Micro-Fracturing and Percolation Theory to Understand the Temporal Evolution of Pre-Fracture Electromagnetic Radiation on Rocks

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Micro-Fracturing and Percolation Theory to Understand the Temporal Evolution of Pre-Fracture Electromagnetic Radiation on Rocks

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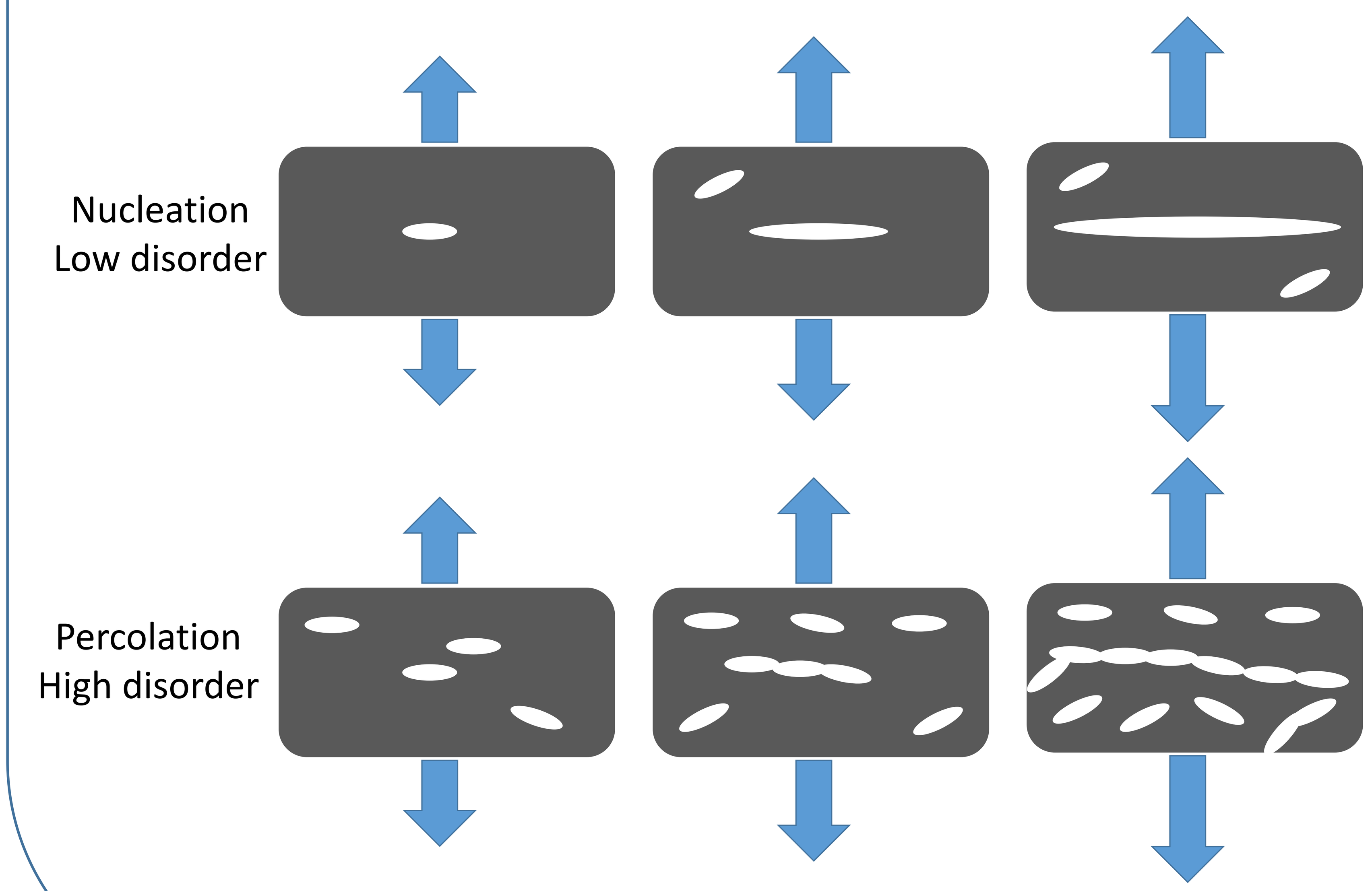
Abstract

In this work we analyze the electromagnetic radiation produced by microcracks, merging the one-dimensional lattice model for fractures with the capacitor model for electromgnetic attenuation. The temporal evolution of the electromagnetic signal is studied assuming coalescence of micro-fractures through the percolation-aggregation process. Although percolation theory is a pure statistical model, it is the most simplest theoretical frame that contains the basic aspects of critical phenomena related with fractures. The results of the model are compared with some experimental data obtained from fracture of rocks under uniaxial stress.

1. Introduction

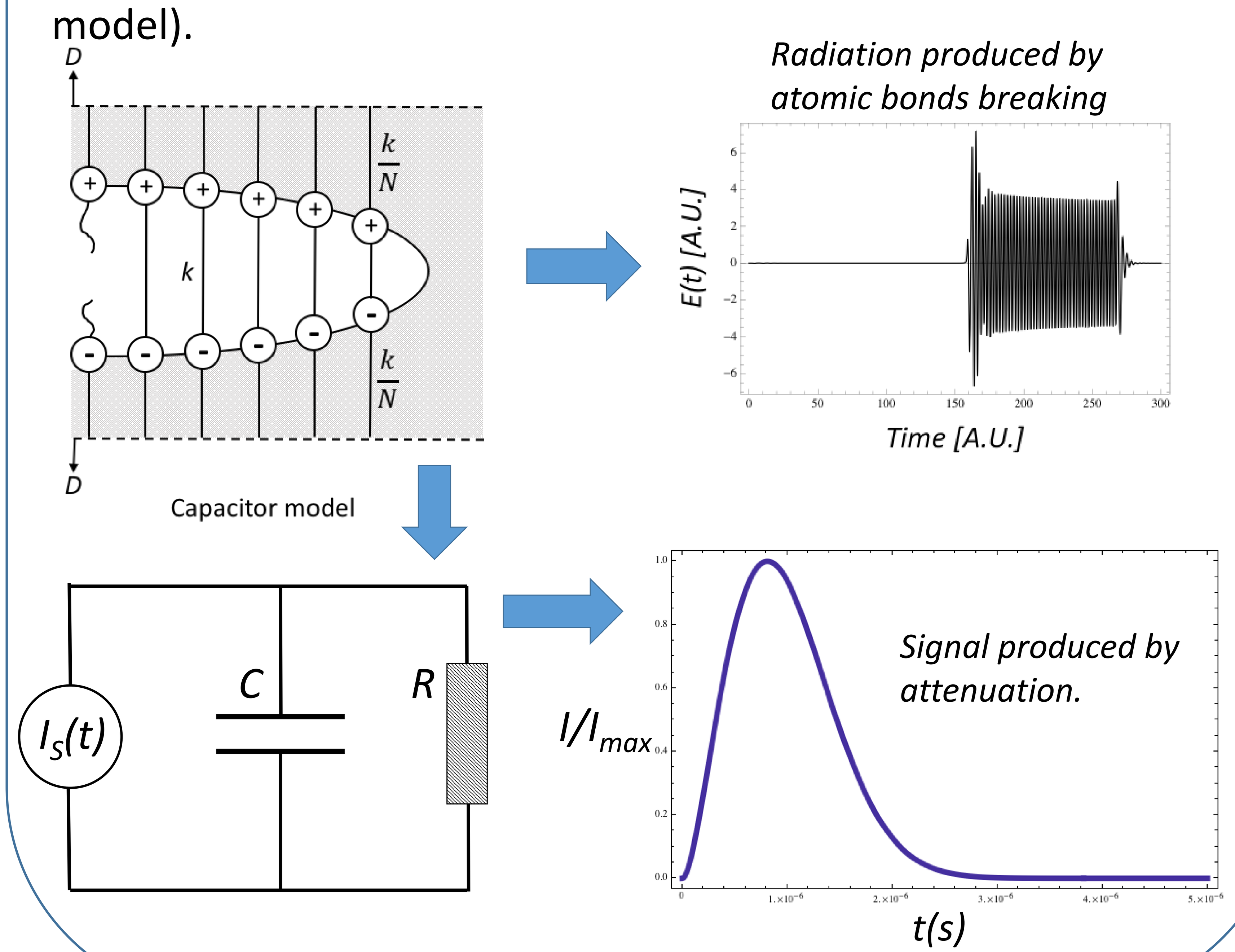
Electromagnetic emissions are detected during fracture processes in laboratory experiments in different kind of rocks. Along with acoustic emissions this radiation can be seen as a precursor of final rupture. Extrapolation to geological scales has been proposed in the design of early alert systems for earthquakes, landslides and mine collapses.

In contrast to perfect crystals where the fracture is governed by nucleation of big cracks, rocks are highly heterogeneous and disordered systems where the final rupture is the result of the generation and coalescense of microcracks. One way to describe this process is throughout a percolation approach.



2. Radiation emitted by a microcrack

Radiation emitted by a microcrack can be seen as a combination of the radiation produced by the breaking of atomic bonds (photon emissions) and the electric charge recombination through a conductive medium (capacitor model).



3. Percolation and aggregation.

If localization of microcraks is not a requirement in the analysis, percolation can be seen as an aggreagation problem. In this scenario the sample is divided into cells and the aplication of increasing stress generates microcracks that randomly occupay the cells. Following the statistical physics lenguaje, the rock can be seen as an open system embeded in a "thermal bath" which permanently injects microcracks until the rock is totally fractured. The size of emerging fractures is simply proportional to the number of agreggated microcracks in a particular cluster.

$$M_i(t+\Delta t) = S_i + \sum_j c_{ij} M_j(t).$$

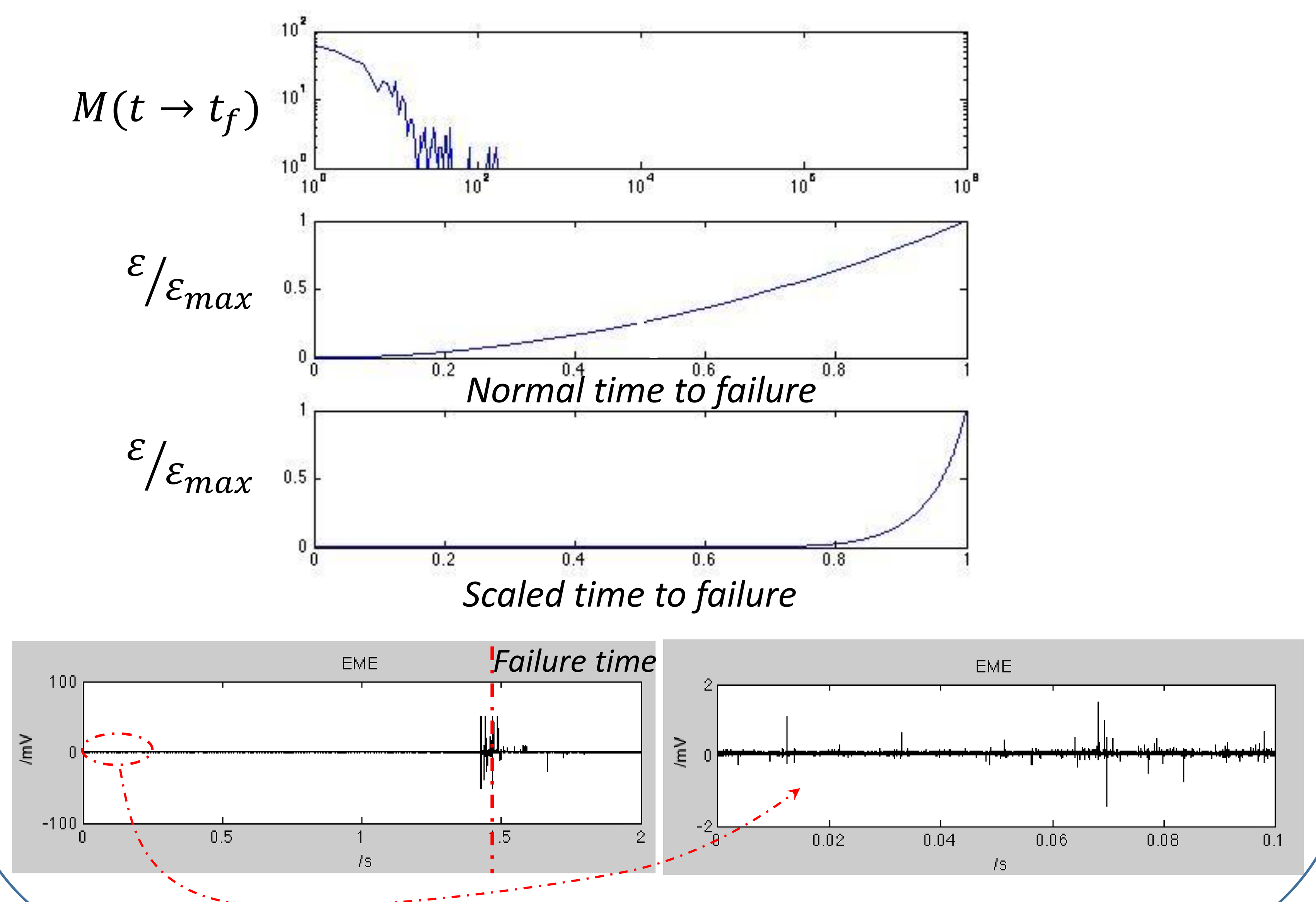
- M_i: Number of microcracks agregtated in the i-th cluster
- S_i: Injection of microcracks from the "thermal bath" into the cell i
- c_{ij}: Transition probability for a microcrack from the cell i into the cell j

For a particular time t, the energy emission $\varepsilon(t)$ is given by:

$$\varepsilon(t) \propto \left[\sum_i M_i(t)\right]^2$$

4. Results

The graphs show the cluster size distribution near the final rupture and the temporal evolution of the process:



Some Experimental Results

Conclusion

The model predicts an increasing number of emissions when the failure time is closer. The energy associated with these emissions increases as well. Comparison with experimental tests shows a good qualitative agreement. More statistical studies have to be done to go deeper in a more complete quantitative comparison.