Path-following methods for quasi-static crack propagation : Application to phase-field fracture

GIMC SIMAI Young 2026

Flavien Loiseau Véronique Lazarus

Numerical simulations of quasi-static crack propagation in brittle materials often suffer from numerical instabilities, such as snapback events, due to structural softening. In variational phase-field fracture models, these instabilities manifest as abrupt crack jumps, thereby impeding physical validity, as the energy minimization is performed over a significant crack increment. Moreover, they often prevent incremental force boundary conditions, as they may lead to a loss of force balance as soon as the crack starts propagating.

This study introduces path-following methods to mitigate such instabilities in quasi-static phase-field fracture simulations. We evaluate existing methods alongside a novel approach, Control by Maximum Strain Increment Outside the Crack (CMSIOC), which enforces stable crack growth by constraining strain increments in the uncracked region. All studied methods rely on a single scalar control equation that depends solely on displacement fields, enabling integration into classical staggered solvers without major changes.

Performance is assessed via three benchmark problems of increasing complexity, with results compared against Linear Elastic Fracture Mechanics (LEFM) references based on Griffith's criterion and the G-max criterion. Our findings show that CMSIOC:

1. Accurately follows the equilibrium path, avoiding abrupt crack jumps while preserving physical validity;
2. Supports force-controlled boundary conditions without loss of force balance during propagation;
3. Ensures uniform incremental crack growth, properly distributing the computational efforts across load steps.

These results highlight CMSIOC's robustness as a model- and problem-independent solution for stable phase-field fracture simulations.