Unexpected Formation of Deformation Bands in the Rate-Dependent Modelling of Single Crystal Plasticity

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The phenomenon of spontaneous formation of deformation bands in metal crystals is investigated using a simple model of crystal plasticity at small strain, with and without the Cosserat-type regularization. A standard and widely used rate-dependent (RD) model has been implemented in a finite element method (FEM). Nevertheless, a laminate pattern emerges spontaneously and is comparable to that obtained using an approach based on incremental energy minimization [1, 2]. It is emphasized that the FEM implementation does not involve any artificial perturbations or geometric imperfections, as well as any predefined laminate kinematics.

The Cosserat model introduces a natural regularization mechanism by inclusion of an internal length scale. The model contains two deformation measures: the relative deformation tensor $\boldsymbol{e}$ and the curvature tensor $\boldsymbol{\kappa}$. The deformation measures are defined based on two independent kinematic fields of displacement $\boldsymbol{u}$ and microrotation vector $\boldsymbol{\phi}$. An isotropic Cosserat part of the elastic response is controlled by two parameters of Cosserat elasticity, $\mu_c > 0$ and $\beta_c > 0$.

FEM simulations were performed using a plane-strain model in which the twelve positive fcc slip-systems were reduced to three effective in-plane plastic slip mechanisms, cf. e.g. [3]. The most important condition for the formation of deformation bands is that the latent hardening of slip systems exceeds their self-hardening. The next key factor in the rate-dependent simulations is a sufficiently small strain-rate-sensitivity parameter, highlighting the crucial role of the yield-vertex effect. The results of RD simulations reveal an entire domain filled with a laminate pattern formed by deformation bands with alternating slip-system activity, as illustrated in Fig. 1.

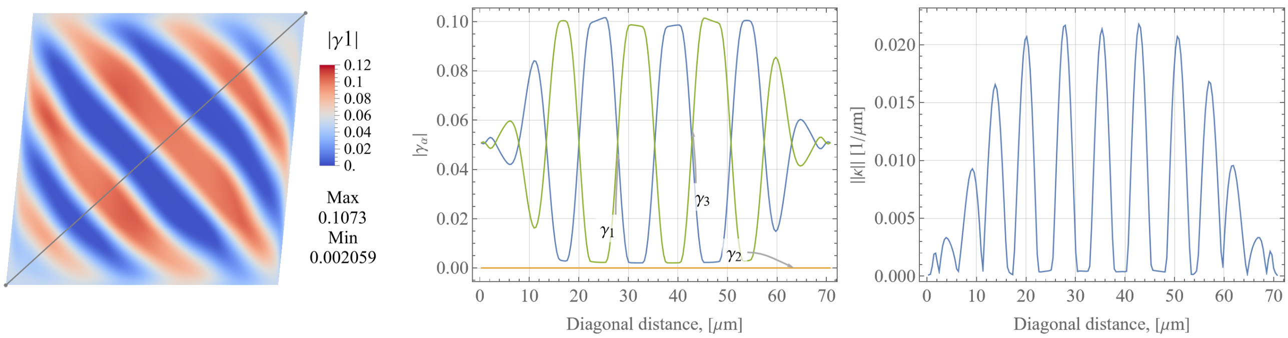

Figure 1: Accumulated slips $|\gamma^\alpha|$ in macroscopically uniform simple shear in case of initial crystal orientation $\omega = \pi/4$, for the Cosserat parameter to hardening modulus ratio $\beta_c/h_0 = 1/2.5$ [mN/GPa] and dimensions $50\mu m \times 50\mu m$, profiles of slips $|\gamma^\alpha|$ along the diagonal, and the norm of the curvature tensor $\|\boldsymbol{\kappa}\|$ which is strongly localized at the band interfaces.

[1] M. Ryś, M. Kursa, H. Petryk, Spontaneous emergence of deformation bands in single-crystal plasticity simulations at small strain, *Comput. Mech.* **75**, 547-574, 2025. https://doi.org/10.1007/s00466-024-02519-8

[2] 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

[3] M.J. Lewandowski, S. Stupkiewicz, Size effects in wedge indentation predicted by a gradient-enhanced crystal-plasticity model, *Int. J. Plast.* **109**, 54–78, 2018. https://doi.org/10.1016/j.ijplas.2018.05.008