11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

FINITE ELEMENT PHASE-FIELD MODELLING OF BRITTLE FRACTURE

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Key Words: *Fracture, Phase-Field Model, Finite Element Method, Crack Propagation.*

The development of an adequate scheme for the numerical simulation of crack initiation and propagation is still a significant challenge for the Computational Mechanics community. A huge effort has already been made to develop novel and accurate models for fracture and an enormous progress has been achieved. A particularly successful approach is provided by the Linear Elastic Fracture Mechanics (LEFM) theory, based on Griffith's theory for brittle fracture, which relates crack nucleation and propagation to a critical value of the energy release rate.

The efforts to model brittle fracture focused essentially on two broad approaches: (i) discrete methods, such as the element deletion method, the embedded finite element method or the extended finite element method, which use the finite element method in conjunction with Griffith's-type LEFM models to incorporate discontinuities into the displacement field, and (ii) continuum-damage (CD) methods, which incorporate a damage parameter into the model that describes the material's deterioration and controls its strength. Some of these methods are already available in commercial CAE software packages and can be used for commercial applications. However, it has long been recognized that, while discrete methods are well suited only for static fracture and when a moderate number of cracks occurs, CD methods are not effective when modeling large dominant cracks, since the damage zone tends to widen in a direction normal to the crack initiation as the simulation proceeds. Another shortcoming of CD methods is that regularization algorithms are needed to overcome mesh dependency.

Additionally, current methods for predicting crack propagation, in particular for dynamics and 3D problems, still lack accuracy and robustness, even when applied to relatively simple benchmark tests [1].

Due to these reasons, several efforts were made in the last decade for the development of alternative schemes. Recently, a new approach for the numerical simulation of fracture has emerged. In this approach, discontinuities are not introduced into the solid to represent cracks. Instead, a fracture locus is approximated by a phase-field, which smoothes the boundary of a crack over a small region [2, 3]. The major advantage of using a phase-field approach is that the evolution of fracture surfaces follows from the solution of a coupled system of partial differential equations. Contrarily to many discrete methods, its implementation does not require fracture surfaces to be tracked algorithmically. Phase-field models avoid these difficulties by introducing a continuous phase-field variable which smoothly interpolates between undamaged and fully failed states of the modeled material.

The goal of this paper is to present a new finite element phase-field model for brittle fracture. Here, the temporal evolution of a crack field is described by a thermodynamically consistent Ginzburg-Landau-type evolution equation. An implicit time-integration scheme is employed for the temporal discretization of the transient evolution equation. The nonlinear coupled system of equations is solved using a Newton-Raphson algorithm.

Several numerical experiments demonstrate that, unlike many of the current numerical methods based on the classical theory of Griffith, the proposed phase-field fracture model is able to reproduce various complex phenomena, such as deflection or branching of pre-existing cracks, as well as the nucleation of new cracks in originally undamaged domains.

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