IMPLICIT ANALYSIS OF CRACK PROPAGATION IN BRITTLE 3D SOLIDS

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1. Abstract

The theoretical basis for simulating unstable crack propagation in 3D hyperelastic continua within the context of configurational mechanics, and the associated numerical implementation, will be presented. The approach taken is based on the principle of global maximum energy dissipation for elastic solids, with configurational forces determining the direction of crack propagation. The work builds on the developments made by the authors for static analysis [1], incorporating the influence of the kinetic energy. The nonlinear system of equations is solved in a monolithic manner using Newton-Raphson scheme. Initial numerical results are presented.

We develop the physical and mathematical description to determine (a) when a crack will propagate, (b) the direction of propagation and (c) how far/fast the crack will propagate. Furthermore, we require a numerical setting to accurately resolve the evolving displacement discontinuity within the context of the Finite Element Method.

In this study, we present a mathematical derivation and numerical implementation that can achieve these goals, solving for conservation of momentum in both the spatial and material domains. We adopt the Arbitrary Lagrangian-Eulerian (ALE) method, which is a kinematic framework to describe movement of the nodes of the finite element mesh independently of the material. Thus, we are able to resolve the propagating crack without influence from the original finite element mesh, and maintain mesh quality. The deformation and crack direction are solved simultaneously and the propagating fracture is continuously resolved by adapting the FEA mesh in a smooth and completely novel way, avoiding the need for element splitting or enrichment. Mesh quality is maintained by an efficient mesh smoothing technique coupled with a face flipping, node merger and edge splitting algorithm. The efficient solution of 3D crack propagation, with a large numbers of degrees of freedom, requires the use of an iterative solver for solving the system of algebraic equations. In such cases, controlling element quality enables us to optimise matrix conditioning, thereby increasing the computational efficiency of the solver.

The application of this work is the predictive modelling of crack propagation in nuclear graphite bricks, which are used as the moderator in UK advanced gas-cooled nuclear reactors (AGRs).

Presented work is implemented in in-house free and open finite element code [2].

2. References

[1] Łukasz Kaczmarczyk, Mohaddeseh Mousavi Nezhad, and Chris Pearce. Three-dimensional brittle fracture: configurational-force-driven crack propagation. *International Journal for Numerical Methods in Engineering*, 97(7):531550, 2014.

[2] MoFEM finte element code. http://mofem.eng.gla.ac.uk.