A new method for modelling of coupled brittle - ductile deformation

Introduction

The combined deformation of brittle and ductile materials plays a role in a number of important geological processes. One such process which is of particular importance is the brittle deformation of carbonate of anhydrite layers embedded in a viscous salt body during tectonics. One other example of coupled brittle-ductile deformation is boudinage.

We are proposing a method where both the viscous and the brittle material are modeled using mesh-less, particle based Lagrangian methods. In this approach the viscous or fluid material is represented by a Smoothed Particle Hydrodynamics (SPH) model and the brittle solid is represented by a Discrete Element Method (DEM) model. Both approaches are well tested in their respective domain and due to the similarities between them it is possible to couple the two approaches to develop a hybrid method.

Methods

DEM and SPH are mesh free, particle based Lagrangian discretisation approaches. In both methods the material is represented by particles, which are carrying mass, momentum and other physical properties. The particles interact with other particles in their vicinity and move due to the forces resulting from these interactions. The difference between the two methods is the way in which these interactions are calculated and the particle positions are updated.

DEM

Discrete Element Modeling was developed by Cundall and Strack (1979) to describe granular material and extended by Mora and Place (1994) to the modeling of brittle solids. Particles interact with their nearest neighbors and with the walls by free elastic and "bonded" forces and the motion of the particles are calculated by updating the velocities of each particle from the sum of the forces exerted on that particle using Newton's law.

SPH

Smoothed Particles Hydrodynamics (SPH) was invented to simulate non axis- symmetric phenomena in astrophysics (Lucy 1977; Gingold & Monaghan 1977).

In SPH simulations any function can be expressed in terms of its values at a set of particles. Each particle is carrying mass, momentum, and hydrodynamic properties.

SPH is an interpolation method, the integral of the particle density is approximated using a special smoothing function, called kernel. The basic equations are the Navier-Stokes equations, which can be solved via time integration.

There are two types of particles: real particles and virtual boundary particles. They have the same properties; the only difference is that the virtual particles are not moving due to forces, but are used to represent the model boundaries.

Coupling of SPH and DEM particles

The coupling between the viscous (SPH) and the brittle-elastic (DEM) material is implemented using DEM particles as virtual SPH particles which interact with SPH particles according to the SPH discretisation of the Navier-Stokes equation and with DEM particles according to the DEM nearest-neighbor interactions. The forces due to both types of interactions are combined and the hybrid particles are moved according to Newton’s law.

Results of pure shear tests

26 tests have run with various differential stress and viscosity values. The decrease of strain is linear with time, consequently the strain rate is constant. We found linear relationship between the calculated strain rate and the applied differential stress. The slope of the fitted line is proportional to the applied viscosity.

Boudinage

Boudins are structures forming during systematic segmentation of preexisting layers. The process leading to the formation of boudins in boudinage.

Boudins forms during deformation if there is a component of thickening parallel to a competent layer in an incompetent matrix. Ductile extension cannot keep pace with that of the incompetent matrix, and the layer tends to pull apart into boudins.

Model setup

In our simulation, top and bottom walls move at constant velocity, right wall is force controlled so that the differential stress remains constant.

Model setup

In our simulation the horizontal walls move at constant velocity, right wall is force controlled (Case 2).

Results of boudinage

Case 1: One-sided extension, bonds with lower breaking strength

Case 2: Two-sided extension, bonds with higher breaking strength

Conclusion

We presented a new method for the simulation of brittle - ductile deformation in a Lagrangian way using mesh-less particle based method. This method coupled Smoothed Particle Hydrodynamics and Discrete Element Method. Our first results were proof of concept. In our model, the linear relationship between the differential stress and strain rate is valid.

This approach can be adopted to model the deformation of carbonate layers embedded in a viscous salt body during tectonics. Furthermore future studies include the investigation boudinage processes in more details as well.

References


