Phase transition in time-dependent fracture

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Disordered materials subject to sub-critical external loads present a time dependent macroscopic response and typically fail after a finite time. Such time dependent fracture evidently plays a crucial role in a large variety of physical, biological, and geological systems, such as the rupture of adhesion clusters of cells in biomaterials under external stimuli, the sub-critical crack growth due to thermal activation of crack nucleation, creep and fatigue fracture of materials and the emergence of earthquake sequences [1].

We present a detailed theoretical study of the fracture of disordered materials subject to a constant external load. We worked out a fiber bundle model, which provides a direct connection between the microscopic fracture mechanisms and the macroscopic time evolution of the system. In the model, fibers fail either due to immediate breaking or undergo a damage accumulating ageing process [2,3]. After a failure event, the load of the broken fibers is redistributed locally over their intact nearest neighbors. Since load redistribution and immediate breaking occur on a much shorter time scale than damage accumulation, the entire fracture process can be viewed on the microlevel as a sequence of bursts of immediate breakings triggered by a series of damage events happening during waiting times, *i.e.*, the time intervals between the bursts. Due to the localized interaction of fibers, the bursts and damage sequences are spatially correlated giving rise to growing clusters of broken fibers. Based on computer simulations we demonstrate that there exists a critical value of the external load σ_c which separates two qualitatively different regimes: below σ_c the fracture process is dominated by the uncorrelated slow damage accumulation, while above the critical point strong correlations occur due to stress concentrations. We found that the distribution of the size of bursts and of damage sequences, furthermore, of the waiting times have universal power law functional forms. When approaching σ_c the cluster size distribution becomes a power law and the average cluster size has a maximum analogous to continuous phase transitions. Our calculations revealed that the macroscopic lifetime of the system decreases as a power law of the external load but only below the critical point.

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