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Quantitative x-ray phase contrast imaging during dynamic deformation and fracture

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Direct visualization of the mechanisms of deformation and fracture can help us understand the response of materials to dynamic loading. X-ray phase-contrast imaging (XPCI) takes advantage of the brightness and pulsed nature of synchrotron radiation to observe these processes in situ in bulk materials with nanosecond-scale temporal resolution and micrometer-scale spatial resolution. In this talk we present several examples of the use of XPCI for dynamic mechanical testing.

One advantage of XPCI is that it significantly enhances the visibility of sharp edges such cracks. Our first example is the use of XPCI during dynamic indentation of a chemically-strengthened glass. We observe the initiation of median cracks below the surface and their subsequent growth. We observe an initial phase of slow crack growth, following which the cracks either terminate inside the glass or accelerate dramatically leading to complete fracture, depending on the loading rate, providing some evidence for strain-rate-dependent fracture behavior.

One limitation of XPCI during dynamic deformation is that it provides only projected, two-dimensional views of the evolving structure. In the case of isolated defects such as single cracks propagating through homogeneous materials (as in our first example), the interpretation of the images can be reasonably straightforward. For more complex materials, or situations in which multiple defects are activated simultaneously, structural features observed in XPCI can overlap in projection, complicating image interpretation considerably. In the worst cases it can be impossible to directly interpret the XPCI images in terms of real-space structures.

Our second example addresses this situation. We describe extraction of quantitative information about the evolution of the structure of sandstone from XPCI data. Sandstone comprises grains of quartz loosely bonded by a cementitious matrix, interspersed with voids and particles of other minerals. The resulting XPCI images are too complex for direct interpretation, but we show that we can observe the evolution of porosity, number of pores, and median pore size using an analytical model that treats the material as a distribution of randomly-oriented ellipsoidal pores. We discuss three ways to use this model, corresponding to different assumptions about the nature of the pore size distribution, and illustrate its application to measurements of the porosity of Berea sandstone under dynamic loading.

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