The Micromechanics Of Brittle Failure At Very High Loading Rates

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Abstract:

Many dynamic phenomena in the Earth sciences generate distributed fracture damage in brittle crustal rock. These include earthquake rupture propagation, underground explosions, and meteorite impacts. For the case of earthquakes, we have demonstrated in the laboratory that off-fault damage can have a significant effect on the propagation velocity and directionality of dynamic ruptures. Any attempt to model this behavior requires a damage evolution (crack growth) law that properly takes into account the size and density of initial flaws and the nucleation and growth of additional cracks as a function of the loading rate. Rate effects are particularly important in the above phenomena where the loading rates are sufficiently high that crack growth lags the loading. Most brittle materials have a power law dependence of failure strength on strain rate at high loading rates.

The micromechanical damage mechanics formulated by Ashby and Sammis (1990) models the nucleation, growth, and interaction of cracks from a given initial distribution of flaws, and thus naturally accounts for the size and density of the initial flaws. However since quasi-static crack growth was assumed (at the critical stress intensity factor) their formulation does not include effects of loading rate. Deshpande and Evans (2008) introduced a simple crack growth law into the Ashby and Sammis model in order to simulate impact loading of ceramic armor plates. However, their growth law has the simple form of laws used to describe stress corrosion and does not contain the known physics of dynamic crack growth. In this talk I will show how we extend the Ashby and Sammis (1990) damage mechanics by incorporating theoretical and experimental dynamic crack growth laws that have been shown to be valid over a wide range of loading rates. This new constitutive law is then used to predict the high strain rate failure strength of marble and is shown to match the experimental data over a wide range of loading rates. Finally I will demonstrate the application of the constitutive law in modeling dynamically generated damage during earthquake propagation and the generation of coherent Shear waves due to an isotropic explosive source, an important problem in understanding the physics of underground nuclear explosions.