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A mixed-mode phase field fracture model in anisotropic rocks with consistent kinematics

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Abstract Under a pure tensile loading, cracks in brittle, isotropic, and homogeneous materials often propagate such that pure mode I kinematics are maintained at the crack tip. However, experiments performed on geo-materials, such as sedimentary rock, shale, mudstone, concrete and gypsum, often lead to the conclusion that the mode I and mode II critical fracture energies/surface energy release rates are distinctive. This distinction has great influences on the formation and propagation of wing cracks and secondary cracks from pre-existing flaws under a combination of shear and tensile or shear and compressive loadings. To capture the mixed-mode fracture propagation, a mixed-mode I/II fracture model that employs multiple critical energy release rates based on Shen and Stephansson, IJRMMS, 1993 is reformulated in a regularized phase field fracture framework. We obtain the mixed-mode driving force of the damage phase field by balancing the microforce. Meanwhile, the crack propagation direction and the corresponding kinematics modes are determined via a local fracture dissipation maximization problem. Several numerical examples that demonstrate the mode II and mixed-mode crack propagation in brittle materials are presented. Possible extensions of the model capturing degradation related to shear/compressive damage, as commonly observed in sub-surface applications and triaxial compression tests, are also discussed.

Keywords mixed-mode fracture, secondary crack, phase field fracture

1 Introduction

Brittle fracture process in geological materials can be explained by Griffith theory [Griffith, 1921], which provides the linkages among stress concentration caused by sharp-tipped flaws, the energy flux, and the conditions for propagation of various type of flaws. The popularity of fracture mechanics' application to geomaterials is largely due to its simplicity, as well as capacity to predict the growth and spreading of the flaws [Rudnicki, 1980, Hutchinson and Suo, 1991].

In the brittle regime where confining pressure, temperature, and loading rate are sufficient low, fracture mechanics provides convenient tools to analyze the onset and early propagation of mode I cracks in a homogeneous, isotropic, and linearly elastic material. Nevertheless, in many geomechanics problems, the geological materials are often subjected to a significant principal stress difference and the materials of interest, such as sedimentary rock, shale, and mudstone, are often inherently heterogeneous and anisotropic. These complexities indicate that the fracture of geological materials under mixed-mode loading is very common. As such, a modeling framework, whether it is based on embedded strong discontinuity or smeared crack approximations, should consider mode mixity in a plausible physical ground that matches the experimental evidence.

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