenching, intergranular precipitates, which can be formed during quenching or during aging, and hardening precipitates formed during the aging treatment. In the components analysed in this work coarse intermetallic precipitates have been identified. It is well known from literature that intermetallic particles consist mainly of Al_7Cu_2Fe and undissolved Mg_2Si. These particles are not modified by thermal treatments such as quenching and aging treatments.

It is known that the Al 7050 alloy may have a tendency to a toughness decrease for example during a slow cooling, due to the presence of bands of dispersoids that nucleated on precipitates formed during quenching, This leads to particle growth that seems to be important in toughness reduction.

Moreover, the presence of microcavities associated to these precipitates not only affect the mechanical properties of the alloy by reducing its toughness, but they can be critical during mechanical machining because they can initiate cracks. The analysed components are obtained from large rolled plates and are subjected to mechanical machining performed to obtain thin walls. This could lead, during the milling process, to the formation of cracks well evident on thin walls.

Therefore an insufficient control of the plate quality to avoid the presence of microcavities, inclusions, dispersoids, that fragment during plastic deformation could be the cause of serious problems during machining. In this stage cracks can nucleate and propagate via preferential paths. Probably less intense mechanical machining could reduce this problem, with higher processing costs related to the increased time. On the other hand, heavy machining in terms of thickness, can generate two types of problems: under the effect of vibration microporosity associated to coarse phases could become site initiation for cracks, moreover the tool could determine detachment of hard dispersoids with consequent formation of other critical defects. Irrespective of the cause that generates them, cracks propagate in a preferential direction coincident with the alignment direction of micropores and second phases. In particular fragmented polygonal shaped particles are more critical because they generate stress intensification.

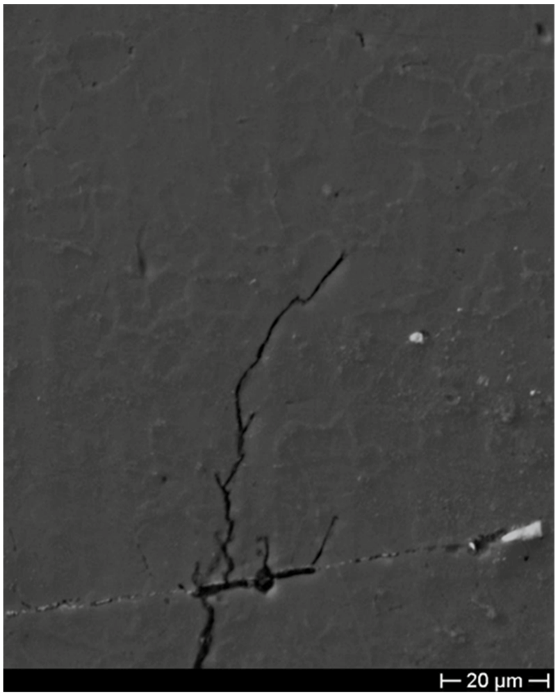

Fig. 10. SEM micrograph showing a crack path.

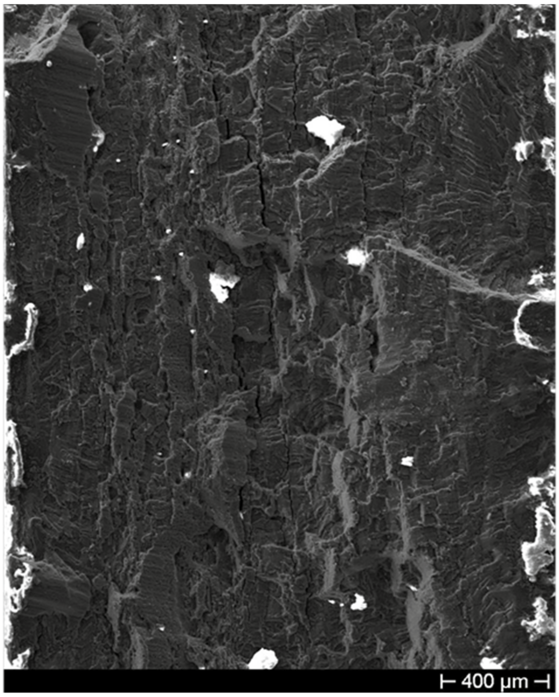

Fig. 11. SEM micrograph showing the fracture surface.

Fig. 12. SEM micrograph showing brittle inclusions on the fracture surface.

5. Conclusions

The study of a cracked component made of an Al 7050 alloy highlighted that different kinds of intermetallic phase formed in the alloy during solidification and hot rolling process probably do not affect the mechanical resistance of the alloy, but seem to determine crack formation during material-removal processes. Cracking at the end of the production line implies that the component must be discarded generating significant costs. On the ground of these results it appears of paramount importance to set-up an in-process inspection by analysing both the plates and, after the shaping process, the components.

References

Chen, J., Zhang, X., Zou, L., Yu, Y, Li, Q, 2016. Effect of precipitate state on the stress corrosion behavior of 7050 aluminum alloy. Materials Characterization 114, 1-8.

Dixit, M., Mishra, R.S., Sankaran, K.K., 2008. Structure-property correlations in Al7050 and Al7055 high-strenght aluminium alloys. Material science & Engineering 478, 163-173.

Dumont, D., Deschamps, A., Brechet, Y., 2003. On the relationship between microstructure, strength and toughness in AA7050 aluminum alloy, Material science & Engineering A 356, 326–336.

Han, N.M., Zhang, X.M., Liu, S.D., He, D.G., Zhang, R., 2011. Effect of solution treatment on the strength and fracture toughness of aluminum alloy 7050, Journal of Alloys and Compounds 509, 4138-4145.

Rometsch, P. A., Zhang, Y., Knight, S., 2014. Heat treatment of 7xxx series aluminium alloys—Some recent developments. Transactions of Nonferrous Metals Society of China 24, 2003-2017.

Williams, J.C., Starke, E.A., 2003. Progress in structural materials for aerospace systems. Acta Materialia 51, 5775-5799.