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NONCONVEX PLASTICITY AND MICROSTRUCTURE

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ABSTRACT

The initial boundary value problem of plasticity can be given a variational structure by means of time discretization. The resulting incremental problems are governed by a minimum principle. In crystals, the pseudo-energy functional whose minimizers define the solutions of the incremental problem is non-convex due to the phenomenon of latent hardening. This lack of convexity promotes the formation of fine microstructure that correlates well with observed dislocation structures in plastically deformed crystals. In particular, the theory correctly predicts salient aspects of the geometry of dislocation structures in fatigued crystals and lamellar dislocation structures in crystals deformed to large strains. When dislocation energies and grain-boundary compliance are taken into account, the theory additionally predicts a 'phase diagram' of possible microstructures and scaling relations, including the Hall-Petch effect. Microstructure evolution can be analyzed within the framework of energy-dissipation functionals. These are functionals whose minimization delivers the entire histories of deformation and microstructural evolution in the solid. Relaxation and optimal-scaling constructions based on energy-dissipation functionals give the effective macroscopic kinetics of the material. Relaxation and related methods also have implications regarding the formulation of convergent numerical methods for solids undergoing microstructure formation. In particular, relaxation methods lead to the formulation of fast and demonstrably convergent multiscale finite-element methods in which the microsctructural evolution is treated optimally at the sub-grid level. Numerical examples illustrate the strong effect of microstructure formation on the macroscopic behavior of the sample, e.g., on the force/travel curve of a rigid indentor. Numerical examples additionally show that 'ad hoc' enhanced-strain elements, e.g., based on polynomial, trigonometric, or similar local strain enhancements, are unlikely to result in any significant relaxation in general.