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Avalanches in the Plastic Deformation of Crystalline Solids[1]

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Plastic avalanches and highly fluctuating stress strain relations have been reported for crystalline materials as diverse as ice or several conventional metals and alloys. The most recent theoretical interpretation of these experimental findings is based upon collective dislocation dynamics and non-equilibrium critical phenomena. Dislocation assemblies in crystalline substrates represent a new example of the broad class of systems that exhibit avalanches and a jamming (or yielding) transition. Rheology experiments carried out on this broad class of systems ranging from granular media to foams show that their dynamics becomes increasingly heterogeneous when approaching the jamming threshold. Likewise, experiments on crystal plasticity at various scales have recently emphasized the heterogeneous character of plastic flow. Here we explore further the analogy between dislocation ensembles and other jamming systems by analyzing the behavior of dynamic response functions, such as the four point dynamic susceptibility, as well as the shear stress distributions in both jammed and moving dislocation arrangements. Our results show the existence of a diverging dynamic correlation length as the jamming threshold is approached. At microscopic scales, where only a limited number of dislocations mediate the deformation process and no dislocation storage phenomena are observed, heterogeneous behavior in the mechanical properties is even more dramatic and technologically relevant. Bursts of plastic activity in microscopic colloidal crystals under compression are broadly distributed, both in strain/stress-controlled tests, but scaling exponents are anomalous, and thus the interpretation of these findings within the framework of collective dislocation phenomena and the yielding transition is no longer appropriate. Moreover, non-trivial size effects on the mechanical properties of micrometer-to nanometer scale crystals can be explained in terms of the interactions of dislocations with the boundaries of the sample.

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