A multi-scale, delayed-damage cohesive model for dynamic fracture

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We describe a delayed-damage, multi-scale cohesive model for elastodynamic fracture. In lieu of a traction-separation law, we adopt a multi-scale model in which the macroscopic cohesive response is governed by mesoscale damage that describes a gradual transition from the fully-bonded state to complete separation. The mesoscale damage, in turn, represents the homogenized effects of microscopic fracture processes. A scalar damage parameter describes a partition of the mesoscale interface into undamaged regions and regions that accumulate damage from microscopic fracture processes. The region subject to damage is subdivided into separation and contact zones, the latter being further divided into slip and stick zones.

The hyperbolic equations of elastodynamics generate jump conditions for momentum balance and kinematic compatibility that determine, at each scale, the velocities and stresses acting on the cohesive interface. Under the overarching assumption that waves with the same characteristic structure impinge from the bulk on the cohesive surface simultaneously at all scales, we derive Riemann solutions for the stress and velocity in each of the mesoscopic zones. In addition to providing homogenization relations between the macro- and mesoscale dynamical response, the Riemann solutions define dynamically consistent conditions for modeling separation, stick and slip contact conditions on the fracture surface.

A delayed-damage model, similar to the one described in [1], drives the damage evolution and naturally incorporates rate-dependent response. Without assuming the existence of a traction-separation relation, the multi-scale model captures the gradual loss of stiffness prior to reaching the cohesive strength that most extrinsic models omit, avoids the spurious initial compliance of intrinsic models and facilitates implicit solution schemes through its differentiable response. We present an implementation of the damage model within an adaptive, spacetime discontinuous Galerkin finite element method and demonstrate its applications to nucleation and rate-dependent behavior.

Acknowledgment: This work was supported by the Center for Process Simulation & Design, University of Illinois at Urbana-Champaign under U.S. National Science Foundation grant DMR-01-21695 and by ENS Cachan through support of a visiting appointment for the second author.

References

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