Finite Gradient Crystal Plasticity Theory Based on an Accumulated Plastic Slip: Modeling of Grain Boundaries

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ABSTRACT

The experimental investigation of micro-specimens of metals, e.g., [1], shows a size-dependent mechanical overall behavior. In oligocrystalline materials, work-hardening induced by dislocation-grain-boundary interactions provides an explanation for these size-effects. It was shown that this behavior can be reasonably captured with a single-crystal gradient plasticity model for small deformations (see, e.g., [2]). Taking the plastic slip on each slip system into account, an additional degree of freedom for each slip system is required. The computational cost of the resulting strongly coupled system of generally non-linear equations is massively increased, compared to a classical continuum mechanical description. In order to reduce the degrees of freedom in crystal simulations, a simplified gradient crystal plasticity theory based on an accumulated plastic slip was introduced in [3]. While preserving the single crystal slip kinematics, the model is restricted to one gradient-stress, associated with the gradient of the accumulated plastic slip, in order to account for long range dislocation interactions. Experimental studies, e.g., [4], showed discontinuous plastic slips on individual slip systems across grain boundaries. Whereas the accumulated plastic slip as an overall measure of plastic slip is assumed to be continuous in [5], the presented model accounts for discontinuities of the accumulated plastic slip at grain boundaries. Based on an energetic grain boundary yield criterion, the introduction of an interface energy penalizes plastic slip at the grain boundaries. This allows to simulate grain boundary behavior in between the limits of full transparency and impenetrability on the continuum scale (see, e.g., [6]). The grain boundary flow rule is evaluated at sharp interfaces, by using discontinuous trial functions in the finite element implementation. Simulations of crystal aggregates are performed under different loading conditions. For the special case of an one-dimensional solution, the numerical results are compared to an analytical solution.

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