ESRF	**Experiment title:** Multiscale analysis of damage in a silicon-molybdenum alloyed ductile cast iron	**Experiment number**: Ma3615
Beamline: ID11	**Date of experiment**: from: 30/08/2017 to: 03/09/2017	**Date of report**: 13/09/2021
Shifts: 18	**Local contact(s)**: Marta Majkut	*Received at ESRF:*

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Report:

The development of highly sophisticated combustion engines is driven by the desire to improve efficiency and power density as well as to reduce emissions. Such developments will inevitably lead to an increase of the combustion pressure and temperature, which has the consequence of an increased loading on the materials. Today, spheroidal graphite iron (SGI) alloyed with silicon and molybdenum, SiMo-alloys, are commonly used in components such as manifolds in exhaust systems, where materials that can withstand the harsh conditions are needed. The mechanical behaviour of these materials has been studied using standard approaches, but the microstructural analysis and the correlation with mechanical behaviour to microstructural properties is performed on polished 2D surfaces taken from the position of final fracture of the specimen. For a detailed understanding of the microstructure and micromechanics of the material related to the 3D microstructure, in-situ 3D analysis during mechanical deformation is needed.

The SiMo alloy studies is a Ductile Cast Iron (DCI), comprising a ferrite matrix with dispersed graphite spheroids and carbides. In this experiment, deformation in this DCI has been studied over different length-scales by analysis of an in-situ tensile test at beamline ID11, ESRF. 3DXRD has been used to study the texture and strain evolution of the crystalline ferrite matrix, which is correlated with continuum strain fields from digital volume correlation (DVC) of x-ray tomography images acquired at the same load levels. Morphological analysis of the material microstructure and its evolution has also been assessed 4D image analysis.

The objectives were:

- To study the micromechanics of SiMo-DCI, i.e., to investigate how different phases of the material, which have different mechanical properties, interact (e.g., by stress/strain concentrations around soft

graphite regions) and contribute to the mechanical responses observed on the macroscopic (engineering) length scale.

- To seek a better understanding of the damage mechanisms active during cyclic uni-axial loading of SiMo-DCI materials as a function of temperature.
- To obtain information regarding damage mechanisms on several length scales using x-ray tomography and digital volume correlation (DVC) of the tomographic images, for meso-scopic strain analyses, with 3D x-ray diffraction (3DXRD), to measure the elastic strains within grains.

Results

During the experiment, two in-situ eperiments were performed with 8 load steps with both x-ray tomography and 3DXRD measurements performed at each stage. 3DXRD measurements were made over 9 line beam scans of 100 microns height and covering the full sample diameter (1.4 mm); this was necessary due to the large number of grains in the sample (about 3000 grains indexed per slice). The analysis has focussed primarily on one of these tests and has involved 3D image segmentation for morphological analysis at each load step, DVC analysis for continuum strain field measurements between steps and crystal strain/stress analysis from DVC. The 3DXRD analysis was limited to the initial load steps due to spot smearing and overlap. Fig. 1 shows some example resuts.

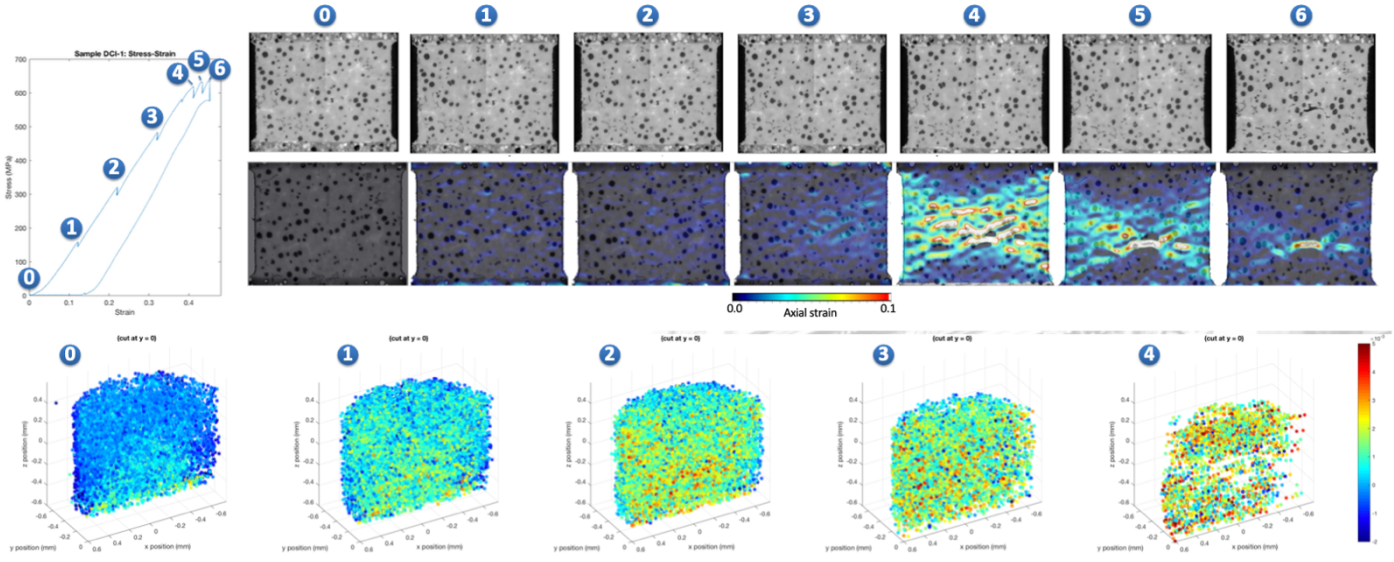

Fig. 1: Macrocopic stress:strain response of the sample, showing also the moments at which the loding was stopped for each measurement. The top row of images shows slices through the reconstructed 3D x-ray tomography volumes indicating the sample morphology. The second row shows sections through the DVC (vertical) strain fields based on the 4D tomography images. The final row of plots shows the 3DXRD-indexed grains coloured by the vertical compornant of the crystalographic strains.

Conclusion

Based on the acquired 3DXRD and x-ray tomography data multi-scale strain analysis combined with microstrucure and microstructural evolution characterisation has been possible for SiMo-DCI samples under mechanical loading in-situ. A first paper has been published [1] and a second is in preparation. The 3DXRD data provides additional information for modelling, e.g., initial grain positions and parameters. Further developments are needed to follow the grains and their evolution further through the deformation when there is sigificant plasticity in the grains.

[1] Sjögren, T., Hall, S., Elmquist, L., Dartfeldt, E., Larsson, E., Majkut, M., Elfsberg, J., Skoglund, P. and Engqvist, J., 2020, In situ analysis of cast irons mechanical behaviour using synchrotron x- ray tomography and 3DXRD, IOP Conf. Ser.: Mater. Sci. Eng., 861**,** 012039