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Transition from damage to localized cracks in dynamic fracture of polycrystalline ceramics

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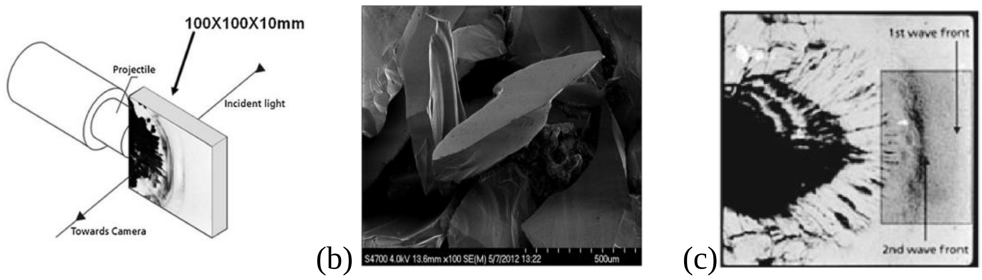
ABSTRACT

We introduce a peridynamic (PD) model to simulate dynamic brittle fracture in polycrystalline materials with cubic symmetry. As a particular example, we analyze the edge-on impact on AlON, a transparent ceramic (see [1] and Fig. 1(a)). We model, approximately, the elastic anisotropy of a cubic-structure crystalline materials by matching longitudinal wave speeds along the [100], [110], and [111] directions. We then construct the polycrystalline PD model by assigning the micromodulus of peridynamic bonds that connect two different grains the smaller of the two corresponding micro-stiffnesses associated with the two orientations of the bond in the two corresponding grains.



(a) (b) (c)

Figure 1: Experimental results (from [1]) for edge-on impact for an AlON sample. (a): sample size and experimental setup; (b) fracture surfaces of fragments; (c) surface damage and failure fronts.

We use a meshfree discretization based on one-point Gaussian spatial integration that allows for autonomous evolution of cracks and damage. In the present model, we use a critical bond elongation that does not depend on the orientation or on the location of the nodes at the end of the bond. Other choices can be made and could result in preferred cleavage planes. The present choice is motivated by the experimental evidence that shows mixed transgranular and intergranular fracture in AlON from impact, indicating that the fracture toughness of the grain boundaries in this material is about the same as that of the single crystal itself. Moreover, experiments show that transgranular fracture surfaces observed in AlON fragments are similar to conchoidal cracks in homogeneous and isotropic materials (see [1] and Fig. 1(b)).

This suggests that cleavage planes in AlON, while present, they could be less clearly defined as in other materials, e.g. sapphire.

We simulate a 3D polycrystalline AlON sample composed of grains with the same average grain size as those in the actual experimental sample used in [1]. However, in order to reduce the computational cost, the computational sample has millimeter dimensions of 2.5mm×2.5mm×0.25mm (with about 200 grains generated by Voronoi tessellation) compared with the sample used in the experiments in [1], which has 10cm×10cm×1cm dimensions. We correspondingly adjust the impact loading to simulate the stress levels used in the experimental conditions [2].

In the peridynamic model, we use a nonlocal region (the PD horizon) that is 1/10 of the average grain size. This is small enough to simulate the influence of microstructure on failure front and fracture propagation.

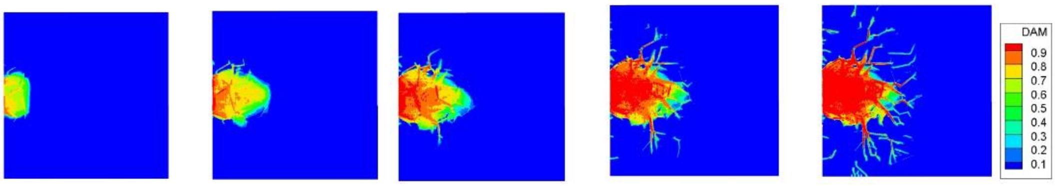


Figure 2: Evolution of damage in the peridynamic model of egde-on impact. Snap-shots taken at 0.05, 0.1, 0.15, 0.2, and 0.25 μs from the time of impact. Experimental results (from [1]) for edge-on impact for an AlON sample. (a): sample size and experimental setup; (b) fracture surfaces of fragments; (c) surface damage and failure fronts.

Simulation results match experimental results very well (see Fig. 2 and Fig. 1(c)). The PD results include intergranular and transgranular fracture. The surface of the sample shows a coherent damage zone moving through the material at relatively high speed. When the failure front slows down, damage transitions to individual, localized cracks that initiate from the edge of the failure front and move at a much lower propagation speeds that the failure front was moving at. This transition between failure mechanisms is well captured by our PD model as well as the propagation speed of the damage front and of the subsequent localized cracks (see [2]).

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