3D characterization of microstructure evolution of cast AlMgSi alloys by synchrotron tomography

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Cast AlMgSi alloys are well established for automotive and aerospace industry. These alloys are multiphase materials containing a rigid eutectic phase of Mg_2Si embedded in the ductile α-Al matrix. This system acts like a composite material where the internal architecture of the eutectic Mg_2Si phase plays a vital role in the macroscopic behavior. Through the internal architecture, which can be modified by varying the casting conditions or applying heat treatments, the mechanical properties of the material can be tailored. To follow and quantify the changes in the microstructure the application of a non destructive 3D imaging technique is necessary.
The aim of this work is to study the evolution of the microstructure of two cast AlMgSi alloys: an AlMg7.3Si3.5 alloy, with an Mg:Si ratio above the stoichiometric Mg_2Si ratio (1.74:1) and an AlMg4.7Si8 with an Mg:Si ratio below this value. The development of the α-Al dendrites and of the eutectic structure have been followed and quantified by synchrotron tomography during in situ solidification tests. The transformation of the eutectic Mg_2Si morphology during solution heat treatment was investigated by ex situ synchrotron tomography. The quantitative results of the morphological changes are correlated with the changes in the elevated temperature strength and hardness of the investigated materials.
A resistance furnace consisting of two heaters enclosed inside a cubic chamber with a hole on the bottom where the specimen can be inserted was used to melt the sample [1]. Their own oxide skin held the molten samples during the experiment. The temperature was measured by a thermocouple at the top of the sample. The alloys were cooled down to solid state with a cooling rate of 5K/min in both cases. Tomographic scans were carried out every 60s. The reconstructions resulted in volumes of 1024^3 voxel with a voxel size of $(1.4\ \mu m)^3$. The α-Al dendritic structure and the eutectic Mg_2Si phase could be resolved for both alloys, while the identification of the Fe aluminide phases was also possible in the AlMg7.3Si3.5. The analysis of the tomographies shows that the dendritic growth of both alloys is characterized by a coarsening of the secondary dendritic arms ending up in a drop-like shape at the eutectic temperature as shown Figure 1. This means that during solidification the smaller secondary dendrite arms disappear, while the larger ones continue to grow resulting in the coalescence of the secondary dendritic arms.
The onset of the eutectic solidification takes place at the interface between the α-Al dendrites in the liquid between secondary dendritic arms. The volume fraction of the eutectic Mg_2Si particles increases during solidification, with a growth rate of the largest Mg_2Si particle faster than the average. The level of interconnectivity of the eutectic Mg_2Si phase shows a monotonic increase while the growing particles coalesce [2].
The evolution of the microstructure of the AlMg4.7Si8 alloy was investigated by ex situ synchrotron tomography in as-cast condition and after 1h and 25h of solution heat treatment at

540 °C. The reconstructions resulted in volumes of 2048^3 voxels with a voxel size of $(0.3\ \mu m)^3$. A strip cast AlMg7.3Si3.5 alloy is investigated by sub-micrometer holotomographic analysis achieving a voxel size of $(60\ nm)^3$ in a volume of 1500^3 voxels by cone beam magnification of the focussed synchrotron beam using Kirkpatrick-Baez mirrors. The three-dimensional microstructure of the same specimen volume in the as cast state is compared with that after exposure to 540°C for 30 min resolving microstructural features down to 180 nm. The eutectic Mg_2Si phase, which presents a highly interconnected structure in as-cast condition in both alloys, undergoes significant morphological changes during solution heat treatment. The statistical analyses of the particle distribution, sphericity, mean curvatures and Gaussian curvatures describe quantitatively this transformation, which is characterised by a disintegration of the interconnected seaweed-like structure followed by a spheroidisation of the disintegrated fractions of the eutectic branches as shown in Figure 2. The ternary eutectic Si resulting from the Si-surplus undergoes similar changes. The morphological evolution during solution treatment is correlated with results from compression tests at 300°C. The elevated temperature strength decreases during solution heat treatment as a consequence of the loss of interconnectivity of the eutectic Mg_2Si structure.

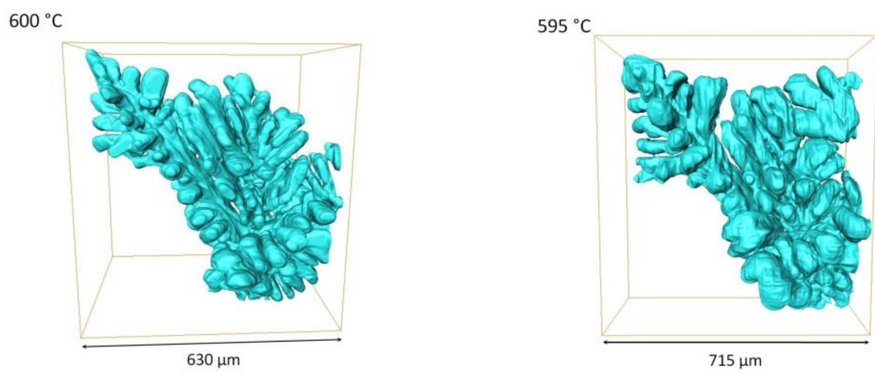

Figure 1: Evolution of the dendritic structure during solidification of AlMg7.3Si3.5.

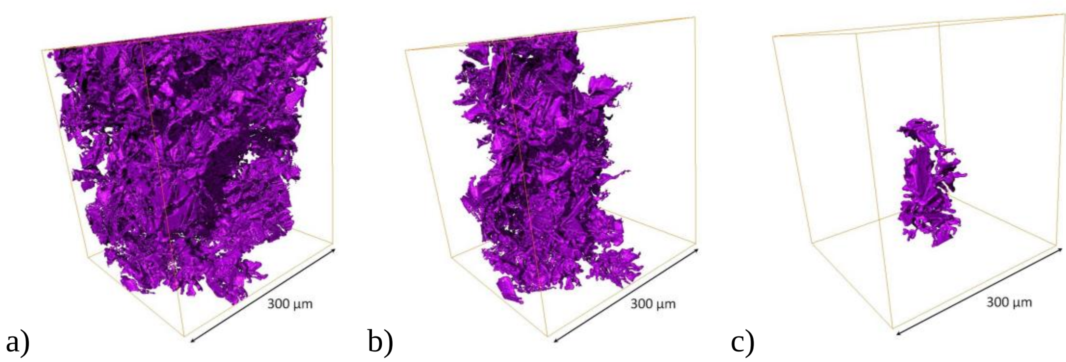

Figure 2 The largest Mg_2Si particle in AlMg4.7Si8 within the investigated volume in a) as-cast condition b) after 1h/540°C and c) after 25h/540°C

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