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Shear localisation in homogeneous, mechanically anisotropic materials

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Shear localisation is a common phenomenon and can be observed on almost all scales in rocks. Despite decades of research, there is ongoing debate on the mechanisms of shear localisation. Processes such as softening reactions, shear heating and grain-size reduction have been investigated intensively. However, the potential role of anisotropy in strain localisation has received relatively little attention.

We use a full-field crystal viscoplasticity code based on the Fast Fourier Transform (VPFFT; Lebensohn, 2001) coupled with the multipurpose modelling platform ELLE (http://www.elle.ws) to simulate the deformation of an anisotropic and homogeneous material in simple shear up to large shear strains (>5). In our simulations we use the symmetry and the slip systems of ice Ih as a model for a strongly anisotropic material. The VPFFT-approach simulates viscoplastic deformation by dislocation glide, taking into account the different available slip systems and the critical resolved shear stresses required to activate them. It is, therefore, particularly well suited for strongly nonlinear anisotropic materials. We varied the intensity of anisotropy (A; ratio of critical resolved shear stresses of hardest and easiest slip system) from A=1 (effectively isotropic) to A=64 (highly anisotropic, assumed for ice Ih), as well as the model resolution (64x64 to 1024x1024 Fourier points).

Shear localisation occurs in all simulations. The von Mises strain rate and stress fields become increasingly heterogeneous with ongoing deformation until a steady state is reached. The degree of steady-state localisation depends strongly on the anisotropy of the material. Probability density functions of strain-rate values show distinct deviations from Gaussian distribution for simulations with anisotropy, indicating self-organization and entailing fractal distributions. Fractal analyses of strain-rate distributions indicate multifractal statistics.

Shear localisation due to anisotropy appears inevitable in our simulations, which raises the question whether there is a larger length scale where shear localisation is averaged out. Fractal statistics indicate that shear localisation is to be expected at all scales, explained by the fact that the reason for localisation, mechanical anisotropy, is a property with no length scale. The degree of anisotropy as well as the system size (up to crustal scale) will mainly control the magnitude of localisation.

Lebensohn, R. A. (2001). N-site modeling of a 3D viscoplastic polycrystal using fast Fourier transform. Acta Materialia, 49(14), 2723-2737.