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Transitioning rate sensitivities across multiple length scales: Microstructure-property relationships in the Taylor cylinder impact test on zirconium

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Abstract

A finite-element based plasticity model is developed for polycrystals deformed to high-strain-rates. The model is multiscale, covering from thermally activated dislocation motion on a specific crystallographic slip system (*nm*), to single crystal plasticity (μm), to polycrystalline aggregate plasticity (*mm*), and ultimately heterogeneous deformation of the macroscale test sample (*m*). Within the model, the rate dependence in macroscale response arises solely from the microscopic characteristic stress to activate dislocation motion. This is accomplished by introduction of a novel methodology, used at the intermediate length scales, to relax the extraneous rate dependencies occurring as a result of the visco-plastic rate sensitive flow rule commonly associated with single crystal plasticity formulations. The multi-scale model developed here also permits simulations to be carried out in stress-imposed, strain-rate imposed, and mixed stress/strain-rate-imposed boundary conditions, another advancement over previous techniques. Simulation results are presented for the deformation of high-purity Zr in a Taylor impact cylinder test. The variation in sample shape changes, texture evolution, and deformation twin fraction after the test are experimentally examined. These same quantities are calculated with the model and good agreement is achieved in all aspects. We show that without adjustment of material parameters that the thermally activated hardening model applies to much higher strain-rates (10^4/s-10^5/s) than the strain-rates used previously to characterize it. This model can be broadly applied to understanding microstructure-property relationships in high-strain-rate deformation processes that generate spatially and temporarily heterogeneous mechanical fields.

Keywords: A Microstructures; B Elastic-viscoplastic material; B Rate-dependent material; C Impact testing; C Finite elements

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