Multiscale tomography study of eutectic structures in aluminium silicon foundry alloys

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Introduction

Hypoeutectic Al-Si alloys are widely used cast materials, e.g. for crank cases or other parts in mechanical engineering. The microstructure of these alloys consists of primary solidified Al-dendrites and an interdendritic Al-Si eutectic. The 3D morphology of Si eutectic in the Al matrix is mainly defined by the cooling conditions, heat treatment but also chemical modification treatment with ppm level doping of Strontium, which has been very difficult to ascertain until today. Furthermore, this 3D arrangement is extremely decisive for the mechanical properties and for its use in the automotive industry as a high-strength, lightweight material with ductile reserves.

Materials and Methods

In this work, the three dimensional microstructures of Sr-modified and unmodified Al-7wt%Si alloys have been analyzed at different length scales. The microstructural change due to chemical modification can be quantitatively described based on light optical images (Leica DM6000) and quantitative 2D image analysis (aquinto a4i analysis). The complex 3D structure and 3D curvatures of the eutectic silicon are imaged by means of FIB/SEM tomography (FEI Helios Nanolab 600) and the effect of chemical modifiers is analyzed by means of atom probe tomography (Cameca LEAP 3000X HR).

Results and Discussion

The fine eutectic structure is analyzed by means of FIB/SEM tomography and compared with results from 2D quantitative image analysis. In the unmodified alloy, tomography reveals a plate like, interconnected structure of the eutectic silicon, which seems to be needle shaped and partly isolated in a 2D section. The Sr-modified alloys shows highly branched Si colonies with a rounded shape (Figure 1).

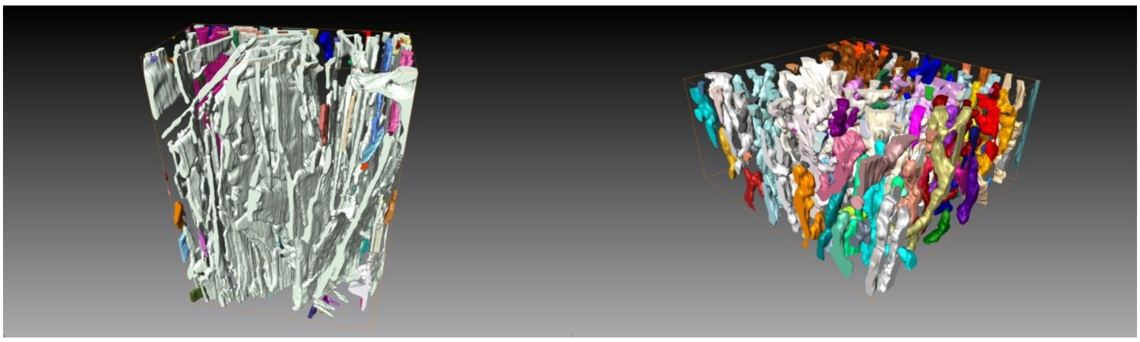

Figure 1. Reconstructions from FIB/SEM tomography. (Left) Interconnected, plate like silicon in the unmodified Al-7wt%Si alloy and (right) coral like morphology of the eutectic silicon in the Sr-modified alloy.

One possible explanation for the change in growth of the eutectic silicon is the so called impurity induced twinning theory (IIT) (Lu 1987). Strontium atoms are adsorbed onto growth steps of the solid-liquid interface of eutectic silicon leading to a higher twinning probability. Thus the eutectic silicon starts branching and the morphology is changed from plate like to coral like. Atom probe tomography was used to study distribution and segregation of Sr in site specific FIB-prepared samples of the eutectic silicon (Barrirero 2014). Segregations of different morphologies and chemical compositions were found (Figure 2) and correlated with twins, stacking faults and defects in the Si crystal lattice.

Figure 2. Reconstruction from atom probe tomography. Aluminium (green) and Strontium (red) rich structures in eutectic silicon of the Sr-modified Al-7wt%Si alloy.

Conclusion

This example shows, that the change in morphology and microscopic growth direction can be analyzed by light optical microscopy and FIB/SEM tomography, whereas the analysis of nano sized segregations causing this change, needs imaging techniques with sub-nm resolution such as atom probe tomography. In this case only the combination of different 2D and 3D imaging techniques allows for a complete understanding of microstructure formation

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