Depinning transition in failure of inhomogeneous brittle materials

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As is by now well known, disorder and interactions give birth to qualitatively new phenomena and a rich phenomenology. For example, random interactions in disordered magnets can lead to a true thermodynamic spin-glass phase where long-ranged amorphous order sets in – i.e., there is long range order, but without any obvious broken symmetry. The dynamics also shows characteristic features: slow relaxation, aging, and intermittency, i.e. long stases in deep metastable states separated by sudden jumps. Similar effects also take place for elastic systems embedded in a material containing random impurities, such as vortex lines, domain walls or charge density waves. Here again, the low temperature phase can be qualitatively different from its "pure" (no disorder) counterpart; these objects can be *macroscopically pinned* by disorder, in the sense that a small external force F is not sufficient to set them into motion; the linear mobility is zero. The external drive must be large enough to depin these systems and allow them to "flow"; at zero temperature there is a well defined depinning threshold F_c, characterized by a diverging correlation length, critical exponents, etc. that have been described with exquisite details within the Functional Renormalisation Group [1,2]. Around the transition, the dynamics is again intermittent: nothing happens for a while before patches of the system unlock, triggering "avalanches" of all sizes. At finite temperature, the transition is smoothed by activated events; the system acquires a finite velocity even below the critical force, but in this so called "creep" regime, the velocity is exponentially small.

Beyond its theoretical beauty, this problem turns out to have concrete and important consequences in material science. One concerns the critical current in high temperature superconductors, which essentially relies on the existence of a low temperature pinned phase. Another one is fracture propagation in disordered materials – quite a common and relevant situation indeed. Crack opening in three dimansional samples is controlled by the motion of an elastic line, the *crack front*. As noted in [3], the morphology of post-mortem crack surfaces is in fact the trace left behind by the motion of the crack front. A detailed understanding of the dynamics of the crack front and the way it interacts with the inhomogenities of the material is obviously crucial to determine the resistance to failure of these materials, and the speed at which a micro-flaw will size up to become a macroscopic crack.

The relevance of the depinning transition for crack propagation was suggested experimentally in the mid-nineties [4], but plasticity adds a level of complexity that prevents direct comparison with theoretical and numerical predictions for *elastic* (albeit long-ranged) models. While some progress had been made on model systems where the crack is confined in a plane [5], the work of Laurent Ponson aims at establishing in a *quantitative* fashion the relevance of these elastic models for the fracture of brittle three dimensional disordered materials. The choice of a brittle rock allows one to belittle the role of plastic deformation. The main result of this work is the determination of the velocity of the crack as a function of the driving force, spanning four orders of magnitude in velocity (from 50 μm s^{-1} to 50 cm s^{-1}). This allows one to see a clear crossover between a creep, intermittent regime and a steady motion regime above a certain threshold F_c that corresponds to the onset of material failure. The velocity $V(F)$ appears to grow in that regime as a power law: $V \propto (F - F_c)^\theta$, as predicted by the theory. The value of $\theta \approx 0.8$ is furthermore in good agreement with theoretical and numerical estimates. The parameters describing the creep regime can also be rationalised using the elastic model and reasonable order of magnitude estimates. Another prediction of the elastic model is that the out-of-plane deformation of the crack front (the only one that can be observed post-mortem on fracture surfaces) decouples from the critical dynamics of the in-plane deformation; this seems to be also borne out by observations [6].

This work seems to me very important as it gives quantitative credit to the idea that the depinning transition is relevant to describe fracture in disordered materials. Other, more detailed predictions of the Functional Renormalisation Group theory can probably be tested as well, which makes fracture an exciting test-bed for these ideas. The next step to account for materials of more relevance in practice. This requires including plasticity and cavity nucleation into an effective description in terms of line dynamics – a major challenge indeed.

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