doi:10.1017/S1431927614006503
Microsc. Microanal. 20 (Suppl 3), 2014

3D Microstructure Characterization and Analysis of Al-Si Foundry Alloys at Different Length Scales

Michael Engstler[1,2], Jenifer Barrirero[2,3], Naureen Ghafoor[3], Magnus Odén[3] and Frank Mücklich[1,2]

[1.] Material Engineering Center Saarland (MECS), Steinbeis Research Center, Saarbrücken, Germany
[2.] Functional Materials, Department Material Science and Engineering, Saarland University, Saarbrücken, Germany
[3.] Division of Nanostructured Materials, Department of Physics, Chemistry and Biology, Linköping University, Sweden

The term microstructure refers to the complete internal structure of a material on the micro, nano and atomic scales. On one hand, it records the entire history of a material's processing and structuring (casting, forming, heat treatments, but also crystal growth, etc.) through its phase composition, defect structure and morphology. On the other hand, all properties (stiffness, formability, conductivity, all structural and functional properties) are determined by the microstructure. Thus, the microstructure can be seen as an intrinsic multi-scale memory from which we can read at each relevant scale the precise information about all microstructure-building processes as well as predict the final material properties. However, it could not be fully exploited so far due to the lack of adequate 3D characterization techniques. Today new emerging tomographic possibilities provide for the very first time all complementary 3D information in micro, nano and atomic scales.

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 [1].

In this work, the three dimensional microstructures of modified and unmodified Al-7wt%Si alloys have been analyzed by means of light optical microscopy, electron backscatter diffraction (EBSD), FIB/SEM tomography, atom probe tomography and HR-TEM imaging.

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). One possible explanation for the change in growth of the eutectic silicon is the so called impurity induced twinning theory (IIT) [2]. 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 combined with HR-TEM imaging was used to study distribution and segregation of Sr in site specific FIB-prepared samples of the eutectic silicon [3]. Segregations of different morphologies and chemical compositions were found (Figure 2) and correlated with twins, stacking faults and defects in the Si crystal lattice.

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

References:
[1] F. Lasagni et al., Adv. Eng. Mater. 10, (2008). p. 62
[2] S. Lu, A. Hellawell, Metall. Trans. A 18 (1987) p. 1721.
[3] J. Barrirero, M. Engstler, F. Mücklich, Light Met. 2013 (John Wiley & Sons, Inc., 2013). doi: 10.1002/9781118663189
[4] F. Mücklich, J. Barrirero, M. Engstler, Proceedings of the 5th Conference on industrial Computed Tomography Wels (2014), accepted
[5] The EU funding for the project AME-Lab (European Regional Development Fund C/4-EFRE-13/2009/Br) for the FIB/SEM is gratefully acknowledged. The atom probe was financed by the DFG and the federal state government of Saarland (INST 256/298-1 FUGG).

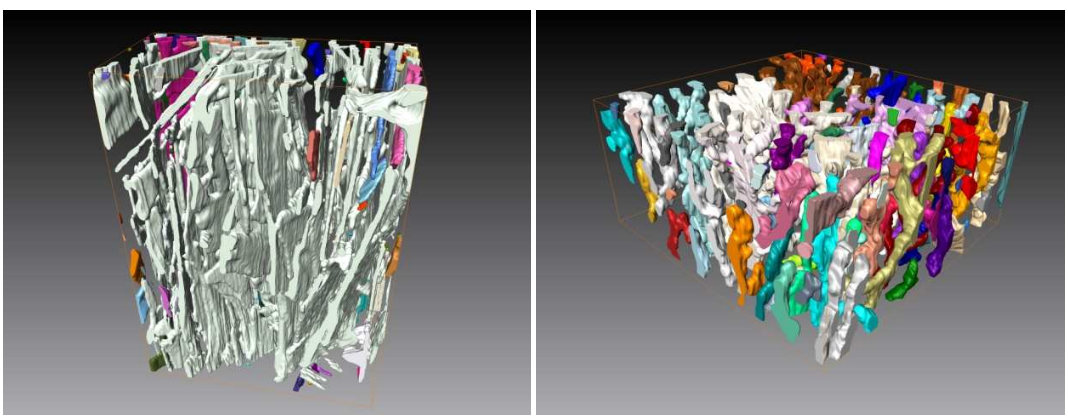

Figure 1. Reconstruction from FIB/SEM tomography of the eutectic silicon in an unmodified Al-7wt%Si alloy (left), approx. 70x100x40 μm^3 and in a Sr-modified Al-7wt%Si alloy (right), approx. 37x17x35 μm^3.

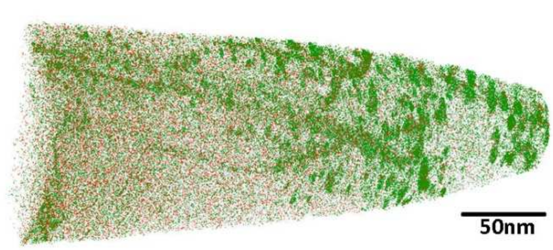

Figure 3. Reconstruction from atom probe tomography of the eutectic silicon of a Sr-modified Al-7wt%Si alloy (300nm in length and 120nm in diameter). Al atoms are shown in green, Sr atoms in red, Si atoms (matrix) are not shown [4]. Nanosized Al and Sr rich structures can be found inside eutectic silicon.