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Numerical study of a rigid circular inclusion in an anisotropic matrix

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Anisotropy and heterogeneity play an important role in structural development of rocks. While both topics have gained much attention independently, joint studies are lacking. We perform a combined study focused on the structure evolution around a rigid circular inclusion embedded in a layered medium subjected to a distant simple shear. Firstly, an analytical solution describing an external flow field around an inclusion for a homogeneously anisotropic matrix sheared diagonally to the anisotropy plane is presented. We discuss characteristics of the flow field such as a range of the flow perturbation, degree of the shearing localization and orientation of highly deformed bands as a function of the anisotropy factor (ratio of normal and shear viscosity). An approximate far field solution, still capturing important features of the solution, is given. An infinitely anisotropic host limit is analyzed and the formation of kink bands aligned with anisotropy trace is predicted. The rotation rate of a rigid circular inclusion is found to coincide with the isotropic host case irrespective of anisotropy factor which is in compliance with symmetry reasoning. The analytical solution is validated numerically using an anisotropic incompressible Stokes finite element method (FEM). The results allow us to assess the influence of the confinement in a finite size computation domain. Then, we directly resolve the anisotropic medium by explicitly introducing host of alternating competent and weak layers with isotropic viscosities adjusted to analyzed anisotropy factors. The impact of finite thickness of layering with respect to inclusion size on inclusion rotation rate is studied and the resemblance of external flow field to the homogeneous host solution is presented. Next, we perform a FEM finite strain calculation integrating behavior of the inclusion and initially homogeneous anisotropic host system up to strains of gamma 5. Now the anisotropy plane

is expected to vary locally as it is reoriented and advected in the non-homogeneous flow field around an inhomogeneity during progressive deformation. In the case of explicitly resolved layers this structure formation is automatically taken care of during updates of the computational geometry in consecutive time steps. In the case of a homogeneously anisotropic host structure development is dealt with an evolution equation for an anisotropy director that relies on the assumption of an underlying layered media. The obtained results show that due to the structure development rotation rate of the rigid inclusion is significantly reduced for all studied anisotropy factors of 2, 10 and 100. For strong anisotropy the rotation becomes virtually antithetic and as such the anisotropy of the host may provide another mechanism of stabilizing a rigid inclusion in a simple shear. The evolution of the rotation rate in the case of the layered host exhibits similarities to the results obtained with the anisotropy code and the convergence of the evolution curve with increasing number of layers across the inclusions is observed. Finally, we analyze structures developed in the host. Already for a weak anisotropy the structural development is apparently different to that of the passive markers in an isotropic host. We observe that secondary folds grow in domains that are reoriented into the favorable direction for the instability to become active. However, the dominant wavelength of the folds in the multi-layer stack increases with viscosity ratio and development of secondary or even primary deflections of the layering may be inhibited. The loss of a definite wavelength of the second generation folds is observed in the case of the anisotropic code as this setup corresponds to the infinitely thin layer thicknesses.