A flexible computational framework for a high-performance extension of a quasi-static phase-field modeling to a dynamic regime

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Abstract

The dynamic aspect of crack propagation is a topic of deep interest in material science. The phase field fracture modeling has shown encouraging results in a dynamic framework but remains challenging in terms of the time discretization resolution. Though the implicit time integration methods are mainly used in the literature, they become limiting in nonlinear problems due to the resolution of the system of equations required. Thus, explicit time integration schemes are an alternative to avoid these massive matrix operations. This paper presents the approaches set up to adapt the coupled formulation to a full explicit time integration for both equations.

1. Introduction

Dynamic fracture arouses interest in many fields in mechanics. Earthquakes, crashes, blasts, and impact phenomena are many examples involving severe dynamic loading. Inertial effects and wave propagations contribute to the nucleation process which often leads to structural failures. A better understanding of these material defect mechanisms would bring improvements in the dimensioning of industrial applications.

Computional methods play a crucial role in the prediction of the failure process. Among them, the phase field fracture modeling becomes popular for its capacity to represent both crack initiation and propagation through a system of coupled variational equations [1]. Originally used to describe quasi-static brittle fractures, the phase field approach was extended to a dynamical framework. However, the use of implicit time integration schemes is highly dominant in the literature. This choice become quickly limiting for larger applications due to massive matrix operations. Explicit approach seems to be a good alternative to limit the use of system linear equations solver provided that the CFL condition is respected. Some works based on explicit schemes, have shown encouraging results but the studies remain less explored or reduced to standard cases [2] [3].

2. Purposes and Approaches

Thus, the present works focus on the extension of resolution method of a phase field fracture problem from a quasi-static regime to a dynamic framework. And the goal is to make compatible the coupled formulation with an explicit time integration scheme.

The first part of the work consists of the implementation of a resolution method in a quasi-static regime to shift efficiently into a dynamic framework. The open-source platform FEniCSx [4] is used, providing a flexible automated resolution of variational formulations. The resolutions are based on an alternate minimization algorithm, using a Newton-Rapshon method to solve implicitly each evolution equation. The asymmetric behavior in tension and compression around the crack can be treated with various strain energy decompositions that we chose to implement with the library MFront/MGIS [5]. This tool is a code generator of behavior law allowing to gather the material knowledges in a standone library for future use outside FEniCSx. The final resolution algorithm has been validated through the Single Edge Notch Shear (SENS) test assuring an efficient transition to a resolution in dynamic regime.

In that case, inertia effects are taken into account in the mechanical problem. We fixed a central difference scheme to handle explicitly the time integration and for comparison with an implicit dynamic approach, we applied a Newmark family scheme. For each resolution, the damage problem remains to solve with the

Newton-Raphson method implemented. A dynamic analysis of a bar in traction allowed us to show similar results in both resolution methods.
Explicit time integration will be finally extended to the phase field formulation from two approaches proposed in the literature. The first one considers the Ginzburg Landau evolution to the phase field equation and introduces a mobility parameter responsible for the dissipation upon stable crack growth [6]. A second method uses a hyperbolic partial differential equation, characteristic of a wave propagation equation [7]. The goal is to compare both phase field evolution under an explicit time integration scheme and to validate the robustness of the final resolution algorithm.
Once the prototyping phase on Fenicsx is fulfilled, the full-explicit time integration strategy of the coupled equations could be transfered in the industrial explicit code EUROPLEXUS [8].

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