Effect of the initial strain state on the evolution of the average elastic strain tensor for 2000+ grains in Armco iron during elastic loading

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Strain heterogeneities in a polycrystal can be detrimental to the lifetime of a material. Understanding the complex behaviour between the initial strain state of a grain and its evolution during mechanical loading is essential to predict strain localizations leading to crack initiation and failure.

We combine Diffraction Contrast Tomography (DCT), Far-field 3DXRD (FF-3DXRD), and Phase Contrast Tomography (PCT) measurements at beamline ID11 of the European Synchrotron Radiation Facility (ESRF) to capture the shape, arrangement, orientation, and average elastic strain tensor of a representative ensemble of grains during mechanical loading. The finalized dataset encompasses the relevant information for each grain within the investigated volume throughout the entire loading sequence. Our analysis follows two distinct approaches: (1) statistical analysis of the strain distribution evolution during loading across all grains, correlating mechanical grain behaviour with microstructural properties such as size, orientation and neighbourhood; and (2) focused investigation of individual grains and their local neighbourhood and how the local properties affect the strain level in individual grains.

In this talk, our latest findings on the evolution of strain heterogeneities in bcc Armco iron are presented. We investigated more than 2000 grains present in the entire gauge section of a micro tensile sample during deformation. The initial eigenstrain distributions in the undeformed state were extensively analysed, which allowed us to identify mechanisms based on i) reduction of free volume during recovery and recrystallization as well as ii) shear-coupled grain boundary migration as possible origins of the unexpectedly very broad strain distributions.

The deformation sequence predominantly focused on the elastic regime, with only the final two steps exceeding the macroscopic yield strength. This experimental design allowed us to follow the transition from elastic to plastic deformation on the microstructural level for a large number of grains, providing relevant insights into micromechanical deformation behaviour. By investigating grains with different initial strain levels, we can observe the effect of the strain state on the formation and dissipation of strain hotspots during loading.

Our results present a significant step forward in understanding the evolution of individual grains in polycrystalline materials during elastic tensile deformation in addition to providing key insights into the phenomenon of microplasticity.