Geophysical Research Abstracts
Vol. 16, EGU2014-6583, 2014
EGU General Assembly 2014

Transition from straight to fractal cracks due to projectile penetration

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We investigate the fracturing of heterogeneous materials due to the penetration of a rod with conical shape. A two-dimensional discrete element model of a disc shaped specimen is worked out coupling randomly shaped convex polygons by cohesive beam elements. Computer simulations are carried out of the process when a rod with a conical nose is pushed perpendicularly into a disc shaped sample. Cracks are generated in the sample by the successive breaking of beams.

Varying the speed of penetration simulations revealed a rich dynamics of the system: In the limit of very slow loading straight cracks are formed along which the sample falls apart. Increasing the loading speed first the number of cracks increases, while above a threshold speed cracks start to branch and form fractal structures. The fractal dimension of three-like branching cracks proved to increase with the speed of loading from $D_f \approx 1.0$ to$D_f \approx 1.65$. When the speed of penetration surpasses a second threshold value the fractal cracks merge forming a network and the specimen breaks up into a large number of fragments. The fragmentation pattern is mainly controlled by the interference of elastic waves generated by the energetic loading and by the reflection at the free external boundary of the disc. The size distribution of fragments determined by the crack structure proved to be a power law with an exponent close to 1.9. Analyzing the simulated data we deduce scaling relations which characterize the straight crack - fractal crack - fragmentation transition. The theoretical results are confronted with experimental findings.