# Understanding brittle crack behaviors to design stronger materials

August 21 2017

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In a paper published in *Nature Physics*, Northeastern University Department of Physics Arts and Sciences Distinguished Professor Alain Karma, in collaboration with his postdoctoral research associate Chih-

Hung Chen and Professor Eran Bouchbinder of the Weizmann Institute of Science's Chemical Physics Department, discovered the mechanism that causes cracks to behave strangely when they spread very rapidly in brittle materials. The results of this study will help researchers better understand how fragile materials, such as glass, ceramic, polymers, and bone break—often catastrophically—and how to better design materials to avoid failure.

Karma's goal was to understand how things break, since a primary way materials fail is through crack propagation, which has long been an issue in materials science, construction, and product development. More specifically, the collaborative research team wanted to understand how the mechanical properties of the region of high stress concentration around the edge of a crack affects the crack dynamics.

"While straight cracks can, in principle, race through a material as fast as the speed of sound, they never reach that speed for reasons that have remained elusive," said Karma. "We have shown that this is because cracks become inherently unstable when their speed is sufficiently high. Instability causes the crack tip to wobble from side to side and trace out a wavy path through the material. This instability has been completely missed by conventional theories of fracture, which all assume that the relationship between stretch and force inside a material is linear, meaning that doubling the force doubles the amount of stretch. Our work shows that this assumption breaks down near the crack tip and explains how the nonlinear relationship between stretch and force produces oscillations with a well-defined period that can be related to materials properties."

Through this research, Karma and his colleagues developed a novel theory to help researchers predict, through large-scale computer simulations, the dynamics of a crack under varying conditions, which has the potential to help understand why and how certain materials fail.

With success in this research, Karma hopes to continue on to more related work. "This study used very thin sheets of quasi-2D materials. We plan to extend this study to 3D bulk materials. In bulk, the instability that prevents cracks from breaking at the speed of sound happens at a lower crack velocity than in 2D but the mechanism is not understood," he said.

To elucidate this mechanism, the team plans to investigate the 3D phenomenon of micro-branching, when the main crack splits into many micro-cracks, to understand its origins in bulk samples of brittle materials. "We believe that the non-linear relationship between force and deformation is at the root of micro-branching instabilities, and we think we can crack that problem," Karma said.

**More information:** Instability in dynamic fracture and the failure of the classical theory of cracks, *Nature Physics* (2017). DOI: 10.1038/nphys4237

Provided by Northeastern University College of Science

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