3D-CHARACTERIZATION OF AlCu4.5Mg0.3 AND AlCu7 ALLOYS

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ABSTRACT

The three dimensional (3D) microstructural evolution of A206 (AlCu4.5Mg0.3) and AlCu7 alloys is studied as function of solution treatment (ST) time by synchrotron tomography. 3D microstructural parameters of rigid phases such as volume fraction, interconnectivity (volume of biggest aluminide/total aluminide volume) and contiguity (touching surface) are presented. In situ synchrotron tomography is carried during tensile deformation out to characterize the damage mechanisms and evolution.

Keywords: cast Al-Cu alloys, damage evolution, damage mechanisms, synchrotron tomography.

1. INTRODUCTION

The use of cast Al-Cu alloys for the production of cylinder heads is well established (D. Altenpohl 1998). However, improvements regarding both room temperature (RT) and high temperature strength are still needed together with the understanding governing the damage initiation and damage evolution. The aim of this work is to study the evolution of the cast microstructure after different ST times and the identification of the microstructural features and parameters that influence the damage under in situ tensile deformation determined during synchrotron tomography of A206 and AlCu7 alloys.

X-ray microtomography is a reliable technique for the characterization of materials. It provides a description of the three dimensional (3D) internal microstructure of materials and it can be applied to follow the evolution of the microstructure under the effect of external thermal/mechanical/thermo-mechanical loads (Suéry et al. 2012). Specifically, it has been applied successfully during the last decade to investigate the damage evolution during tensile deformation of metals (Landron et al. 2011).

2. EXPERIMENTAL

Two different Al-Cu cast alloys produced by Nemak Linz GmbH were investigated: A206 and AlCu7. They were submitted to different solution treatments at 530ºC during 1h, 4h, 8h and 16h. All conditions were overaged during 100h at 250ºC to minimize precipitation hardening.

The microstructure before deformation was characterized by synchrotron tomography at the beamlines ID15 (ID15 description-web), Energy=20 keV, voxel size=$(1.1\ \mu m)^3$, minimum particle size=$(30\ \mu m)^3$, and ID19 (ID 19 description-web), Energy=17.6 keV, voxel size=$(0.28\ \mu m)^3$, minimum particle size=$(0.6\ \mu m)^3$ of the European Synchrotron Radiation Facility (ESRF) in Grenoble, France and at the BAM Line (BAM Line description-web), Energy=27 keV, voxel size=$(0.4\ \mu m)^3$, minimum particle size=$(1.7\ \mu m)^3$, of the Helmholtz Zentrum Berlin at BESSY. Interrupted tensile tests were performed at RT for the A206 and AlCu7 alloys. The sample was scanned after successive deformation steps until fracture using a dedicated tensile test rig (Buffiere et al. 2010). Samples with 1x1 mm² cross section and a central radius = 1mm as shown in (A. Bareggi et al. 2012).

3. RESULTS AND DISCUSSION

Figure 1 shows the evolution of interdendritic aluminides in the AlCu7 alloy during ST at 530°C. The results reveal that the biggest particle (green) remains highly interconnected even after 16 h ST.

Figure 2 shows the evolution of the volume fraction (Vf) and interconnectivity (Int) of the aluminides after different ST times. There is a partial dissolution of the phases segregated during casting that stabilizes already at < 4 h ST for both alloys. On the other hand, the interconnectivity of the aluminides decreases up to 4 h ST resulting in microstructures with a remaining interconnectivity of ~ 80 % and ~ 85-90 % in the investigated volumes of the A206 and AlCu7 alloys, respectively.

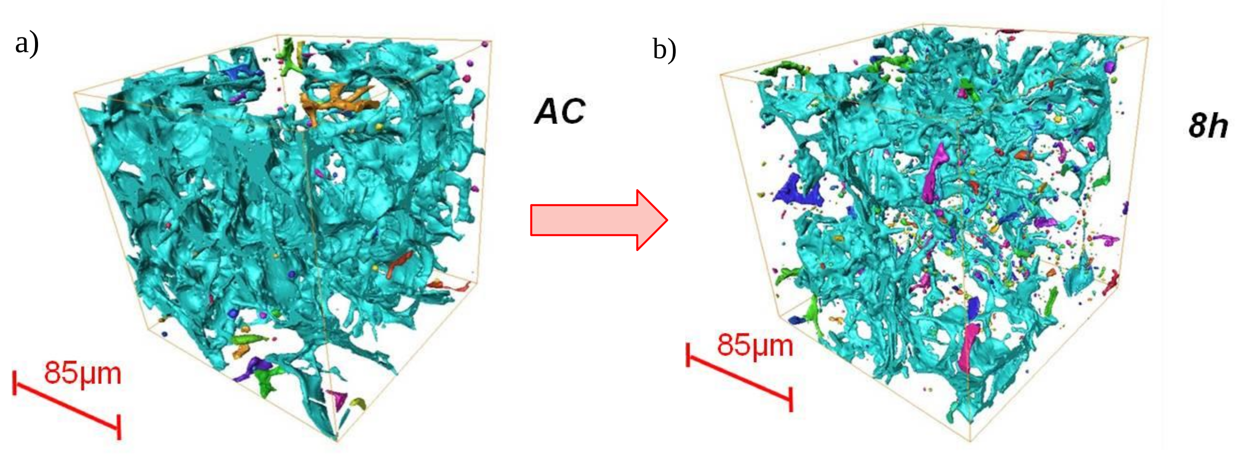

Figure 1: 3D structure of the aluminides network of the AlCu7: a) as cast condition, b) after 8h ST at 530°C (ID19-ESRF) (voxel size=(0.28µm)^3 – same field of view)

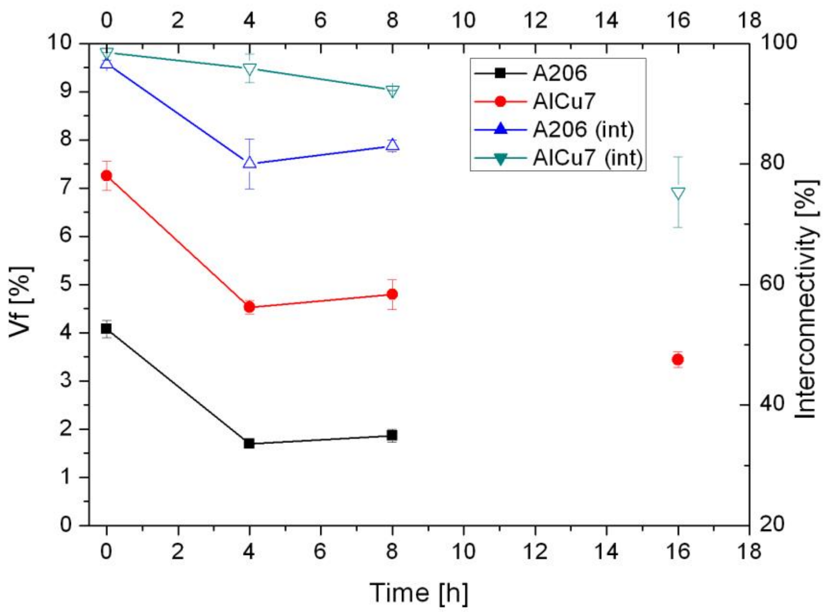

Figure 2: Evolution of the Volume Fraction (Vf) and Interconnectivity (Int) of the aluminides during solution treatment at 530 °C of the A206 and AlCu7 alloys (voxel size=(1.1µm)^3)

The in situ tomography experiments during tensile deformation show that damage initiation seems to be more likely in the aluminides with a large surface or eutectic areas perpendicular to the loading direction. Cracks propagate along the aluminide network while shrinkage pores ~ (100 µm)^3 play a minor role either for initiation or propagation as can be seen in the Fig.3. This confirms that the interconnectivity of the aluminides network plays a decisive role in the crack propagation process. We can see in lilac the main crack right before the sample failure. It is possible to observe that it tends to propagate along the aluminide network represented in red.

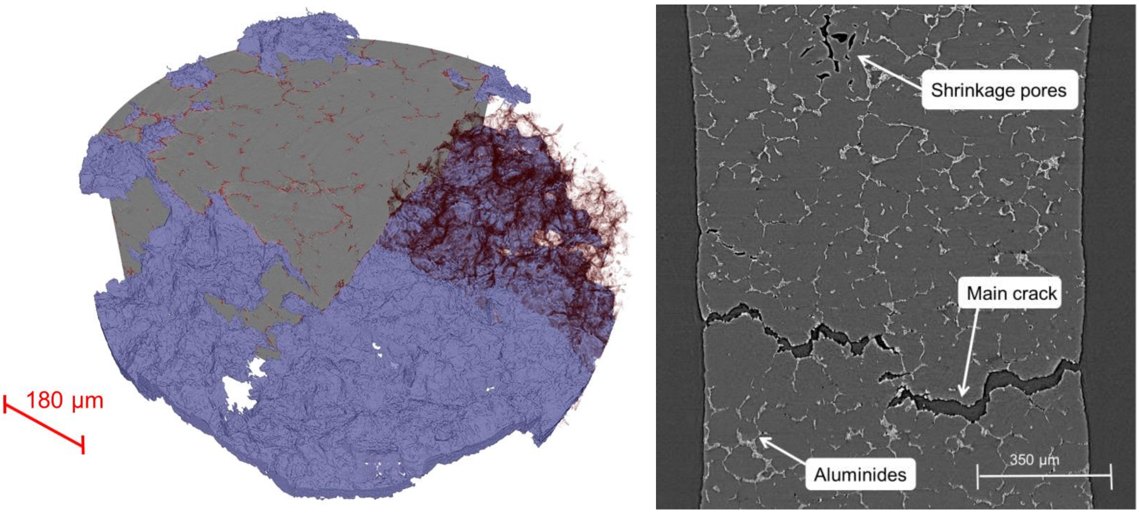

Figure 3: Main crack formed along the aluminide network during tensile deformation of AlCu7 solution treated during 1 h at 530 °C (voxel size=$(0.4\mu m)^3$). The load direction is the vertical axis.

The true-stress vs true-strain curves obtained during the in situ tensile tests for the A206 in as cast condition and after 4 h solution treatment at 530 °C are shown in Figure 4 a). The alloy after 4 h ST shows an ultimate tensile strength ~ 50 % higher than in as-cast condition as well as an increase of ductility by a factor of ~ 3. The evolution of the number and volume fraction of voids determined from the tomographies are shown for the alloy in both conditions as a function of the true stress in Figure 4 b) and c), respectively. The sample in 4 h ST condition has a larger initial volume fraction of voids created during the casting process. The voids fraction and number remain practically constant in the

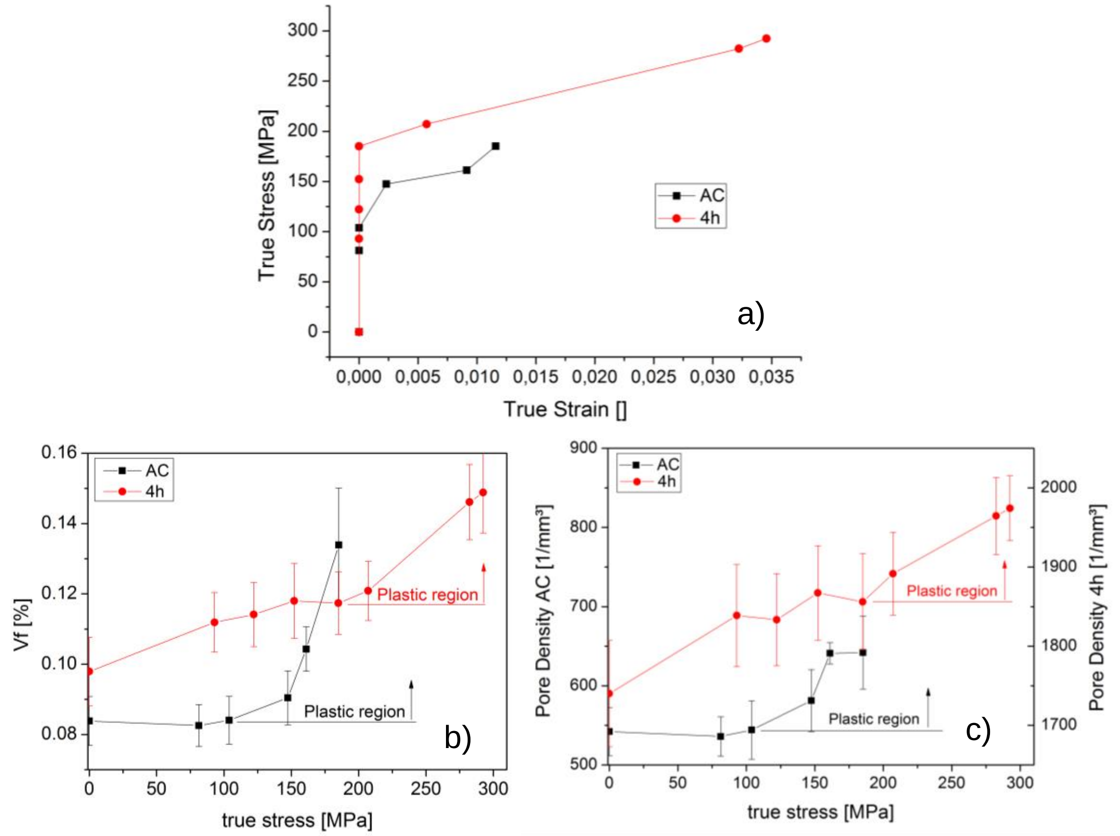

Figure 4: a) Interrupted tensile test carried out at the in-situ experiment, b) porosity volume fraction and c) pore density (number of pores/volume) during tensile test for A206 alloy

elastic region for the AC condition, while they present a more or less monotonically increase throughout the experiment for the solution heat treated sample. At above 100 MPa, the AC condition presents a rapid increase of voids number up to a stress of about 160 MPa where it remains constant until failure. On the other hand, the volume fraction of voids increases throughout the plastic period until failure. This is an indication of a growth process followed by either coalescence or, more likely owing to the brittle behavior of the alloy, the propagation of cracks formed in the aluminides network (see Figure 3). The data is being evaluated to analyze these hypotheses.

The volume fraction of voids created in the plastic region up to the ultimate tensile strength is about 0.02 vol% for the alloy in both conditions, although this is reached at a higher strain after 4 h of ST at 530 °C. This indicates that the microstructure is able to accommodate the same amount of damage in AC and 4 h ST conditions. This seems independent of the initial porosity presented by the tested samples. The fact that the solution heat treated alloy shows an increase of strength together with an increase of ductility is a result of the homogeneization of rigid phases (decrease in Vf of aluminides shown in Figure 2) that retards the damage formation in the highly interconnected alumide network.

5. ACKNOWLEDGEMENTS

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