
Deformation patterns in finite strain crystal plasticity

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Abstract

It has been known since at least Piercy et al. (1955) (1), that the interaction between dislocations gliding on different slip systems can lead to "patchy slip" (2). This phenomenon is characterized by the segregation of plastic deformation in regions of single slip with little or no overlap between each region. Mathematically, this behaviour can be modeled by accounting for strong latent hardening effects in the crystal plasticity constitutive equations (3). Ortiz and Repetto (1999) (4) reviewed the occurrence of patchy slip in experiments and proposed a methodology to predict the onset of this phenomenon based on nonconvex energy minimization. They showed that the formation of patches follows a lamination process. The authors then drew a link between this deformation mechanism and the emergence of dislocation structures. Recently, Dequiedt et al. (2015) (5), Wang et al. (2018) (6) and Ryś et al (2024) (7) have shown the occurrence of patchy slip in single crystal plasticity simulations. Viscoplastic and rate-independent crystal plasticity models were considered in these studies and both were shown to induce formation of single slip patterns provided that the rate-dependence is sufficiently weak. To this day, regularization of the size of single slip regions predicted in these simulations is still missing in the literature. In addition, the occurrence or absence of patchy slip in 2D and 3D polycrystal simulations is still an open question.

We revisit the plane strain cases investigated by Ryś et al. (7) in the context of finite strains. A crystal viscoplasticity model based on dislocation densities evolutions is implemented in a finite element software. First, we show the emergence of single slip deformation patterns. We demonstrate that these patterns are indeed associated to dislocation structures similar to cells and labyrinths. The sensitivity of deformation microstructures to numerical parameters such as mesh size, finite element type and integration scheme is discussed. We then extend the simulations to 3D single crystal specimens loaded along the highly symmetric (001) direction. The crystal plasticity model is then extended to strain gradient plasticity in order to regularize the size of single slip regions and associated dislocation structures. Finally, we discuss the occurrence of patchy slip in 2D and 3D polycrystal simulations.

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