Towards identification of local material properties of a ductile cast iron using Synchrotron Radiation micro Computed Tomography, Digital Volume Correlation and FE modelling

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Abstract. Increasing emission requirements are a strong motivator for the heavy truck industry to seek materials that can withstand increasing combustion temperatures and pressures. In this context, the mechanical performance of an industrial Ductile Cast Iron (DCI) has been studied during mechanical loading (in-situ) using Synchrotron Radiation micro Computed Tomography (SRµCT) at ESRF (ID11, Grenoble, France). The output from this experiment in terms of 3D images (i.e. voxel data) at multiple load levels are further analysed using Digital Volume Correlation (DVC) to obtain the displacement field, as a function of the applied external load, within the test specimen. This data provides profound information about the mechanical behaviour of the material. To further deepen this understanding, steps are taken towards linking the DVC data to an FE model representing the specimen microstructure in a parameter identification scheme designed to identify local material properties. Such information can potentially be used to execute virtual experiments where the impact of microstructure alterations on the macroscopic material performance can be studied.

Introduction and background

The present study was carried out as part of a pilot project that was initiated to illustrate the potential of using synchrotron facilities available at e.g. MAX IV (Sweden), ESRF (France) and DESY (Germany) for Swedish industry. The aim of this particular work was to study how features in the microstructure of an industrial ductile cast iron contribute to its mechanical performance. The test material [1] was provided by Scania and is used in their heavy truck engines.

Experimental procedure

Test specimens (gauge diameter ~1.4 mm) were manufactured from the provided material. A tensile stage, designed and built by Lund University, was used to apply mechanical loading to the test specimen during the experiment, see Figure 1 for further details. Scanning was carried out at 78.4 keV.

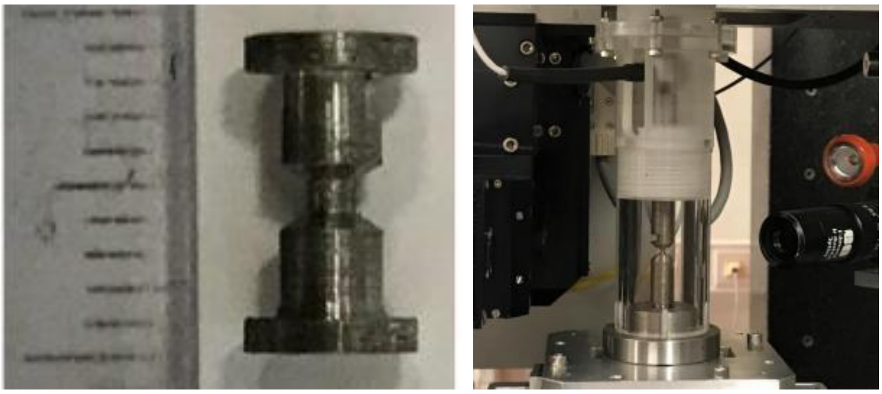

Figure 1. Left: test specimen. Right: test specimen mounted in tensile stage.

Analysis and preliminary results

The obtained voxel data, see Figure 2, can be studied qualitatively both to understand the true 3D morphology of the microstructure and to understand how it is linked to e.g. damage processes.

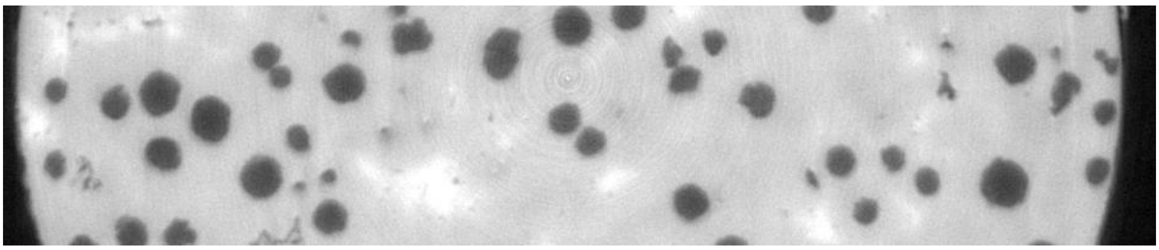

Figure 2. Section through test specimen showing the microstructure of the tested material.

An open source tool, 3D Slicer [2] has been used to reveal the 3D nature of individual features, see Figure 3. To be able to rotate individual particles gives another level of understanding for the morphological complexity. It also raises concerns regarding how to resolve it adequately in an FE mesh.

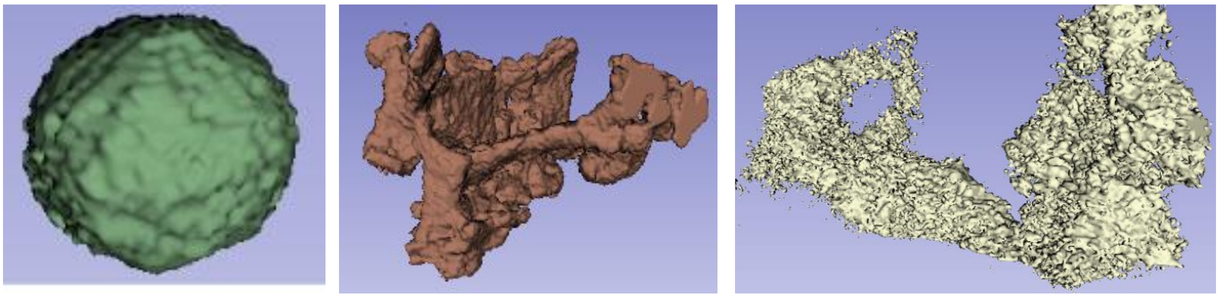

Figure 3. Microstructural features. Left: Graphite nodule. Middle: Porosity. Right: Carbide structure.

In a subsequent step the volumetric images were analysed quantitatively using Digital Volume Correlation to obtain e.g. local displacements within the test specimen as function of the applied loading. The analysis was carried out using DaVis 10.1 [3] These results can be used to further understand the mechanical response of the material, see Figure 4.

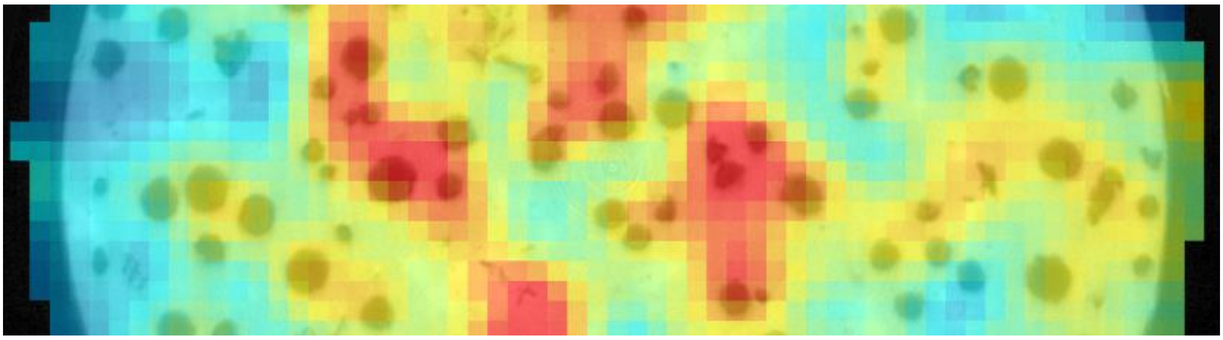

Figure 4. Maximum normal strain obtained from DVC analysis. Contours range from 0% (blue) to 12% (red). Image corresponds to a load of ~925 N.

Within the study steps are taken towards implicitly measuring local mechanical properties by minimising the difference between the displacements obtained from the DVC analysis and the displacements from a Finite Element Model of the test specimen [4].

Concluding remarks

Ductile Cast Irons are highly relevant in an industrial context. Knowledge about the relation between the microstructural morphology and the mechanical performance is valuable when seeking new alloys that can withstand more harsh conditions due to e.g. increasing environmental requirements. By analysing volumetric images obtained through tomography using Digital Volume Correlation and Finite Element Modelling new insights regarding the relation between the microstructure of the material and its mechanical performance are gained.

References

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