Phase-field numerical modelling of crack propagation through a fully-explicit time stepping method

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Dynamic fracture arouses interest in many engineering applications under severe dynamic loading such as earthquakes, crashes, blasts, and other impact conditions. Inertial effects and wave propagation contribute to the crack nucleation process, which propagation often leads to structural failure. These phenomona raise many questions in numerical analysis that leads to the development of various models. Among them, the variational phase-field approach becomes popular for its capacity to represent both crack initiation and propagation through a system of coupled variational equations [1]. Originally developed in quasi-static framework, it was extended to dynamic regime. The time incremental approaches can be treated both with implicit or explicit time integration methods. In the literature, implicit schemes are widely chosen for their stability property. But this advantage comes at a computational cost per iteration since it requires the use of non-linear solvers such as Newton Raphson to operate a convergence process within each time increment. On the opposite, explicit methods avoid iterations as well as the resolution of system of linear equations and convergence problems but their stability has to be ensured by a very small time step. To benefit from the advantages of explicit approaches, some authors have proposed strategies of resolution in which both formulations are integrated with an explicit time integration scheme. Nonetheless, this method rises questions about the adaptation of the damage formulation and an appropriate choice of critical time stepping. The damage equation is naturally stated in a quasi-static formulation, non-suitable for explicit time schemes. Some authors have proposed two alternatives to make it compatible with. The first one considers the Ginzburg Landau evolution to the phase-field equation, introducing a viscous parameter weighted the time derivative of the damage [2]. Whereas the second method uses a hyperbolic PDE, characteristic of a wave propagation equation [3]. Both strategies present a formalism that tends to limit the rate of damage evolution and thus, the crack growth speed. Nonetheless the last strategy improves the time resolution through a $\Delta t_c \propto h_{min}$ compared to $\Delta t_c \propto h_{min}^2$ for the parabolic PDE.

The purpose of this work is to propose an efficient resolution of the coupled variational fracture problem compatible with a full-explicit time integration approach and to transfer the resolution algorithms into an industrial explicit code, EUROPLEXUS. To achieve this goal, we undertake a prototyping phase under the open-source platform *FEniCSx.*[1], coupling with a code generator of laws, *MFront/MGIS.*[2]. This tool allows to gather the material knowledges in a standalone library for future use in different solvers. Currently, the code generator is used to provide fracture behavior laws of tension/compression asymetry, preventing spurious crack closure under compressive loads. The aim is to extend his use to nonlinear material behavior and finally achieve to a full-explicit time integration resolution compatible with nonlinear material.

References

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[1] *FEniCSx* : https://fenicsproject.org/
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