Peridynamic analysis of dynamic fracture processes in brittle solids

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ABSTRACT

In this study we investigate dynamic fracture processes in brittle materials, using a peridynamic computational model. Peridynamics [1] is a non-local integral re-formulation of partial differential equations of classical continuum mechanics. Strain energy density at a material point $\mathbf{x}$ is computed using a weighted average of the difference of displacements between $\mathbf{x}$ and all other material points up to a finite distance $\mathscr{H}_x$, called the horizon. Use of these differences of displacements instead of the classical deformation gradient, there are no spatial derivatives involved in the formulation.

We investigate the ability of the peridynamic model to reproduce the features observed in dynamic fracture experiments [2, 3]. These features include the onset of micro-branching instability, crack surface topology obtained at different crack speeds, material toughening with increasing crack velocity as well as the limit of crack velocity below the Rayleigh wave speed for mode-I cracks. Three dimensional peridynamic analyses of dynamic propagation of single cracks in PMMA plates subjected to quasi-static loads are carried out. The results obtained from the simulations are in a good qualitative agreement with the experiments. Simulations are able to reproduce the transition from a single crack propagating at lower crack speeds, to the development of micro-branches from the main crack with the increasing crack velocity. This transition from a single crack to an ensemble of micro-branches leaves distinct features on the crack surfaces. Simulations are able to reproduce the mirror, mist and hackle transition of the topology of the fracture surfaces observed in experiments.

As the stored energy in front of the crack tip is increased, the velocity of the tip increases and reaches an asymptotic constant value. Our analyses show that this constant asymptotic value of the crack velocity depends on the choice of the peridynamic horizon, but is always less than the Rayleigh wave speed as observed in the experiments. Delta convergence analyses, i.e. the effect of the peridynamic horizon, reveal that the maximum crack propagation velocity observed in simulations decreases and converges to a constant value with the decreasing horizon size. As the crack starts propagating, we observe that the total kinetic energy increases faster for a larger horizon and vice versa. This can lead to the higher crack velocities at larger horizon sizes, as observed in the simulations. It was shown in [4], that an increasing peridynamic horizon leads to an increasing elastic wave dispersion. We investigate if the trailing waves caused due to wave dispersion can affect the crack propagation velocity. The effects of the geometry and the size of the specimen on the dynamics of the fracture is investigated. As presented in [5], we also conclude that the micro-branching process is a three dimensional phenomenon.

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