
In-situ characterization of Plastic Strain Localization and Strain Partitioning in Polycrystalline Materials via 3D X-ray Diffraction Imaging Techniques

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Abstract

Plastic deformation in metals often manifests as localized slip bands, which are characterized by complex dislocation structures leading to lattice distortions and rotations. Advanced 3D X-ray diffraction imaging techniques enable the non-destructive visualization and quantification of these phenomena, as demonstrated by Ludwig et al. (2019). This study highlights recent advancements in the characterizing lattice rotation fields during the early stages of plastic deformation in alloys such as Inconel 718, pure Ti, 304L, and 316L. The focus is on the roles of twin-related domains, phase transformations, and microstructural evolution under applied external stresses.

To complement synchrotron-based diffraction techniques, high-resolution digital image correlation (HR-DIC) from laser scanning confocal microscopy (LSCM) and scanning electron microscopy (SEM), provide additional insights into local slip activity (Stinville et al., 2023). The integration of near and far field methods (e.g., Diffraction Contrast Tomography, Topotomography, 3DXRD and s3DXRD) with high-resolution tomography enables multimodal characterization during in-situ tensile tests at room and elevated temperature, particularly

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at the ID11 synchrotron beamline. This combination yields comprehensive data on grain topography, mosaicity, and local strain fields across the sample volume (Arnaud et al., 2025).

The results underscore the potential of these advanced imaging techniques to unravel mechanism of strain localization and partitioning in polycrystalline materials. Through a synthesis of experimental data and simulations, the study demonstrates the critical influence of crystallographic orientation and twin-related domains on strain distribution and slip activity. Furthermore, high-temperature in-situ experiments reveal the evolution of deformation mechanisms under realistic loading conditions. These findings shed light on grain interactions, twin nucleation processes, and the microstructural responses to applied stresses, paving the way for improved understanding of plastic deformation in polycrystalline systems. Ultimately, this knowledge informs the design and optimization of next-generation high-performance alloys.

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