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EDITORIAL

Phase-field approaches to fracture in the 3rd millennium

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More than twenty years after their introduction as approximations of the variational theory of brittle fracture (Francfort and Marigo, 1998), phase-field models of fracture (Bourdin et al., 2000) have emerged as powerful macroscopic approaches to describe and predict the propagation of cracks in homogeneous linear elastic isotropic brittle materials under quasistatic loading conditions.

Recent developments of phase-field formulations to account for material heterogeneity, nonlinearity, inelasticity, anisotropy, multi-physics, and dynamic loading conditions, as well as to incorporate fracture nucleation and healing point to the core concept behind the theory — *i.e.*, the competition between bulk and surface fields — as a truly pervasive idea capable of describing, explaining, and predicting fracture in a broad spectrum of materials and loading conditions.

This Special Issue aims at providing a snapshot of the state of the art as well as an outlook of the future for the field. The volume comprises 10 articles:

The first article (Francfort, 2022) provides a review of the current mathematical state of brittle fracture as a variational problem, which is the bedrock of phase-field approximations.

The following four articles are devoted to extensions, all within the setting of homogeneous linear elastic isotropic brittle materials, of the phase-field approximation in its most basic form (Bourdin et al., 2000) to account for fundamentals aspects — crack interpenetration, fatigue loading, crack nucleation — beyond crack propagation under "tensile" quasi-static loading conditions. Precisely, Steinke et al. (2022) make use of a crack orientation vector to introduce a new split of the strain energy in the bulk that seeks to address the issues of crack interpenetration and tension/compression asymmetry in crack propagation. Yan et al. (2022) deal with an extension of the basic phase-field model to account for fatigue loading. In particular, they propose to add to the strain energy in the bulk a contribution encoding the microscopic damaging effects of cyclic fatigue that can be calibrated directly from experimental observations. The contribution of De Lorenzis and Maurini (2022) extends the interpretation of the classical phase-field approximation as a gradient-damage model, wherein

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the regularization length is endowed with physical meaning, to account for Drucker-Prager-like strength surfaces. In the last article of the subset, Kumar et al. (2022) present simulations of the indentation of glass and of the bending of U- and V-notched PMMA beams based on the phase-field theory of Kumar et al. (2020) with the aim of providing further validation results of this theory as a possible complete theory of fracture nucleation and propagation.

The last five articles are devoted to extending the phase-field approximation beyond the setting of homogeneous linear elastic isotropic brittle materials, with the last three focusing on hydraulic fracture. Clayton et al. (2022) put forth a phase-field model alongside a large set of simulations for the deformation, fracture, and deformation twinning of a two-phase polycrystal bonded by grain boundaries with their own mechanical behavior. The model makes use of two order parameters, one to describe fracture, the other to describe twinning. Extensive parametric calculations on synthetic microstructures are reported in order to unveil trends in structure–property-performance relations. Yin et al. (2022) introduce a phase-field model for linear viscoelastic isotropic brittle materials subjected to quasistatic deformations wherein a split of the total strain energy based on the concept of “representative crack elements” is used to set up a Griffith-type competition for crack propagation. Costa et al. (2022) present a global–local scheme to solve the equations for a model of hydraulic fracture in a computationally efficient manner. Specifically, at the global scale, cracks are represented as sharp cracks, while at the local scale cracks are described as phase-field cracks. The contribution of Tanné et al. (2022) also deals with the phase-field modeling of hydraulic fracture. In particular, results are put forth that show that a single crack typically propagates asymmetrically in toughness dominated hydraulic fracturing, in which viscous dissipation of the fluid is negligible, irrespectively of the presence of material heterogeneity. Finally, Kienle and Keip (2022) propose a phase-field model for hydraulic fracture in poroelastic-plastic materials alongside its numerical implementation and sample simulations.

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