Discrete element modelling of the tensile failure of porous rocks

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Rocks experience complex loading conditions including tension, compression, and shear during their geological history. Deformation is accompanied by the release of elastic energy from micro-cracking events, which can be registered in the form of acoustic waves [1]. Acoustic emissions (AE) form the primary source of information about the microscopic processes of fracturing providing us with valuable data about the temporal and spatial evolution of the ensemble micro-cracks leading to ultimate failure. The acoustic noise generated during the compressive failure of rocks in laboratory experiments has been found to exhibit scale-free statistics similar to earthquakes, which addressed the universality of cracking phenomena across a broad range of length scales. In spite of the intensive research, the effect of the loading conditions on the statistical features of crackling noise generating acoustic emissions has not been fully understood.

Due to the limitations of acoustic emission experiments, computer simulations of realistic models of geomaterials can be used to complete our insight into the deformation and fracture of rocks. In order to understand how the loading condition affects the jerky evolution of the fracture process and the spatial structure of damage in porous rocks, here we use discrete element simulations to analyze the statistical and dynamical features of crackling noise emerging during the tensile failure of a realistic model rock and compare the results to the outcomes of simulations obtained under compressive loading of the same samples [3]. In the model numerical porous rock samples are generated by sedimenting spherical particles with a random radius in a cylindrical container under the action gravity. The center of particles are connected by beam elements which represent the cementation of the material. The cylinder is slowly elongated by moving boundary particle layers at the bottom and at top of cylinder against each other.

We demonstrate that under uniaxial tensile loading the system has a quasi-brittle behaviour where the fluctuating ultimate strength and the strain where cracking sets on are both described by Weibull distributions. Simulations showed that as the sample is elongated fracturing proceeds in bursts of microcracks which have a scale free statistics: the size, duration, and energy released by the avalanche are all power law distributed with a finite size cutoff. Simulations revealed that the beginning of the failure process is dominated by the disordered micro-structure of the material which gives rise to random nucleation all over the sample. Approaching failure, breaking avalanches localize and merge into a sharply defined fracture plane at which the specimen falls apart. We give a quantitative characterization of the fluctuating sharpness, orientation, and position of the fracture plane. The results are compared to the outcomes of the simulations of uniaxial compressive failure of the same specimens [3]. In spite of the strong differences of the spatial structure of damage in the two cases, for the statistics of avalanche quantities the same qualitative trends are obtained and also the value of the exponents fall rather close to each other.

References

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