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The effects of perturbations on the strain distribution in numerical simulations – elasto-viscoplastic modeling of boudinage as a case study

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During necking of a mechanically stiffer layer embedded in a weaker matrix, relatively large amounts of strain localize in small areas. As this deformation style appears under distinct geological conditions, necking phenomena, e.g. boudinaged veins, are associated with a variety of deformation modes. So far, there exists rather limited knowledge about the origin of instabilities and their role as precursory structures, i.e. strong localization of elastic energy affecting further plastic deformation (e.g. Regenauer-Lieb & Yuen, 1998; 2004; Karrech et al., 2011a).

We applied the finite element solver ABAQUS in order to investigate the 2-D strain distribution in layers including different mechanical material properties during plane strain co-axial deformation. First, linear perturbation analyses were performed in order to evaluate the imperfection sensitivity in the elastic and viscous regimes. We perform a classical modal analysis to determine the natural mode shapes and frequencies of our geological structure during arbitrary vibrations. This analysis aims at detecting the eigenmodes of the geological structure, which are sinusoidal vibrations with geometry specific natural modal shapes and frequencies. The eigenvalues represent the nodal points where the onset of (visco)-elasto-plastic localization can initiate in the structure (Rice, 1977). The eigenmodes, eigenvalues and eigenvectors are highly sensitive to the layer-box' aspect ratio and differences in Young's moduli, or effective viscosity, respectively. Boundary effect-free strain propagation occurs for layer-box aspect ratios smaller than 1:10. Second, these preloading structures were used as seeds for imperfections in elasto-viscoplastic numerical modeling of continuous necking of a coarse-grained mineral layer embedded in a finer-grained matrix (pinch-and-swell type of boudinage), following the thermo-mechanical coupling of grain size evolutions by Herwegh et al. (in press). The evolution of symmetric necks seems to coincide with the transition from dislocation to diffusion creep dominated viscous flow with dramatic grain size reduction and grain growth from swell to neck, respectively, at relatively high extensional strains. Strain propagates from initial stress concentrations in the layer (necks) at an angle of 45° into the matrix, in form of conjugate shear band sets.

Preliminary results show that pre-calculated eigenmodes (and corresponding imperfection sizes) amplify these concentrations and lead to a significant reduction of computational time for individual simulations. Moreover, the strain imperfections seeded around the pre-calculated distribution severely change the geometry of necking structures and amount of accommodated plastic strain.

We reveal that elastic stress concentrations control localized visco-plastic deformation, which is expressed in the plastic strain energy increase in necking structures. These findings underline the importance of the transient (elasticity and strain hardening) deformation regimes as triggers for plastic deformation and the need for thermodynamics-based (total) energy considerations.

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