Summary report

Al–Si base alloys are widely used in the automotive and aerospace industry and general engineering industries, where they have been steadily replacing many conventional ferrous alloys due to their excellent combination of properties such as low coefficient of thermal expansion, high strength-to-weight ratio, good corrosion resistance, weldability and minimum energy requirement for recycling.

Application of recycled aluminum alloys with even small amounts of iron causes formation of a rich variety of intermediate Fe-rich phases having morhpohologies described as polyhedral, Chinese script, needles, cubes, platelets. Beside many phases, the most important one is the so-called β-Al_5FeSi phase. Its needles are hard and brittle and thus have a detrimental effect on the alloy properties: They cause porosity, act as stress concentrators and promote crack initiation and lower fatigue life, but lower soldering of especially high-pressure die casts to molds.

The project “iPhaseFlow” aimed to understand the effect of fluid flow on the microstructure and intermetallics in Al-alloys with 5, 7 and 9 wt.% Si. To these base alloys Fe is added in amounts of 0.2 to 1.0 wt.% and Manganese (Mn) in the same amounts, since it is a so-called “rule”, that the addition of Mn would reduce the bad effects of Fe. The experimental technique used was directional solidification under well defined thermal and fluid flow conditions (rotating magnetic field, RMF). The microstructure and especially iron intermetallic phases were studied using light microscopy and SEM with EDX, X-Ray tomography and numerical simulation.

The results showed that forced flow can cause shortening of the β platelets in dendritic regions and lengthening in eutectic ones together with an increasing of their number density. The studies proved that application of RMF to AlSi alloys could lead to better results in shortening β-Al_5FeSi than lowering Fe content in the range from 1.0 to 0.2 wt.% Fe. From the results and flow analysis it can be deduced that in directionally solidified specimens, the melt loaded with β particles transports them to the overheated bulk liquid having a temperature near or higher than the precipitation temperature of β where intermetallics could be fragmented or completely dissolved. This leads to microstructures with shorter β-Al_5FeSi and a higher number density.

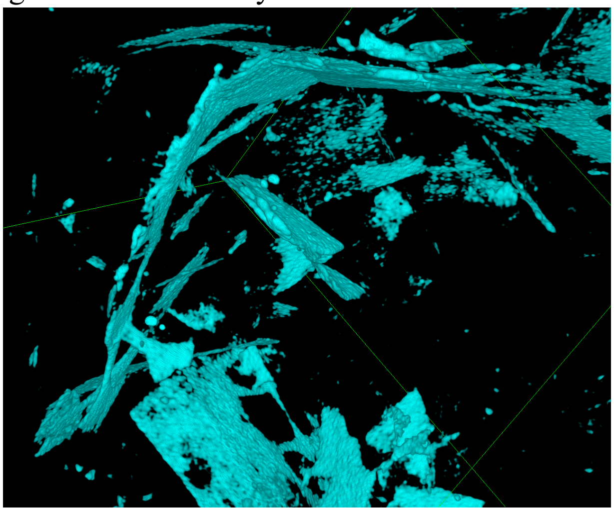

Figure 1. X-Ray tomography of the branched β-Al_5FeSi platelets.

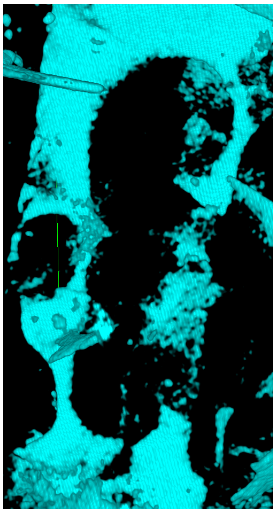

Figure 2. X-Ray tomography of the shaped β-Al_5FeSi platelets. The holes represent dendrites taken away by image techniques.

X-Ray nano-tomography gave a 3D visualization of β intermetallics and presented simple β-Al_5FeSi platelets and revealed complicated structures formed through β-Al_5FeSi phase that can drastically influence mushy zone permeability. The results can resolve an open problem in the literature. It was claimed, that small amounts of intermetallics precipitating during solidification would restore diffusive mass transport in the transition zone between the fully liquid and the fully solid state (the mush). This observation was not understandable, since the amount of intermetallics even in alloys with 1 wt.% Fe is that small, that the spongy structure of the Al-dendritic network is hardly being affected by them. Although this seemed plausible on the first sight, the nano-tomography clearly showed for the first time, that the intermetallics grow between the dendrites a few millimeters behind the their tips almost transverse to the solidification direction, build plates which block any fluid flow from the bulk into the mush. Thus even small amount of "dirt" can clog the mushy zone filter.

The results were presented at several international conferences and several scientific publications are currently being prepared to be presented in peer reviewed journals.

The project also included a list of training activities for the fellow, which were finished in the time of the project. The trainings realized during the "iPhaseFlow" execution were

- Trainings dedicated to activities in host laboratories (DLR): familiarization with the solidification technique, the aerogel based furnace facility Artemis-3, metallographic sample preparation, quantitative image analysis, scanning microscopy, EDX and EBSD, X-ray tomography, numerical modeling.
- Solidification Course. Organized by EPFL Lausanne, Calcom and ESI Group. Les Diablerets (Switzerland), April 25th-30th 2010.
- Qualification course for executive leaders, module 1, DLR Cologne, Germany, 2010.
- Qualification course for executive leaders, module 2, DLR Cologne, Germany 2010.
- LabView 2010 – Introduction, DLR Cologne, Germany 2011.
- Successful Presentations in English, DLR Cologne, Germany 2011.
- LabView 2010 – Advanced, DLR Cologne, Germany 2011.
- German Language Course – DLR Cologne, Germany, from September 2009 till September 2011.

The potential impact

The results of the project are important for secondary aluminum alloys, especially in automotive applications, but also elsewhere since the energy needed to recycle one ton of Al-alloy is just 5% of the energy needed to obtain Al from the aluminum oxide ore. The utilization of secondary aluminum will increase with increasing energy prices and is a necessity in view of a resource preserving economy.

The presence of small amounts of Fe and Mn, but also Cr, Ni, Ti and Co brings about a complicated microstructure due to the formation of a rich variety of intermetallic phases (IMPs) during solidification, which generally have a negative effect on the mechanical and physical properties of a as cast part.

The project allowed to realize and visualize interactions between fluid flow and microstructure and intermetallics in AlSi alloys. Fluid flows are integral parts of many metallurgical processing operations offer a new way to manipulate IMPs. "iPhaseFlow" was an essential step in resolving problems concerning intermetallics in cast Al products. It was clearly shown how dedicated fluid flow can change the morphology and appearance of intermetallics and how suitable electromagnetic stirring could improve the microstructure and thus the properties.

Therefore the project enhanced the EU scientific excellence in the following way, since it shows European foundries how to manage fluid flow to yield better castings.