Unveiling emerging hierarchical dislocation structures by multifractal analysis of in situ SEM-EBSD tensile tests

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Résumé pour (effacer la mention inutile) : poster

Interactions among crystal defects lead to the self-organization of dislocations into complex patterns. Understanding their evolution during plastic deformation is essential for predicting material behavior. The self-organization produces hierarchical dislocation structures across multiple length scales, often exhibiting fractal geometry, which enables quantitative characterization. Fractal analyses have been applied to dislocation patterns at various scales, such as those corresponding to transmission electron microscopy images, deformation-induced surface roughness, and fracture surfaces. However, the mesoscopic scale accessible by scanning electron microscopy combined with electron backscatter diffraction (SEM/EBSD) has not been explored from this perspective, despite its ability to reveal heterogeneous dislocation density fields on scales ranging from micrometers to millimeters. Moreover, conventional fractal analysis captures only global hierarchy, while local heterogeneity remains largely unaddressed.

In this study, in situ SEM/EBSD tensile testing is combined with multifractal analysis to investigate the evolution of deformation-induced dislocation structures. The presentation focuses on the first application of this approach to solution-annealed 304L stainless steel that was deformed in both its as-received and neutron-irradiated states. In addition, selected EBSD examples will be presented to illustrate the potential of this methodology for a broader range of materials.

The first results can be summarized as follows. Multifractal analysis was applied to kernel average misorientation (KAM) patterns obtained at successive stages of deformation. The KAM maps show pronounced visual differences between the non-irradiated and irradiated specimens, most notably the early formation of dislocation channels after irradiation. Nevertheless, the multifractal analysis reveals a progressive development of hierarchical dislocation arrangements in both material states. Despite the visual differences, the multifractal characteristics indicate the evolution toward a similar underlying hierarchy of dislocation structures in both conditions. At the same time, the analysis highlights an accelerated formation of these structures under irradiation, accompanied by a restriction of their spatial extent that is likely associated with dislocation channeling. These results demonstrate that irradiation not only modifies the microstructure but also alters correlation-driven dislocation organization. More broadly, they show that multifractal analysis provides a powerful framework for probing mesoscale deformation mechanisms.