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Fully optimized second-order homogenization estimates for the macroscopic response and texture evolution of low-symmetry viscoplastic polycrystals

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Abstract

In this paper, we present a finite-strain homogenization model for the macroscopic response of viscoplastic polycrystals deforming by crystallographic slip. The model makes use of the recently developed fully optimized second-order (FOSO) variational homogenization method, together with self-consistent estimates for the instantaneous response of a linear comparison composite (LCC) with optimally selected properties, to generate corresponding estimates for nonlinear viscoplastic polycrystals. The estimates are guaranteed to be exact to second order in the heterogeneity contrast, and to satisfy all known bounds. Unlike earlier second-order methods, the FOSO method has the distinct advantage that the macroscopic behavior and field statistics in the nonlinear composite can be conveniently extracted directly from the corresponding quantities in the LCC. Moreover, consistent homogenization estimates for the average strain-rate and spin fields in the grains are used to derive the evolution equations for the morphological and crystallographic textures of the polycrystals at large deformations. The FOSO method is then used for the first time to investigate the effects of rate sensitivity and grain anisotropy on the macroscopic response and field statistics of untextured (low-symmetry) HCP polycrystals. Comparisons with full-field simulations and earlier homogenization models show that the FOSO method is the most accurate to date. In addition, the FOSO method is used to predict the texture evolution for ice-like HCP polycrystals subjected to finite-strain loading conditions. It is found that the method is able to capture the strong basal texture that is observed experimentally in these materials under compression, leading to strong geometric softening/hardening effects, as well as strong viscous anisotropy in the overall response.