Subgrain dislocation structures and ductile fracture of metals

We consider single-crystal plasticity in the limiting case of strong latent hardening, which signifies that the crystal prefers to deform in single slip at all material points. This requirement introduces a nonconvex constraint in the dissipation and thereby induces the formation of fine-scale structures. We first study a scale-invariant (local) problem in the linearized kinematics limit. We show that, by developing microstructures in the form of sequential laminates of finite depth, crystals can beat the single-slip constraint, i.e., the macroscopic (relaxed) constitutive behavior is indistinguishable from multislip ideal plasticity. In a second step, we include dislocation line energies, and hence a length scale, into the model. Different regimes lead to several possible types of microstructure patterns. We present constructions that achieve various optimal scaling laws and discuss the relation with experimentally known scalings, such as the Hall-Petch law. Finally, we allow for finite kinematics and show that a competition between local sub-linear growth and a non-local regularization promotes the formation of void sheets and, ultimately, ductile fracture.