Mixed-mode Fracture Simulation by the Phase-field Method

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The failure mechanism of rock-like materials has been of great research interest. From the experimental observations, fracture is in general anisotropic and the evolution process is rather complex, often characterized by multiple cracks initiating sequentially at different positions and orientations. Researchers often refer to this type of failure as mixed-mode failure, in the sense that anisotropic failure is comprised of at least two types of mechanisms – Mode I failure caused by tensile loading and Mode II failure by shear loading. Numerous works have reported such behavior in different materials, such as cement-based materials, marbles, gypsums etc.

In terms of the numerical description of the fracturing process, the phase-field methodology has been proven to be a promising approach during the last years. Consistent with the GRIFFITH theory on the energetic description of fracture, the approach is capable of numerically capture the nucleation, initiation, propagation and merging of cracks without additional numerical manipulations.

Recently, the phase-field model has been combined with the so-called Representative Crack Element (RCE) framework in [1]. Within the RCE, the material state is interpreted as an interpolation governed by the degradation function, between an intact state and a completely failed state. This renders physically meaningful crack kinematics, i.e. post-crack behavior including the opening and closing of the crack, as well as the shearing at the crack surface, which is not the case for most of the previously existing phase-field models. The crack-induced displacement discontinuity is explicitly considered as an internal variable, facilitating the consideration of many mechanisms at the crack surface, such as cohesive behavior and friction. In this work, the crack coordination system (CCS) that is embedded in the RCE concept, has been employed to work together with an orientation-dependency of the fracture toughness. As such, the mixed-mode phase-field model is formulated in a straightforward manner.

Following the minimization of virtual power on the RCE level, the analytical solution for crack deformation is directly obtained. Based on a consistent derivation, the finite element implementation of the mixed-mode RCE phase-field model is carried out in a straightforward manner. Several illustrative examples serve to describe failure mechanisms in the experiments.

References

[1] J. Storm, D. Supriatna, M. Kaliske, The concept of representative crack elements for phase-field fracture: Anisotropic elasticity and thermo-elasticity, Int J Numer Methods Eng 121 (2020) 779–805.