Phase field approach to ductile damage

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ABSTRACT

The approximation of the ductile damage propagation with phase field method is investigated in this work. In the context of continuous damage mechanics, this model can be viewed as an alternative to the gradient enhanced nonlocal approaches while from the fracture mechanics point of view, it captures the ability to predict the damage initiation and propagation prior to the onset of meso-cracks. Phase field approximation of failure initially developed based upon the brittle fracture context [1-2] while in recent years it paves the way of ductile failure design via its introduction into the plasticity and damage contexts [3-4]. This approach utilizes the spatial gradients of the phase field order parameter, $\varphi \in [0,1]$, which highly resembles the continuous damage mechanics field variable by taking the values of zero and one for the undamaged and damaged material states, respectively. This necessitates the definition of a finite-width length scale parameter that takes the role of regularizing the crack discontinuity by replacement of the Griffith-type, sharp crack interface integral with the following smeared, volume integral:

$$\int_{\Gamma} \mathcal{G}_c \, d\Gamma = \int_{\Omega} \mathcal{G}_c \left[\frac{1}{2l_0} \varphi^2 + \frac{l_0}{2} |\nabla \varphi|^2 \right] d\Omega$$

Such averaging strategy greatly reduces the algorithmic difficulties by eliminating the need to numerically track the crack extension path. It also efficiently resolves the discretization-dependence issues of the continuous-discontinuous approaches like XFEM [5] thanks to the nonlocal nature of the phase field parameter.

In the present study, such approximation is applied to the Lemaitre continuous damage model which is based on the phenomenological aspects of the material. Following an appropriate coupling between the regularizing crack functional and the plasticity-damage constitutive model, an efficient staggered scheme used to solve the equations iteratively. Finite element method is used to solve the numerical problem and the performance of the algorithm is assessed through several failure benchmarks.

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