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# THE NOISE SPECTRUM OF HIGH-ENERGY CRACK BRANCHING

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**Summary.** *Massively parallel finite element simulations of dynamic fracture and fragmentation of brittle solids are presented. Fracture is introduced by the adaptive insertion of cohesive elements. The model is used to investigate the massive crack branching and fragmentation in the high-energy regime.*

The dynamic fracture and fragmentation of brittle solids exposed to high energy loadings has attracted much attention due to its technological and scientific interest, as well as its intriguing complexity. It governs very diverse phenomena such as the response of brittle solids to explosive loadings, quarry blastings, or the study of meteorite showers. The mechanism of fragmentation starts with the dynamic propagation of cracks. At high crack speeds (a fraction of the Rayleigh wave speed), the emission of secondary branches is energetically favorable to the acceleration of the primary crack tip. This dynamic instability causes repetitive micro-branches to appear[1], as well as roughness in the crack surface, accompanied by a clear acoustic emission signature[2]. The microbranching process presents universal features independent on details such as the structure of the material[3]. If the energy input is large enough, macrobranches are emitted. At high energies, massive crack branching leads to crack merging and the subsequent formation of fragments. The continuum theory of dynamic fracture appropriately describes the dynamic propagation of a single crack, and recent developments in this theory explain the onset of kinking and branching instability[4]. The onset of the branching instability has also been studied by massive molecular dynamics[5,6]. While a detailed deterministic analysis of these first stages in the fragmentation process can be attempted, the full fragmentation phenomenon calls for alternative approaches. Typically, post mortem statistical analysis of the cumulative mass (or size) distribution of fragments is performed to investigate this phenomenon. It is well known that the fragment size distributions present power-law behavior over decades largely independent of details of the experiment, a manifestation of the scale-invariance of the phenomenon. Although there have been many advances in the understanding of high energy branching and fragmentation in the last decade, the phenomenon is far from being understood. The goal of the present work is to further illuminate the phenomenon of high-energy crack branching and fragmentation through massive finite element simulations.

Our approach is based on the use of cohesive models to describe processes of separation leading to the formation of new free surface. Within the framework of the conventional finite element analysis, the cohesive fracture models are introduced through cohesive elements embedded in the bulk discretizations. These cohesive elements bridge nascent surfaces and govern their separation in accordance with a cohesive law[7]. The cohesive elements are introduced adaptively in the simulation, driven by the fracture criterion naturally introduced by the cohesive law. Fig. 1 shows a simulation of the fracture process (dynamic propagation of a single crack, crack branching and fragmentation) of a square pre-notched PMMA plate subjected to an initial uniform high strain rate in the vertical direction and illustrates the ability of the model to reproduce qualitatively the hierarchy of the branching phenomenon (micro and macro branching).

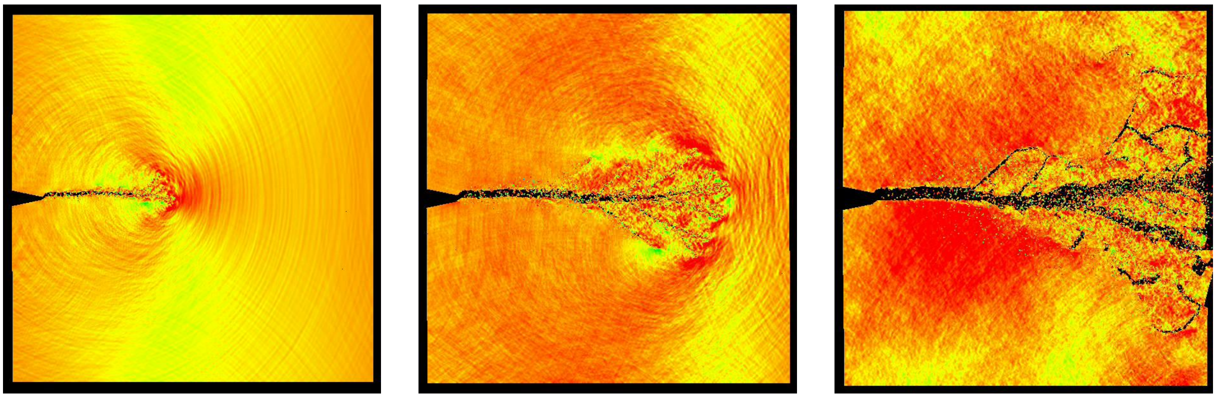

Figure 1: Snapshots (increasing times to the right) of the fracture process of a square pre-notched PMMA plate subjected to an initial uniform strain rate in the vertical direction[8].

Cohesive finite elements in large scale computations allow one to simulate the full dynamics and complexity of massive branching and fragmentation, accessing a sufficiently wide span of scales to extract relevant scaling laws. Complexity is addressed by searching universal features, self-similar structures, and robust scaling laws. We analyze the power spectrum of the acoustic emissions in the high energy case [7]. The results reveal previously unreported scaling laws, which suggest that despite the apparent complexity, a simple underlying phenomenon of diffusion drives the system. We venture mechanistic explanations. We also investigate the deviations from this behavior and the possible explanations.

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