Hardening and strengthening behavior in rate-independent strain gradient crystal plasticity

Two rate-independent strain gradient crystal plasticity models, one new and one previously published, are compared and a numerical framework that encompasses both is developed. The model previously published is briefly outlined, while an in-depth description is given for the new, yet somewhat related, model. The difference between the two models is found in the definitions of the plastic work expended in the material and their relation to spatial gradients of plastic strains. The model predictions are highly relevant to the ongoing discussion in the literature, concerning 1) what governs the increase in the apparent yield stress due to strain gradients (also referred to as strengthening)? And 2), what is the implication of such strengthening in relation to crystalline material behavior at the micron scale? The present work characterizes material behavior, and the corresponding plastic slip evolution, by use of the finite element method. The pure shear problem of an infinite material slab is investigated, with the previously published model displaying strengthening, while the new model does not. In addition to the numerical approach an exact closed form solution, to the pure shear problem, is obtained for the new model, and it is demonstrated that the model predicts proportional straining in the entire plastic regime. Somewhat surprising it is found that the predictions for strain gradient hardening coincide for the two models.
An incremental flow theory for crystal plasticity incorporating strain gradient effects

The present work investigates a new approach to formulating a rate-independent strain gradient theory for crystal plasticity. The approach takes as offset recent discussions published in the literature for isotropic plasticity, and a key ingredient of the present work is the manner in which a gradient enhanced effective slip measure governs hardening evolution. The effect of both plastic strains and plastic strain gradients are combined into this scalar effective slip quantity, the energy associated with plastic strain is dissipative (unrecoverable), while the energy from plastic strain gradients is recoverable (free). The framework developed forms the basis of a finite element implementation and is demonstrated on benchmark problems designed to bring out effects such as strengthening and hardening. Monotonic loading and plane strain deformation is assumed throughout, but despite this, non-proportional straining is predicted in the plastic regime even under pure shear conditions. Results of single slip and symmetric double slip reveal that strengthening and hardening are governed by the slip system orientation and the material length parameter only.

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