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MODELLING AND SIMULATION OF FRACTURE AND FRAGMENTATION

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Fracture often sets in motion processes of deformation and failure of great complexity. Examples of technical import include hydraulic fracture, in the quasistatic range, and hypervelocity impact, in the dynamic range. In these and similar examples, the fracture pattern can be exceedingly complex in geometry, topology and evolution. Thus, cracks may develop stochastically, branch and reconnect, thereby drastically modifying the topology of the solid. Even under quasistatic conditions, fracture patterns may involve fine microstructure when it fracture takes place under all-around compressive loads, e. g., in geological formations or in confined brittle solids. In addition, fracture is inevitably accompanied by processes of deformation and failure, e. g., at a crack tip, that involve extreme material behaviour. Finally, fracture is a multiscale phenomenon that is the net result of mechanisms playing out at the microscale, such as cleavage, void growth and crazing.

These modelling constraints and predictive targets select for computational methods that are: i) capable to handle geometrical and topological *complexity* in the crack set; ii) *agnostic* as regards material behaviour, i.e., apply equally well regardless of whether the material is elastic or inelastic, undergoes small or large deformations, quasistatically or dynamically; iii) grounded in micromechanics, with clear connections between macroscopic and micromechanical properties; iv) defined in terms of material constants that are amenable to experimental measurement by means of standard fracture tests; and v) provably convergent with respect to mesh refinement. Once these requirements are set forth, the palette of methods that rise to the occasion is limited indeed.

Cohesive elements [1-4] supply one of the few general paradigms that meet all the entry requirements. Thus, in combination with graph methods [4, 5], cohesive elements can simulate arbitrarily complex topological changes in any dimension. Cohesive elements can be combined with finite elements encoding arbitrary material models, undergoing small or finite deformations in the static or dynamic regimes. Cohesive models also constitute a self-contained and complete theory of fracture and have traditionally provided an avenue for multiscale modelling. In some cases, cohesive models can be actually *derived*, instead of postulated, rigorously from micromechanical considerations (cf., e. g., [6-8]). Whereas cohesive testing is not part of the ASTM standards, considerable progress has been made as regards the experimental identification of cohesive laws of fracture, e. g., by recourse to the *J*-integral [9]. Finally, cohesive-element formulations of fracture are known to converge with respect to mesh refinement when mesh adaption is provided for [10].

Despite these attractive features, the need for mesh adaption in order to ensure the convergence of cohesive models can introduce an onerous overhead in some applications. A general alternative to cohesive models is provided by *material-point erosion* [11, 12]. As in the case of cohesive models, material-point erosion methods satisfy all entry requirements. Indeed, material-point erosion schemes handle arbitrary changes in geometry and topology with the greatest of ease and, when combined with local averaging, they can be shown to converge with respect to mesh refinement [13]. Material-point erosion schemes *are material-agnostic*, i. e., can be employed in conjunction with arbitrary bulk material models. Often, the sole fracture parameter that is required is a critical energy-release rate G_c or J-critical J_c, both amenable to characterization by means of standardized tests and widely reported in the literature for a broad range of materials. In some cases, the critical energy-release rate or critical-J criteria can be related directly to micromechanics, e. g., strain microplasticity, by optimal scaling methods [8]. The range and scope, fidelity and predictive ability of material-point erosion methods have been thoroughly established in a number of areas of application [11, 12, 14].

REFERENCES

1. Ortiz, M. and S. Suresh, *Statistical Properties of Residual-Stresses and Intergranular Fracture in Ceramic Materials.* Journal of Applied Mechanics-Transactions of the Asme, 1993. **60**(1): p. 77-84.
2. Xu, X.P. and A. Needleman, *Numerical Simulations of Fast Crack-Growth in Brittle Solids.* Journal of the Mechanics and Physics of Solids, 1994. **42**(9): p. 1397-&.
3. Ortiz, M. and A. Pandolfi, *Finite-deformation irreversible cohesive elements for three-dimensional crack-propagation analysis.* International Journal for Numerical Methods in Engineering, 1999. **44**(9): p. 1267-1282.
4. Pandolfi, A. and M. Ortiz, *Solid modeling aspects of three-dimensional fragmentation.* Engineering with Computers, 1998. **14**(4): p. 287-308.
5. Mota, A., J. Knap, and M. Ortiz, *Fracture and fragmentation of simplicial finite element meshes using graphs.* International Journal for Numerical Methods in Engineering, 2008. **73**(11): p. 1547-1570.
6. Nguyen, O. and M. Ortiz, *Coarse-graining and renormalization of atomistic binding relations and universal macroscopic cohesive behavior.* Journal of the Mechanics and Physics of Solids, 2002. **50**(8): p. 1727-1741.
7. Braides, A., A.J. Lew, and M. Ortiz, *Effective cohesive behavior of layers of interatomic planes.* Archive for Rational Mechanics and Analysis, 2006. **180**(2): p. 151-182.
8. Fokoua, L., S. Conti, and M. Ortiz, *Optimal Scaling in Solids Undergoing Ductile Fracture by Void Sheet Formation.* Archive for Rational Mechanics and Analysis, 2014. **212**(1): p. 331-357.
9. Chalivendra, V.B., et al., *Experimental validation of large-scale simulations of dynamic fracture along weak planes.* International Journal of Impact Engineering, 2009. **36**(7): p. 888-898.
10. Fraternali, F., M. Negri, and M. Ortiz, *On the convergence of 3D free discontinuity models in variational fracture.* International Journal of Fracture, 2010. **166**(1-2): p. 3-11.
11. Pandolfi, A., B. Li, and M. Ortiz, *Modeling fracture by material-point erosion.* International Journal of Fracture, 2013. **184**(1-2): p. 3-16.
12. Pandolfi, A. and M. Ortiz, *An eigenerosion approach to brittle fracture.* International Journal for Numerical Methods in Engineering, 2012. **92**(8): p. 694-714.
13. Schmidt, B., F. Fraternali, and M. Ortiz, *Eigenfracture: An Eigendeformation Approach to Variational Fracture.* Multiscale Modeling & Simulation, 2009. **7**(3): p. 1237-1266.
14. Li, B., et al., *Verification and validation of the Optimal Transportation Meshfree (OTM) simulation of terminal ballistics.* International Journal of Impact Engineering, 2012. **42**: p. 25-36.