Modelling of thermal shock induced fracture growth

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ABSTRACT

The properties and characteristics of geothermal reservoirs are highly influenced by the presence of fractures at various scales. The fractures may be pre-existing or, as in the case of enhanced geothermal systems, induced by various energy production related processes, such as pressure elevation and cooling due to fluid injection.

Modelling and numerical simulation of fracture nucleation and propagation offers a valuable supplement to experimental studies and field observations, both in predicting behaviour and in furthering the understanding of the physical processes involved. This is a highly challenging task, not least due to the constantly changing, possibly highly complex fracture network geometry. This aspect requires deliberation in the model design, and trade-offs between accuracy and computational cost are inevitable. In this work, the finite element (FE) method is used, with re-meshing whenever the fracture geometry changes. This approach allows capturing complex geometries at moderate computational costs compared to alternatives such as discrete element methods, and the extended FE method.

If the mechanical deformation and fracturing is influenced by other processes such as fluid pressure or thermal non-equilibrium inducing thermal stresses, the complexity of the modelling is further increased by the need to couple the models involved. Thermo-mechanical (TM) phenomena have been extensively investigated experimentally, e.g. through thermal shock testing of ceramics. One classical experiment considers a pre-heated thin ceramic plate which is rapidly cooled by water immersion. If the thermal shock is sufficiently large, fractures form at the specimen's interface with the coolant. Typically, the fractures are dyed to allow detection of their geometry and length and spacing statistics.

The thermal shock experiment may lead to extensive and complex fracture formation, while the set-up and material parameters may be tightly controlled. This makes it a favourable case for validation studies on numerical simulation tools, as has been done in 2d using FEM, e.g. by Li et al. (2013), and more recently also in 3d for DEM methods based on peridynamics theory, see Bourdin et al. (2014) and D'Antuono and Morandini (2017). Following this tradition, we here validate the TM part of a FE based model in which the fractures are represented by 2d surfaces in the surrounding 3d rock matrix. Furthermore, we investigate applicability to geothermal processes by considering relevant temperatures and rock properties. We investigate which ranges of heat shock magnitude caused by fluid injection may cause fracturing in the near-well region.

The implementation is part of the Imperial College Geomechanics toolkit (Paluszny and Zimmerman, 2011), and more details on the implementation of the TM model are found in Salimzadeh et al. (2018).

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