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MULTIPHYSICS COUPLINGS AND INSTABILITY IN GEOMECHANICS

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Even under uniform loading conditions, a critical configuration of a deformed body can exist, where homogeneous deformation breaks down into deformation bands. Shear bands, dilation bands, compaction bands, as observed in nature and in laboratory experiments, are examples of such strain localization phenomena. Deformation bands resulting from localized deformation appear at all scales from tens of kilometers for large crustal faults, which accommodate tectonic deformation of the Earth's crust, to few microns for slip zones observed inside faults core. Faults and compaction bands significantly influence the stress field and fluid transport. Localized compaction in porous rocks dramatically reduces permeability across the compaction zone, providing highly anisotropic channeling of fluid flow in reservoir rocks. Change of permeability and compartmentalizing of fluid flow resulting from the presence deformation bands is thus of major importance in geo-energy systems.

Although strain localization in the form of deformation band formation can occur with negative or positive rate of strain hardening, softening behavior definitely favors shear banding. This softening behaviour may correspond to a mechanical degradation of the rock properties (microcracking, grain crushing and grain size reduction…), but various other physical processes can be responsible for it. The effect of an infiltrated pore fluid which interacts with a rock mass can lead to a hardening or softening behavior depending on the volumetric response of the rock (dilatant or contractant). The fast heating of a saturated geomaterial leads to pore-fluid pressurization due to the discrepancy between the thermal expansion of water and solid grains. Thermal pressurization is a softening mechanism as it results in a decrease of the effective mean stress and thus of the shear strength. Chemical reactions such as dissolution/ precipitation, mineral transformation at high temperature (dehydration of minerals, decomposition of carbonates, …) affect the solid phase and the porosity of the rock and can induce a positive feedback in the progressive mechanical degradation. Thermal decomposition of minerals at large rise in temperature liberates a fluid product phase and enhances the generation of additional pore pressure excess [1,3]. It can form a mineral assemblage stronger (reaction hardening) or weaker (reaction weakening) than the original material. On the other hand, mechanical damage increases the reaction surface between a reactive fluid and the solid and enhances dissolution and further material weakening [2]. Competing effects of fluid released by the chemical reaction and volume change by dehydration affect the pore fluid pressure and can potentially lead to pore pressure run away.

A key parameter when studying multi-physics effects on the formation and evolution of deformation bands is the actual width of the localized zone. Obviously, this parameter plays a major role in the energy budget of the system as it controls the feedback of the dissipative terms in the energy balance equation. Narrow deforming zones concentrate the frictional heating, which leads to large temperature rises and thus to more rapid weakening. The width of the deforming zone is determined by the various physical processes involved in the weakening mechanisms but it also controls the multi-physics couplings which occur during dynamic slip.

In this talk, we review some multi-physics couplings, which enhance strain localization in geomaterials. The conditions for deformation band triggering are investigated analytically through linear stability analysis by considering various multi-physics couplings. The post bifurcation behavior is studied both analytically and numerically revealing the localization thickness (Fig. 1). The localization zone thickness can be captured either by considering rate dependency of the constitutive law or by resorting to higher order continua that possess an internal length. In order to explore the link between the two different modeling approaches a comparison between a) rate dependent Cauchy continuum and b) rate independent Cosserat continuum is shown for the scaling of the localized zone thickness.

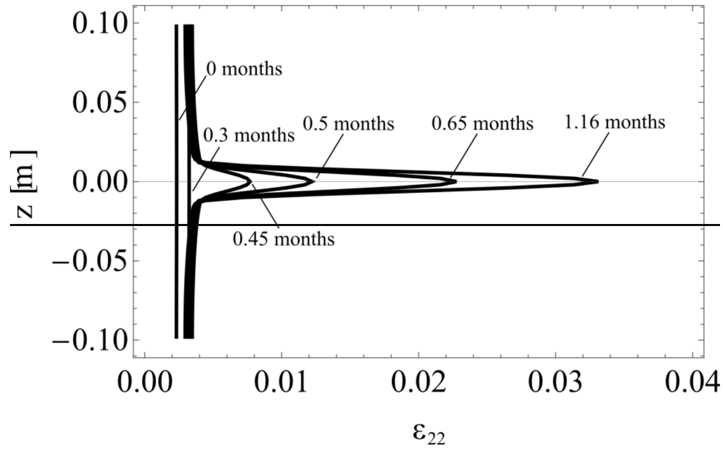

Figure 1. Profile of the vertical deformation at various times of a rock specimen under oedometric conditions submitted to dissolution. After a creep phase the deformation localizes into a narrow band, i.e. a compaction band, (adapted from [4])

REFERENCES

[1] N. Brantut and J. Sulem. Strain Localization and Slip Instability in a Strain-Rate Hardening, Chemically Weakening Material. *Journal of Applied Mechanics*, 79(3), 031004. doi:10.1115/1.4005880, 2012.

[2] I. Stefanou and J. Sulem. Chemically induced compaction bands: Triggering conditions and band thickness. *Journal of Geophysical Research: Solid Earth*, 119(2), 880–899. doi:10.1002/2013JB010342, 2014.

[3] J. Sulem and V. Famin. Thermal decomposition of carbonates in fault zones: Slip-weakening and temperature-limiting effects. *Journal of Geophysical Research*, 114(B3), B03309. doi:10.1029/2008JB006004, 2009.

[4] J. Sulem and I. Stefanou. Thermal and chemical effects in shear and compaction bands, *Geomechanics for Energy and the Environment*, 10.1016/j.gete.2015.12.004, 2016.