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Damage-based cohesive crack propagation of multiple cracks in the extended finite element method

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Modelling diffuse cracking in heterogeneous rocks is an important engineering problem. For instance, the permeability under stress of materials such as granite depends on their cracking state, which motivates microstructural simulations for distributed cracking at grain boundaries. The generation of conforming meshes for such grains-based configurations is challenging. An XFEM scheme is therefore defined to represent strong discontinuities in elements [1]). A stable displacement–Lagrange multiplier discretization scheme is developed to enforce perfect bonding of grains with quadrilateral elements.

To formulate cohesive crack laws, the works of [2] is exploited. A change of variable is first performed for the original Lagrange multiplier field, which allows differentiating loading and unloading situations. Next, instead of solving a nonlinear problem with a given extrinsic cohesive zone model, a thermodynamically consistent reformulation is derived by introducing damage variables in normal and tangential directions. A free energy function is defined such that its derived interfacial traction is equivalent to the one of the cohesive zone model given in traction-separation form, and the evolution equations for the damage variables are expressed in terms of the energy release rates. The energy release rate can be directly calculated from the Lagrange multipliers obtained in the XFEM scheme. A staggered solution is used to split the solution of the equilibrium problem at a given damage state from the damage field update. The damage field is updated with an explicit scheme, which then allows avoiding the need to solve a nonlinear equilibrium problem. The crack propagation is driven by prescribed damage increments. The corresponding external load level is then determined based on the evolution laws. The versatility and effectiveness of the proposed methodology will be illustrated by means of several microstructural simulations on grain-based microstructural models.

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