Dynamic Fracture: Discrete Versus Continuum Damage Modeling

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The modeling of catastrophic failure of materials and structures, including dynamic fragmentation, is a long standing scientific challenge with important societal impact. For example, the observation and prediction of fragment sizes have profound implications on the resistance of a material to ballistic impact, energy absorption capacity during crash, hydraulic fracturing, and clustering of galaxies. Upon severe loading, multiple micro-cracks initiate at seemingly random locations. High-speed cameras reveal that these cracks then propagate at high velocities. Their paths may be tortuous, single cracks may form complex branches, but eventually the cracks coalesce, resulting in the formation of fragments. Material failure is accompanied by a complex stress-wave communication network. At first glance, this catastrophic process appears chaotic and unpredictable. Yet, universal features, which can be explored through numerical calculations, emerge from the chaos.

In this presentation, we discuss two different classes of methods to investigate dynamic fracture and fragmentation: the cohesive element method (discrete approach) and a non-local integral-type continuum damage model (continuum approach).

We begin with the analysis of explosive fragmentation of simple structures, including brittle plates and hollow spheres, using cohesive elements [1, 2]. A comparison between our numerical results and analytic energy models [3] reveal an identical scaling law exponent for the dependence of the average fragment size on strain rate. However, our simulations, which include explicitly stress wave interactions, yield a higher number of fragments. The calculations give also access to statistics on fragment shapes and orientations. We show that thin membranes generate roughly structured orientations, whereas for larger membranes thicknesses, crack branching mechanisms bring random fragment orientations.

The robustness of our predictions regarding fragment shapes should be contrasted with the fact that cohesive approaches suffer from mesh dependency. In the last part of the presentation, we explore the extension of classical static non-local continuum damage models to dynamical problems. This approach is used to smear the crack front over several mesh elements to achieve crack path mesh independence. We discuss the non trivial choice of material parameters, in particular for the non-local regularization, and present recent results on a benchmark problem involving dynamic crack-branching instabilities in a pre-cracked PMMA plate [4].

References

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