

Research Group Profile

Poromechanics at Eindhoven University of Technology

Fracture and Swelling in Porous Media

Problem

Numerous saturated porous materials exhibit fracture and/or swelling. Ionized groups, such as clay platelets, proteins or carboxyl groups attract counter ions and hence water. Examples are clay, clay-stone, shale, intervertebral disc, cartilage, hydro-gels, ion-selective membranes and living cells. The physico-chemical events associated with the swelling are intimately linked to the three-dimensional stress and strain distribution, fluid and ion flow. In order to quantify these coupled phenomena for engineering solutions, there is a need for the development of robust constitutive and numerical models that are able to capture, in 3-D, the complex physical chemistry phenomena at stake, and its coupling with the finite order of the swelling deformation, and fracture it induces.

Approach

A robust finite element solution methodology is developed that captures the 3D swelling in finite deformation of incompressible and compressible saturated media. Dual porosity descriptions, fiber reinforcements, viscoelasticity, deformation dependent permeabilities are options that are readily available. Electro-osmosis, streaming potentials, streaming currents, diffusion currents, diffusion potentials, Donnan osmosis are just a few of the phenomena associated with finite deformation in these media. For validation, experimental facilities are available for direct observation of electro-osmotic flow, streaming potential, 3D swelling, nano-scale displacements and fatigue testing under salt solution.

In addition, the continuum poromechanics also allows us to model fracturing in porous media; the physics of

Core Competencies

- Experimental measurement facilities from nano to macro, including AFM, two photon microscopy, optical tweezer, ESEM.
- Constitutive modeling of porous materials.
- In-house development of advanced numerical simulation of swelling and fracture.

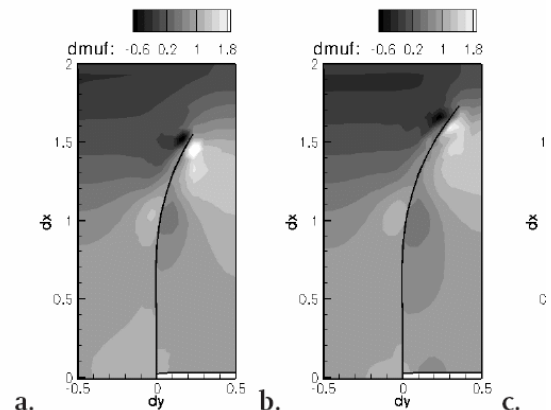


Figure : Pressure distributions in prestressed fluid saturated media subject to mode II fracture.

which is entirely different from the fracturing of solid, because of the fluid exchange between the crack and the solid. Recent developments include a meshfree method for crack propagation in porous materials that allows one to capture realistically both the fracturing and the fluid exchange phenomena.

Hydraulic fracturing, shear band formation, herniation of the intervertebral disc, sliding of tectonic plates or bore hole instability are just a few examples of fracturing in porous media, which we envision as applications for these developments.

Recent Findings

An interesting finding of these developments is that in contrast to the smooth crack propagation in homogeneous solids, the fracturing of fluid saturated porous media occurs in a staccato fashion. The crack progresses in a stepwise fashion. Swelling and osmosis affects this cracking dramatically.

Impact

Reliable numerical models for complex coupled phenomena are critical for engineering applications. We witness this in the increasing use of our models and software by multinational geotechnical companies. Furthermore, the pioneering application of poromechanics to biological tissues in general, and the insights gained into swelling and crack propagation through porous materials, becomes a new basis for medical device design, and has led to the development of a swelling disc prosthesis that is presently tested for fatigue resistance. All this points to a trend that poromechanics has become an enabling discipline for engineering innovation based on sound physics principles, rigorous mathematics and engineering discovery.

Selected Publications

1. Huyghe J.M., Molenaar M.M., Baaijens F.P.T., "Poromechanics of compressible charged porous media using the theory of mixtures", *J. Biomech. Eng.* **129**: 776-785 (2007).
2. Huyghe J.M., "Analytical solution of a pressure transmission experiment on shale using electrochemomechanical theory", *ASCE J. of Engin. Mech.* **133**(9), 994-1002, (2007).

Current Research Team Members:

- Kamyar Malakpoor (senior researcher)
- Yvonne Schroeder (Post-doc)
- Rob Petterson (Engineer)
- Francesco Pizzocolo (Ph.D. Candidate)
- Faisal Irzal (Ph.D. Candidate)
- Veronique Barteley (Ph.D. Candidate)
- Peter van den Broek (Ph.D. Candidate)
- Afsaneh Mojra (Ph.D. candidate)

Recent Graduates and Co-workers:

- Dr. Famke Kraaijeveld (Ph.D. 2009), now at Shell Research, Rijswijk, The Netherlands
- Dr. Kamyar Malakpoor (Ph.D., 2007), now at Keygene, BV, Wageningen, The Netherlands.

Current Research Collaborations:

- Shell Research
- Proctor and Gamble
- Abaqus
- European Union

3. K. Malakpoor, J.M. Huyghe, "An analytical solution of compressible charged porous media", *Z. Angew. Math. Mech.*, **89**(9), 742-753, (2009).
4. J.M.Huyghe, W. Wilson, K. Malakpoor, "On the thermodynamical admissibility of the triphasic theory of charged hydrated tissues", *J. Biomech. Eng.*, **131**(4), 044504-1/5, (2009).