The Effect of Water on Crack Interaction

O. Gaede (1) and K. Regenauer-Lieb (1,2)

(1) Multiscale Earth System Dynamics, School of Earth and Environment, The University of Western Australia, WA 6009, Australia (gaede@cyllene.uwa.edu.au), (2) CSIRO Exploration and Mining, PO Box 1130, Bentley, WA 6102, Australia

While the mechanical coupling between pore fluid and solid phase is relatively well understood, quantitative studies dealing with chemical-mechanical weakening in geological materials are rare. Many classical poroelastic problems can be addressed with the simple law of effective stress. Experimental studies show that the presence of a chemically active fluid can have effects that exceed the predictions of the law of effective stress. These chemical fluid-rock interactions alter the mechanical properties of the solid phase. Especially chemical-mechanical weakening has important ramifications for many areas of applied geosciences ranging from nuclear waste disposal over reservoir enhancement to fault stability.

In this study, we model chemically induced changes of the size of the process zone around a crack tip. The knowledge of the process zone size is used to extend existing effective medium approximations of cracked solids. The stress distribution around a crack leads to a chemical potential gradient. This gradient will be a driver for mass diffusion through the solid phase. As an example, mass diffusion is towards the crack tip for a mode I crack. In this case a chemical reaction, that weakens the solid phase, will increase the size of the process zone around the crack tip.

We apply our model to the prominent hydrolytic weakening effect observed in the quartz-water system (Griggs and Blacic, 1965). Hydrolytic weakening is generally attributed to water hydrolyzing the strong Si-O bonds of the quartz crystal. The hydrolysis replaces a Si-O-Si bridge with a relatively weak hydrogen bridge between two silanol groups. This enhances dislocation mobility and hence the yield stress is reduced. The plastic process zone around a crack tip is therefore larger in a wet crystal than in a dry crystal.

We calculate the size of the process zone by solving this coupled mechanical-chemical problem with the Finite Element code ABAQUS. We consider single crack, collinear crack and parallel crack configurations and assume that the solute transport in the solid phase is diffusion limited. First, the stress field around the crack-tip is modeled. In a second step, the stress field is used to determine the chemical potential gradient and subsequently the diffusion process is modeled.

In order to obtain the effective elastoplastic stress-strain relations for a cracked solid with hydrolytic weakening, the numerical results for the individual cracks are upscaled with an effective medium approximation. We follow the approach of Chernyakov et al. (2003) and incorporate the size of the process zone via the Dugdale crack model.

We show that a chemical reaction, such as hydrolytic weakening, changes the overall effective mechanical properties of a cracked solid. The time scale of this change is a function of the diffusion and reaction rates. These rates themselves are dependent on other environment variables such as temperature and pressure.

References:

D. T. Griggs and J. D. Blacic, 1965. Quartz: Anomalous Weakness of Synthetic Crystals. Science 147, 292-295.

Y.A. Chernyakov, V. Grychanyuk and I. Tsukrov, 2003. Stress-strain relations in elastoplastic solids with Dugdale-type cracks. Engineering Fracture Mechanics 70, 2163-2174.