ZPT+
Non-destructive testing and Tomography Plus
Programme: COMET – Competence Centers for Excellent Technologies
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Sub-project S1, 03/2015 – 08/2018, strategic

Improved characterization of microstructural components of cast near eutectic Al-Si piston alloys

The thermo-mechanical performance of cast Al-Si piston alloys is strongly dependent on the condition of highly interconnected 3D hybrid networks formed by primary and eutectic Si and intermetallic phases embedded in the α-Al-matrix. Using computed tomography, the similar x-ray attenuation of Si and the α-Al-matrix poses a problem for the segmentation and accurate characterization of the rigid phases within the network. A combination of conventional x-ray tomography, synchrotron tomography and chemical etching combined with tomography of the same alloy at the same position enables automatic segmentation and a more accurate characterization of phases over large, representative volumes, providing the necessary information to quantify the 3D microstructure of the alloys.

Success Story Long Version

The microstructure of cast near eutectic Al-Si piston alloys is formed by interconnected 3D hybrid networks of eutectic and primary Si as well as various intermetallic phases embedded in a comparatively soft α-Al matrix. The interconnectivity of these networks is strongly correlated to the mechanical performance of the material. The load carrying capability of these structures is affected by topological and morphological changes which occur during thermal heat treatments and due to the thermo-mechanical conditions during service. As such, 2D investigations are insufficient to accurately characterize all microstructural features affecting the thermo-mechanical performance of Al-Si piston alloys. A possible way to overcome this issue is by non-destructive computed tomography. However, due to the very similar x-ray attenuation of eutectic and primary Si and the α-Al matrix, conventional x-ray tomography (XCT) alone is not sufficient for the characterization of all phases present in the alloy. Synchrotron X-ray computed tomography (sXCT) is better suited than XCT since the higher phase contrast provided by some synchrotron imaging beamlines can be used to reveal phases with similar attenuation. However, phase contrast artefacts hinder the proper evaluation at interfaces between phases, i.e. matrix-Si, matrix-aluminides, aluminides-Si. Until now, mostly only aluminides have been taken into consideration for quantitative evaluations over larger, representative volumes, since they can be easily revealed with the means of tomography due to their high phase contrast and thus, automatic segmentation is unproblematic. However, this does not apply to the Si phase. Segmentation has to be done manually or semi-automatic with the need for manual corrections. This complicates the accurate quantitative evaluation of Si for representative volumes.

Within the sub-project S1, a combination of conventional XCT available at FHW, sXCT available at the ESRF in Grenoble as well as at DESY in Hamburg and chemical deep etching combined with sXCT was conducted for the same alloy at the same position, to provide the
necessary information to quantify the 3D microstructure of the alloys taking into account all microstructural components. Fig. 1 shows 2D reconstructed slices of an AlSi12Cu3Ni2Mg alloy at the same position acquired by XCT, sXCT and deep etching combined with sXCT clearly revealing the difference quality and phase contrast acquired between the used methods.

Fig. 1: 2D reconstructed slices of an AlSi12Cu3Ni2Mg alloy at the same position acquired by (a) XCT (FWH, voxel size = (0.4 µm)³), (b) sXCT (DESY/P05, voxel size = (1.18 µm)³) & (c) deep etching combined with sXCT (ESRF/ID19, voxel size = (0.33 µm)³) and (d) 3D visualization of automatically segmented aluminaides (red, left), primary and eutectic Si (blue, middle) and the hybrid 3D network formed of these phases (right) on the example of a cast at the hub of the piston. The Al-matrix is transparent in the 3D view.

**Impact and effects**

The characterization of the 3D microstructure with the means of combined x-ray tomography, synchrotron tomography and deep etching + tomography will enable automatic segmentation of all the microstructural constituents and thus, provide a more accurate evaluation of all the phases present within the material and their interaction with each other (e.g. interconnectivity) over large, representative volumes. This will give rise to a more detailed understanding of 3D microstructural features which can change due to heat treatments or external loading conditions. In further consideration, this will facilitate the determination of a quantitative relationship between 3D architecture and their thermo-mechanical behavior and result in a great contribution to the development and optimization of Al-Si piston alloys for resistance to different kinds of thermal and mechanical loading conditions. Also, the data acquired through this combined characterization method will help to develop a knowledge-based alloy design supported by experimental observations and finite element simulations.

**Contact and information**

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