Hydraulic Stimulation Modeling in Geothermal Systems

web: ibf.webarchiv.kit.edu/forschung/hysm/hysm_en.html

The extraction of geothermal energy is typically achieved by use of deep wells with openhole well intervals, providing a hydraulic interaction with the hot rock mass. By means of an induced circulation of water between the wells and a heat exchange between the solid and liquid phase the heat is mined from the aquifer. It is obvious that the extraction of thermal energy from the hot rock depends on the availability of permeable fractures in which water can be circulated to mine the heat content and the possibility to connect wells with the greatest possible mass of hot rock. In order to improve the permeability of the rock and to increase the activated area of contact between wells and the far-field system, a network of fractures can be artificially opened or even created. The aim of hydraulic stimulation is obviously the maximization of productivity. It is however linked to risks, such as induced microseismicity or borehole stability, which in turn are likely to increase significantly production costs. Therefore it is necessary to develop methods of determining the exact stimulation procedure suitable in each specific case. The present project suggests an approach to the subject from several different aspects.

From the experimental point of view, an investigation of crack propagation, coalescence and interaction was performed on gypsum specimens with predefined crack spacing and orientation. 36 specimens with 12 different crack angles were prepared with an especially designed and constructed metal mould and tested in a simple shear apparatus. A typical result is shown in Figure 1.

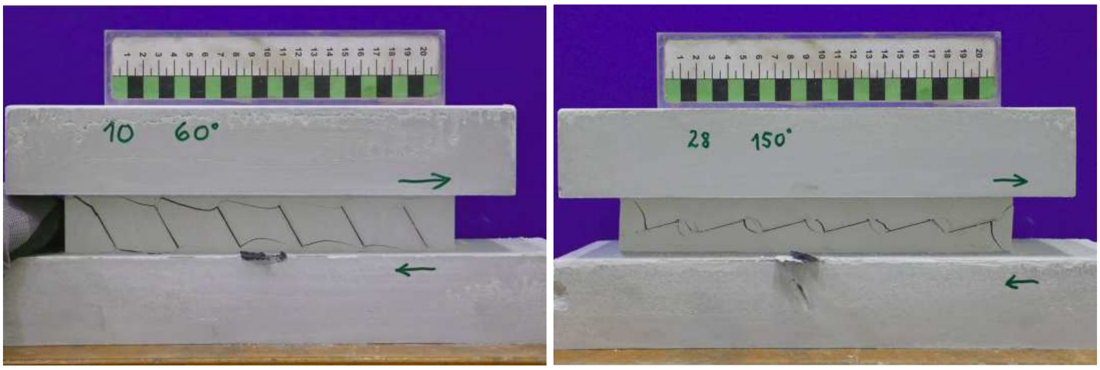

Figure 1. Post mortem specimens

The specimens were tested under a normal stress of 0.5 MPa, corresponding to less than 10% of the uniaxial strength of the material. The cumulative results of the shear strength as a function of the crack orientation are shown in Figure 2. Comparison to theory demonstrated that the failure mechanism is essentially controlled by the material bridges rather than the cracks.

The effect of fracture orientations on the strength of rock mass during hydraulic stimulation was further investigated by means of Discrete Element simulations. A two dimensional material with two fracture families was considered, under a given biaxial stress state. The program MechSys, developed by S.A. Galindo Torres, was used. A suitable mesh generator was programmed for the needs of the project. The control parameters were the relative lengths of the blocks and the angles formed with the principal stress axes. Subsequently the hydraulic pressure was increased in the center of the assembly up to the point where fracture propagation was observed. The maximum hydraulic pressures were thus gained for a large variety of different orientations and block shapes.

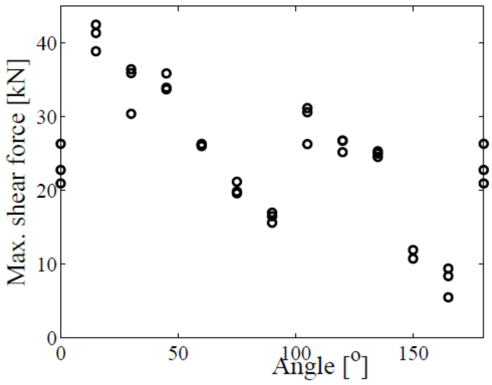

Figure 2. Maximum shear stress

An example of a typical result is shown in Figure 3, where the borders of the blocks are shown in yellow and the propagating fracture in blue. The cumulative results are shown in Figure 4. As can be seen, both orientation of the preexisting fractures with respect to the principal axes and block shape play a significant role for the hydraulic pressure required for fracturing. In addition tensile and shear failure were observed for different specimens, depending on the orientations of the preexisting fractures.

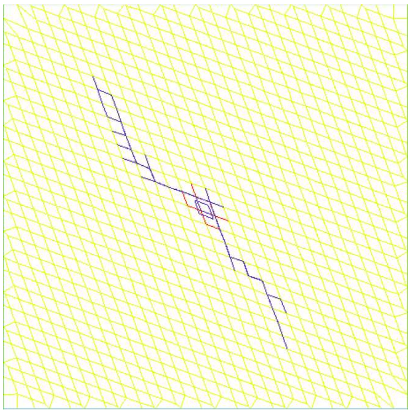

Figure 3. Example of fractured numerical specimen.

Within the frame of the constitutive work package of the project the permeability of a fractured medium containing multiple fractures was evaluated in accordance with the method of Oda [1] on the basis of the probability density function of the fractures. This formulation then was modified to account for changes in permeability arising from changes in the normal and shear stresses. The mechanical behavior of the rock itself was described by a model of the damage type. The damage in this case is governed by a set of parameters describing the fracture distribution and geometric properties. For the evolution of the fracture distribution a simplified form of the Kachanov method [2] was used, in combination with the results of the experimental tests, as it was deemed important that the model should be simple enough for application. It was deemed sufficient to use the commercial code Abaqus for the simulations, though the possibility of one way coupling to the multiphysics transport code TOUGH2 was examined and deemed feasible. A UMAT script was written for the mechanical behavior of the material and a USDEV script for the evolution of the permeability of the fracture matrix. In Figure 5 the effect of the anisotropy of the fracture distribution on the hydraulic pressure distribution resulting from injection is shown.

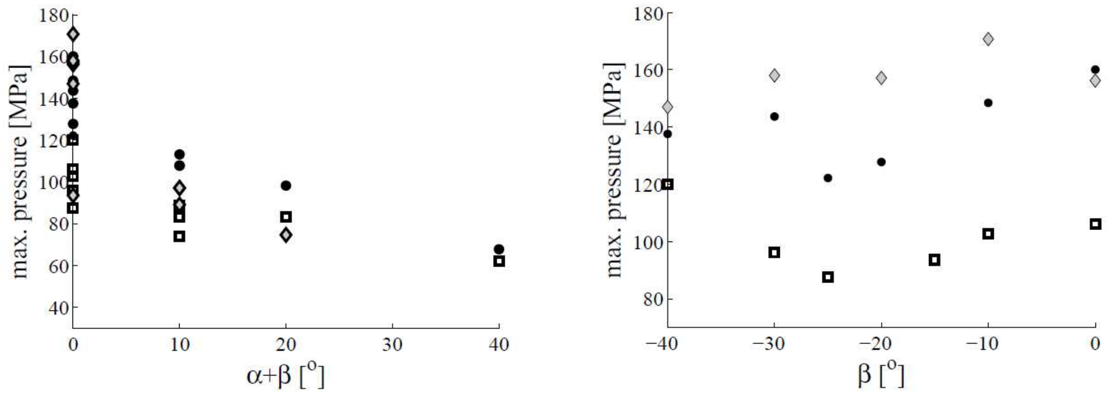

Figure 4. On the left the effect of the block shape and on the right the dependence of the maximum pressure on the block orientation for different height to width ratios of the blocks.

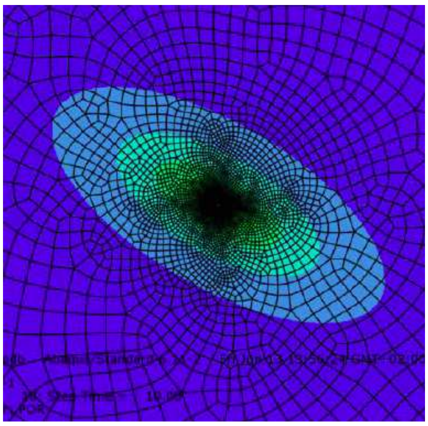

Figure 5. Effect of the anisotropy of the fracture distribution on the water pressure distribution.

[1] Oda M. Permeability tensor for discontinuous rock masses. Géotechnique, 35:483 – 495, 1985.

[2] Kachanov M. Elastic solids with many cracks and related problems. Advances in applied mechanics, 30:259–445, 1994.