Physical insight into dislocation avalanches by Dislocation Dynamics Simulations

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Résumé pour un oral

At the mesoscale, plastic deformation proceeds through heterogeneous and intermittent dislocation activity, manifested as avalanche-like bursts. While material hardening can often be described through average dislocation behavior, phenomena such as strain-rate sensitivity, plastic localization, and stress concentration arise from the collective dynamics of these avalanches. Avalanche properties reflect both microstructural organization and statistical fluctuations of material response, and their rationalization is a cornerstone for developing consistent meso-to-macroscale coarse-graining frameworks. Despite extensive work over the past decades, many aspects of the critical nature of plastic deformation remain unresolved, and most mesoscale studies to date have focused on 2D systems or finite-size geometries such as micropillars.

In this work, we present a detailed statistical analysis of dislocation avalanches in bulk Cu single crystals using large-scale, three-dimensional discrete dislocation dynamics (DDD) simulations. Extensive datasets reveal a well-defined critical behavior characterized by power-law statistics spanning 3 to 5 decades of plastic event sizes. The sharp cutoffs delimiting these regimes correlate systematically with features of the evolving dislocation microstructure. Thorough microstructural analysis identifies critical configurations and spatial distributions that give rise to these avalanches.

The simulations further provide quantitative insight into the roles of individual slip systems, cross-slip activity, and strain-rate competition in shaping the observed avalanche behavior. These results establish direct connections to experimental observations, including in-house acoustic emission data, and offer a mechanistic interpretation of the avalanche signatures observed in crystalline plasticity.