A probabilistic approach for dynamic fracture and fragmentation study of brittle materials

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Abstract

Unlike ductile materials that can redistribute high stresses by large inelastic deformations, the fracture of (quasi-)brittle materials—e.g. bone, concrete, rocks, high explosives, beryllium alloys, and ceramics—is greatly influenced by their microstructural architecture, yielding a wide scatter in their ultimate strength and the so-called size effect. We also note that in addition to high strain-rate loading scenarios, *i.e.* explosive rock blasting and ceramic armor, the failure processes in the majority of brittle materials are transient in nature even under nominally quasi-static loading.

Motivated by these observations, we present a probabilistic approach for contact/fracture modeling of brittle materials under dynamic loading. Material randomness is modeled by adapting a probabilistic model for the nucleation of cracks. It is assumed that cracks nucleate from defects that pre-exist in the material with a given spatial and strength distribution. We discuss the importance of incorporating material randomness in the model and nonphysical responses that may be predicted otherwise by theoretical and computational approaches.

We also propose a unified interfacial damage model that enables seamless transition between various contact modes under dynamic loading and also take rate effects on the fracture surface into account. This sharp-interface damage model is distinct from bulk-damage representations of fracture processes and is an alternative to cohesive models with traction-separation relations. We use a spacetime interfacial damage field, D, to describe transitions between intact and fully debonded conditions on fracture surfaces. A delayed-damage relation governs the evolution of D and includes a relaxation time scale to capture rate-dependent response. Using the local value of D, we first interpolate between Riemann solutions for intact and de-bonded interfaces at each point on a fracture surface. The resulting interfacial Riemann solution field is then weakly enforced within a spacetime discontinuous Galerkin finite element model. This approach preserves the characteristic structure of the underlying hyperbolic system and handles crack closure and impact, with distinct response for contact-stick and slip conditions with friction [1].

Numerical solutions for impact problems are typically marred by prolonged nonphysical oscillations or under/overshoots at contact and fracture-mode transitions unless nonphysical stabilization is added to the model. We demonstrate that the dynamical consistency of our Riemann solutions delivers high-fidelity solutions with almost no artifacts at mode transitions. In contrast to intrinsic cohesive models, our model generates no artificial compliance in the undamaged state at any level of grid refinement. It also avoids the non-smooth response that can complicate numerical implementations of extrinsic cohesive models. We discuss parameter selection for realistic fracture response and present applications to fragmentation and spalling.

References

[1] R. Abedi and R. Haber. Riemann solutions and spacetime discontinuous Galerkin method for elastodynamic contact. Comput. Methods Appl. Mech. Engrg., Vol. 270, 150-170, 2014.