Spacetime Interfacial Damage Model for Dynamic Fracture in Brittle Materials

Robert Haber[1] and Reza Abedi[2]

[1]Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, 1206 W. Green St., Urbana, IL 61801
[2]Mechanical, Aerospace & Biomedical Engineering, University of Tennessee Space Institute (UTSI) / Knoxville (UTK), 411 B. H. Goethert Parkway, Tullahoma, TN 37388

Abstract

While most of fundamental physical questions in dynamic fracture mechanics are settled science, there remains a significant gap between this fundamental understanding and our ability to apply it in computational models of failure in the complex systems and materials that arise in geophysics, biology, and contemporary engineering design. This talk describes recent progress at the University of Illinois and the University of Tennessee Space Institute in developing new numerical methods and models intended to close at least some aspects of this gap.

A spacetime discontinuous Galerkin (SDG) method is the numerical foundation for our fracture model. This particular SDG method [1] is tailored to the requirements of hyperbolic systems, and differs from most others in that it is asynchronous, locally implicit, embarrassingly parallel, and supports fine-grain adaptive meshing. It enforces jump conditions with respect to Riemann solutions on element boundaries to preserve the characteristic structure of the underlying system. As with other DG methods, conservation fields balance to within machine precision on every (spacetime) element.

We model crack opening and closure with specialized Riemann solutions for the various modes of frictional dynamic contact [2]. We weakly enforce these Riemann solutions using the same framework that enforces jump conditions and boundary conditions at inter-element and domain boundaries elsewhere in the SDG formulation. This approach produces contact conditions that are distinct from those that arise from simple constraints against inter-element penetration.

We can implement cohesive fracture models in this SDG framework by incorporating traction–separation laws in the Riemann solutions [3]. However, in this presentation we focus on *interfacial* damage as an alternative means to model fracture along sharp interfaces. Time-delay evolution equations determine the damage rate as functions of the tractions and velocity jumps across fracture surfaces. A probabilistic model for microscopic flaws provides a mechanism for nucleating new fracture surfaces and is sufficient to captures crack branching. Adaptive refinement ensures that the solution fields are well resolved at multiple crack tips and along wave fronts. The same adaptive procedures continuously reconfigure the mesh so that it follows the crack paths determined by our physical model.

We discuss some of the open challenges in modeling fracture with interfacial damage and present several numerical examples to demonstrate existing capabilities.

References

[1] R. Abedi, R.B. Haber, B. Petracovici. A spacetime discontinuous Galerkin method for elastodynamics with element-level balance of linear momentum, Comput. Methods Appl. Mech. Eng. 195 (2006) 3247–3273.
[2] R. Abedi, R.B. Haber. Riemann solutions and spacetime discontinuous Galerkin method for linear elastodynamic contact. Comput. Methods Appl. Mech. Engrg. 270 (2014) 150–177.
[3] R. Abedi, M.A. Hawker, R.B. Haber, K. Matouš. An adaptive spacetime discontinuous Galerkin method for cohesive models of elastodynamic fracture, Int. J. Numer. Methods Eng. 1 (2009) 1–42.