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## MODELING AND SIMULATION OF CRACKING IN QUASI-FRAGILE MATERIALS BY USING PHASE FIELD METHOD: APPLICATION TO CONCRETE

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**Abstract:** This paper is devoted to the application of Miehe method [3] to the case of damage in concrete, in the particular framework of multiscale mechanics using 3D representative elementary volumes (REVs) at the mesoscale. More specifically, this work consists in the treatment of instabilities in the crack propagation modeling in isotropic elastic solids, which may arise due to the dependency of Miehe scheme [3] with respect to the choice of time step. Our algorithm allows for modeling crack propagation within complex microstructures, in a robust manner that is independent of the choice of time step. Several cases of concrete mesostructures exhibiting different aggregate shapes have been analyzed under classical tension and compression loadings.

### 1. Introduction

The phase field method has recently been widely used in fracture mechanics to avoid the local modeling of discontinuities at the crack location. Instead, cracks are represented by a damage field which is diffuse over a characteristic length. Based on a variational approach introduced by Bourdin, Francfort and Marigo [2], a robust and efficient numerical scheme devoted to the crack evolution modeling has been presented by Miehe [3]. Robustness and efficiency of such a general scheme are due to the use of an energy approach that insures the thermodynamic irreversibility of the damage process. Precisely, Miehe [3] has proposed an explicit scheme to predict the crack initiation and propagation, consisting in solving successively in an incremental manner both the damage and mechanical equilibrium equations. This approximate linear scheme allows for avoiding any instability in the crack modeling, and any dependency of the result with respect to the choice of the time step. The objective of this research is to propose an alternative robust implicit scheme based on an iterative process that takes into account the nonlinear material behavior, in order to overcome the drawback of Miehe scheme regarding the time step dependency. This iterative scheme is then accelerated using an algorithm proposed in [4].

### 2. Results

In order to validate our numerical scheme, we compare the results for a 2D single edge notched specimen in tension case with those of Miehe [3]. A good agreement concerning the crack pattern as well as the force-displacement curve, for the case of length scale parameter  $l = 0.015 \text{ mm}$ , can be observed in Fig. 1 (a) and (b).

The proposed numerical scheme is then used in a 3D application, which consists of a heterogeneous concrete REV subjected to a tension load. The REV is generated using the Combs

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procedure [1] where the aggregates are randomly distributed and bonded together with the cement matrix, inside an unit cube. In this example, only the cement matrix is assumed to exhibit damage while the aggregates are chosen as purely isotropic elastic materials. The fracture toughness of the cement, the length scale parameter, the Young modulus and Poisson coefficient of the aggregates and of the cement matrix are respectively chosen as  $g_c = 0.0005 \text{ kN/mm}$ ,  $l = 0.05 \text{ mm}$ ,  $E_{inc} = 15 \text{ GPa}$ ,  $\nu_{inc} = 0.2$ ,  $E_{mat} = 10 \text{ GPa}$ ,  $\nu_{mat} = 0.3$ . The mesh includes a total of 283,000 tetrahedral elements and the elements with maximum dimensions are smaller than half of the length scale. The simulation is done with 100 time steps while the displacement loading reaches  $0.09 \text{ mm}$ . For both examples, the numerical scheme is implemented in the Cast3M finite element software ([www-cast3M.cea.fr](http://www-cast3M.cea.fr)) and the behavior law is integrated via the code generator Mfront ([www.tfel.sourceforge.net](http://www.tfel.sourceforge.net)).

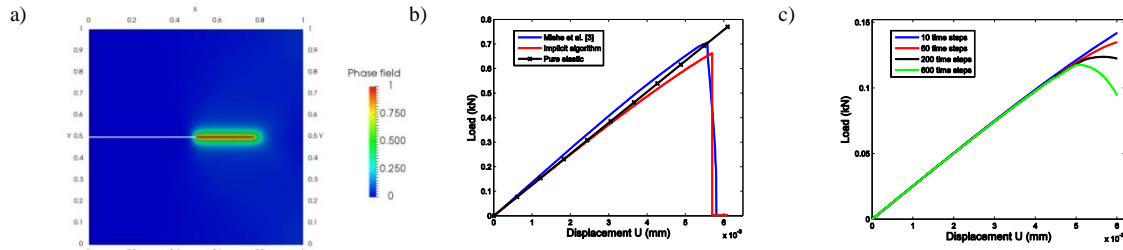


Figure 1. 2D tension test: a) Crack pattern at a displacement loadings of  $u = 5.7 \times 10^{-3} \text{ mm}$  and b) force-displacement curves c) An example for the time step dependency of Miehe scheme

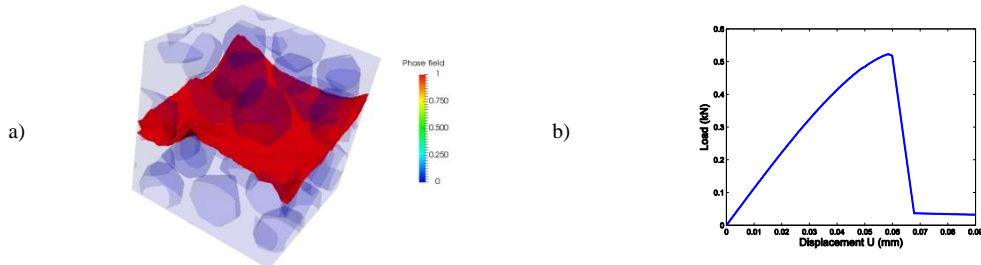


Figure 2. 3D application: (a) Crack pattern at a displacement loading of  $u = 8.92 \times 10^{-2} \text{ mm}$  and (b) force-displacement curve

### 3. Conclusions

The proposed algorithm allows for simulating the initiation and propagation of cracks in an arbitrary complex microstructure made up of quasi-fragile materials, this in a robust manner which is independent of the choice of time step.

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