A variational model coupling cavitation and damage for fracture in nearly incompressible materials

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Abstract

Variational phase-field models for brittle fracture are widely used due to their ability to reproduce complex crack patterns without the need for ad hoc criteria (1) and to effectively handle crack nucleation under tensile loading (2). However, the treatment of crack nucleation under multi-axial stress states in phase-field models remains a topic of active discussion, with several unresolved challenges. Among these challenges are the inability to flexibly define the crack nucleation criterion under multi-axial stress states and the difficulty of modeling crack nucleation in materials approaching the incompressibility limit. In this contribution, we focus on the issue of crack nucleation in nearly incompressible materials, with particular attention to the well-known poker-chip test introduced by Gent and Lindley (3). We propose a novel phase-field model coupled with a nonlinear model describing cavitation at the macroscopic level. The nonlinear cavitation model describes two phases: the first phase captures the material's behavior when it is nearly incompressible and undergoes minimal deformation until the cavitation threshold is reached, while the second phase reflects a nonlinear response caused by the presence of bubbles in the material. These bubbles lead to the loss of the material's nearly incompressible nature, enabling expansion. We combine this macroscopic cavitation model with a variational phase-field model in which the scalar damage variable influences the cavitation threshold. The variation of the cavitation threshold with the damage thus becomes the new variational driving force. In this way, we capture the key features of cavitation and fracture processes in nearly incompressible materials, relying solely on energy minimization and remaining within the variational framework without using ad hoc criteria and non-variational driving forces.

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