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A simple model for fractalization of fault gouge

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A constitutive law of fault gouge is essential in describing the stability/instability of the motion of a fault. Extensive experiments and simulations have been conducted to reveal that the frictional properties of granular matter, such as the fluctuation of frictional force, are significantly affected by the particle-size distribution (PSD). For example, see Marone and Scholz 1989, Morgan and Boettcher 1999, Mair et al. 2002, and Abe and Mair 2005. Because the PSD depends on the nature of comminution in a fault, comminution is one of the key processes that dominate the frictional properties of fault gouge. However, we still cannot answer the following fundamental questions: Why is gouge fractal? What sets the fractal dimension?

Here we show a simple (perhaps the simplest) model that can give answers to the above questions. Our model is somewhat similar to a classical model by Sammis et al. (1989), but quite different in modeling successive fragmentation processes. Our model involves the time evolution equation of PSD so that we can discuss any transient states of PSD during the comminution process.

One of the important results is that the PSD for a steady state is always fractal irrespective of the fracture criterion of each particle. This makes a quite contrast to the model of Sammis et al, which requires a certain condition to the fracture criterion in order to reproduce the fractal PSD; otherwise the lognormal PSD is obtained in their model.

Another important prediction of our model is the fractal dimension. It is found that the fractal dimension depends on the fracture criterion. To reproduce the universal value 2.6, the fracture probability of a single particle should be proportional to $d^{-0.4}$, where d denotes a dimension of a particle. We can explain this fracture probability by taking two ingredients into account: the strength of single particle and the statistics of force chains.

Furthermore, by means of discrete element simulation, we investigate the rate dependence of friction coefficient of granular matter that has fractal PSD. It is found that the (time-averaged) friction coefficient of fractal systems is lower than that of a non-fractal system, but is insensitive to the fractal dimension.