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Consideration of different hardening mechanisms in a higher-order crystal plasticity theory

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ABSTRACT

It is well known that size effects are present in plasticity with the observation that smaller being the stronger. This effect is attributed to the presence of geometrically necessary dislocations (GNDs). The hardening associated to GNDs can be separated in two groups: energetic and dissipative. The first is associated with defect energy and different definitions for it are possible. In all cases, however, this type of hardening depends on plastic strain gradients. The second is associated with plastic strain rate gradients. Different theories can be used to model the effects of GNDs at different scales. In this study, the Gurtin's continuum model of crystal plasticity is used. It has the advantage of clearly separating hardening effects, which can lead to a better understanding of the hardening mechanisms. Besides isotropic defect energy, an energy based on dislocation pile-up is also considered. Being a higher-order theory, the computational solution of the Gurtin's model is sometimes difficult to obtain. Depending on material properties, one of the problems is the lack of uniqueness of the numerical solution. This problem is addressed in this study considering a dynamic explicit solution of the balance equations. As a test case, the simulation of wedge indentation of single crystals in plane strain is considered. Three active slip systems are taken into account. Comparisons are made with experiments and also with discrete dislocation simulations which are performed for same crystal geometry and boundary conditions. Preliminary observations indicate that energetic hardening is an essential parcel of the overall hardening process. The results obtained considering only the dissipative hardening are not compatible with discrete dislocation simulations.