The energy approach to deformation banding in Cosserat crystal plasticity

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Numerical simulations employing classical crystal plasticity models have encountered two major, long-standing issues: the ambiguity in selecting active slip systems, and the instability of uniform plastic deformation due to deformation banding. To address these challenges, regularization techniques have frequently been applied by introducing a rate-dependent model of crystal plasticity and/or a gradient-dependent enhancement of the continuum framework. However, experimental observations have repeatedly shown that ductile metal crystals tend to develop deformation bands, suggesting that efforts to eliminate this phenomenon in calculations may lack a solid physical foundation. In accordance with that, in a companion presentation at this conference, M. Kursa demonstrates that this phenomenon is not eliminated even if using a standard rate-dependent model, provided that latent hardening exceeds self-hardening of slip systems and the strain-rate sensitivity parameter is sufficiently small. Notably, this does not require any artificial perturbations or geometric imperfections.

The focus of this lecture is the explanation of the deformation banding phenomenon using a rate-independent model of crystal plasticity with the Cosserat-type regularization, applied within the framework of incremental energy minimization [1]. A strictly variational micropolar approach has been implemented in a finite element code. The present study demonstrates that spontaneous emergence of deformation bands is predicted, under the same basic condition that latent hardening of slip systems exceeds their self-hardening, provided the size of the crystal domain is not too small. This is made specific by requiring that the band wavelength exceed the established minimum value, proportional to the square root of the quotient of two factors: the coefficient of the energy density due to the lattice curvature, and the positive difference between the cross-hardening and self-hardening modulus. A nearly perfect agreement has been found between the analytical estimate of the minimal band wavelength and the band interface thickness in full-field finite element simulations in plane strain. It has been demonstrated that the incremental energy minimization is a suitable tool for computing deformation patterns in ductile single crystals with the Cosserat-type regularization.

[1] M. Ryś, M. Kursa, H. Petryk, Selecting deformation patterns in Cosserat crystal plasticity by incremental energy minimization, *J. Mech. Phys. Solids* **212**, 106569, 2026. https://doi.org/10.1016/j.jmps.2026.106569