**Proceedings of the 7th GACM Colloquium on Computational Mechanics
for Young Scientists from Academia and Industry
October 11-13, 2017 in Stuttgart, Germany**

Diffraction and Attenuation X-ray Imaging of Ductile Damage Combine with Crystal Plasticity Finite Element Modelling

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Micro Abstract
Recent techniques of 3D synchrotron imaging allow to fill the gap between several fields of experimental damage mechanics. The present work combines local crystallographic characterisation and the related plasticity mechanisms to observations and quantitative measurements of the three stages of ductile fracture, applied on aluminium. Phase and diffraction contrast tomography are used as input for modelling to better understand the local stress and deformation state governing damage.

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Introduction

Recent techniques of 3D synchrotron imaging allow today to fill the gap between several fields of experimental damage mechanics, from crystallographic texture characterization to high resolution imaging of phases, voids and cracks as they evolve during in situ loading. Coupling local crystallography and the related plasticity mechanisms to observations and quantitative measurements of the well established stages of ductile fracture in metallic alloys (namely initiation, growth and coalescence of cavities) greatly helps understanding the development of fracture. It can also be used to design safe, high performance alloys for use in the transportation industry but also in biomedical applications for example. In this study, ductile damage is investigated by X-ray tomography in a 1050 aluminum alloy during in situ tensile testing at the ID11 beamline of the European Synchrotron Radiation Facility (ESRF). The heterogeneity of plasticity is later assessed by crystal plasticity finite element modeling (CPFEM) based on the actual polycrystal microstructure.

Results

Diffraction Contrast Tomography (DCT, [3]) alloys to map the initial polycrystal in 3D (grain size, morphology as well as crystallographic orientation). This is illustrated in Fig. 1a where the recrystallized Al sample presents about 100 grains in the volume of interest. Damage is subsequently followed in situ by Phase Contrast Tomography (PCT) during loading [4]. Fig. 1b depicts the cavities (red) in the PCT-reconstructed deformed volume. The in situ procedure and the use of appropriate markers at the sample surface allow an easy alignment of the successive volumes acquired after each deformation step. A recent automatic tracking algorithm [2] was used in order to follow each cavity individually and to characterize their different strains at initiation and growth rate. As anticipated, there is a significant scattering of growth rate, which is related to the local microstructural and crystallographic environment of each cavity.

In order to assess the local heterogeneity of strain and stress fields in the polycrystal, full-field CPFEM simulations of the tensile test were carried out based on the actual 3D DCT volume. This was done using a boundary conforming procedure, after fitting the parameters of an elasto-viscoplastic crystal plasticity constitutive law on a macroscopic tensile curve [1].

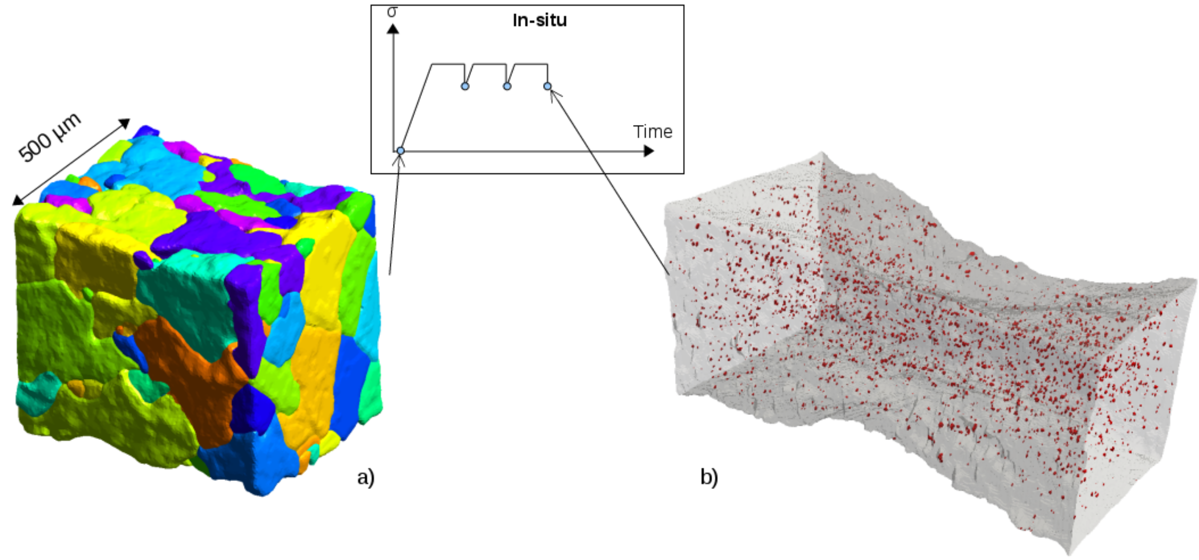

Figure 1. In situ tensile testing of an Al polycrystal during synchrotron X-ray tomography. (a) Initial DCT mapping of the grains and (b) damage cavities (red) observed by PCT.

The CPFEM simulation results are illustrated in Fig. 2, where the heterogeneity of stress is clearly visible. Such simulation is subsequently used to model the heterogeneous cavity growth based on the actual crystallographic environment, to compare with the experimental cavity tracking measures.

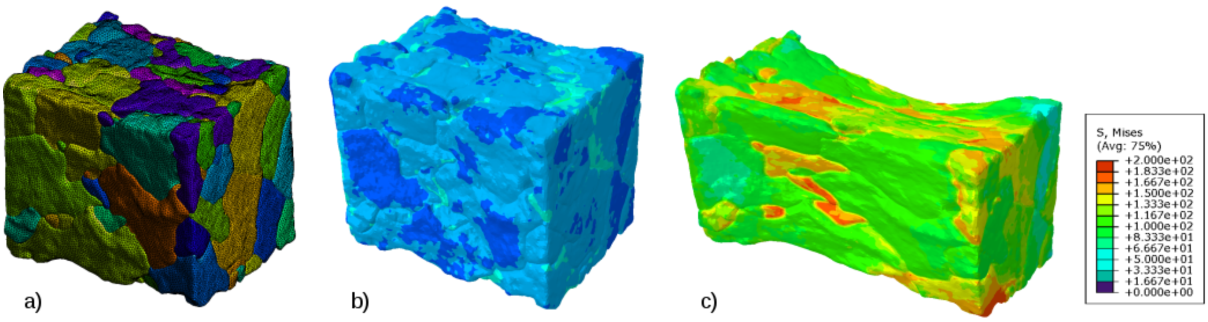

Figure 2. CPFEM simulation of the tensile test. (a) Conformal mesh of the DCT volume from Figure 1. (b) and (c) development of stress heterogeneity from 2.5% to 50% tensile deformation.

Conclusions

Diffraction and attenuation X-ray imaging provides a powerful environment to characterize ductile damage mechanisms in situ, in relation with local microstructure and crystallography. DCT-based CPFEM simulations open a wide range of opportunities to analyze deeper the heterogeneity of plastic flow governing damage in this context.

Acknowledgements

The authors acknowledge the support of ESRF, ID11 beamline, for providing the beamtime required for the experiments.

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