Modeling of Electrical Fragmentation of Rocks

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Introduction:

Rock breaking is an essential operation in mining engineering as well as in geothermal, oil and gas drilling. The difficulty of optimal rock fragmentation is growing with the increase in the exploitation of natural resources. In this context, novel efficient rock-breaking technologies are crucially required for a given range of rock materials.

The high-voltage pulsed fragmentation (HVPF) technique, which attracted a wide attention, has shown great efficiency and huge development potential. The main advantage of HVPF method is its possible lower energy consumption and higher advance speed compared to mechanical drilling methods in hard rocks. This may lead to much smaller, lighter, and safer drilling rings.

Several studies were performed with the HVPF technology, but these studies were done on an empirical basis.

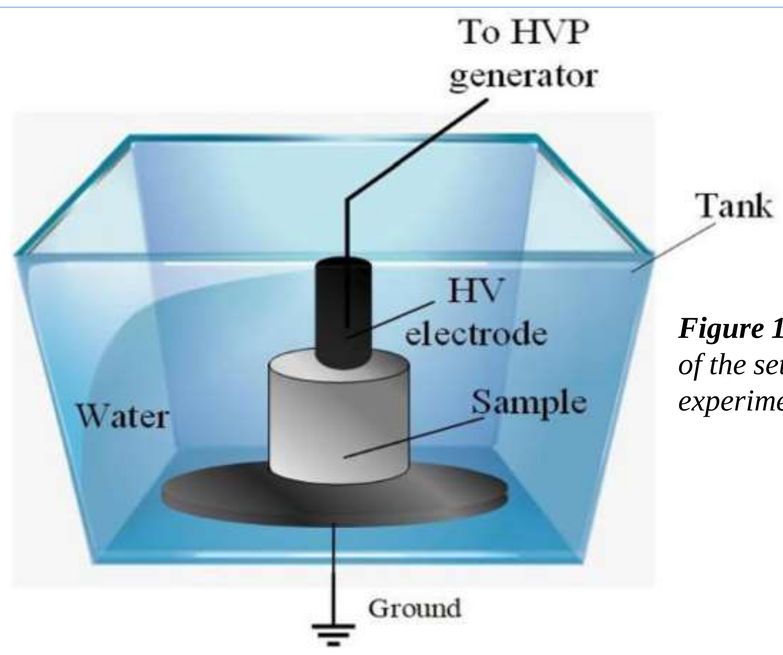

***Figure 1**: Schematic diagram of the setup for HVPF experiment [3]*

Phenomena:

During electric discharge, strong power is released in the form of voltage surges with peaks of up to 600 kV.

- When discharge plasma is produced in a liquid medium, rock is mainly fragmented by the mechanical forces produced by the discharge, such as shock wave. This effect is indirect or delocalize mode and called electro-hydraulic rock breaking (figure 2a).

- With a high-pressure short pulse having a pulse rising time less than 500 ns, the breakdown field strength of the rock is less than the liquid medium used (figure 3). Thus, the discharge plasma is mainly in the rock. Due to the stress caused by the expansion of the plasma channel, the rock is broken. This effect is direct or localized and called electro pulse breaking (figure 2b).

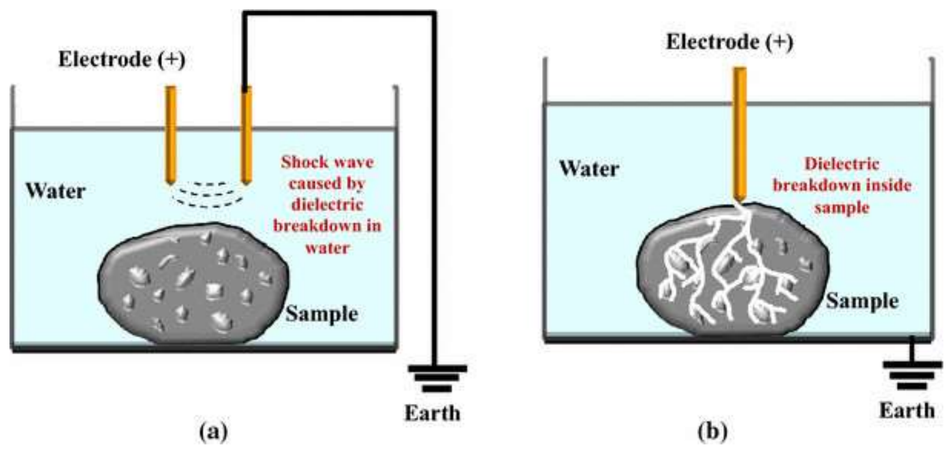

***Figure 2:** High-voltage discharge induced fragmentation of a solid*
***2a)** Electro-hydraulic rock breaking*
***2b)** Electro pulse rock breaking*

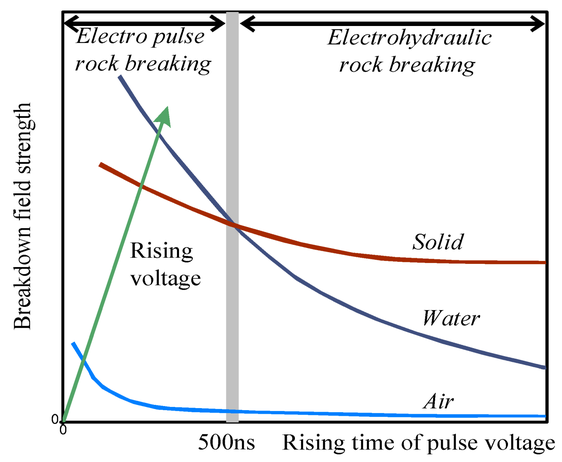

***Figure 3:** Relationship between breakdown field strength of different media and rising time of pulse voltage*

Given the same amount of power, direct electro pulse rock breaking produces a better effect. **Thus, the crushing efficiency of electro pulse method is higher.**

The process of electro pulse breakdown can be explained as follows:

- Under a strong electric field, some filamentary discharges known as streamers, merely weakly ionized plasma with relatively low conductivity, appear at time t_1 (Figure 4a).

- The streamers continue to grow, and usually, one or two highly conductive channels finally form (Figure 4b-4c).

- The main conductive channel causes the current to increase rapidly and drastically reduces the voltage drop between electrodes, thereby preventing other channels from forming. The bridge of the electrodes results in energy release from the discharge channel to create massive tensile pressure that break down the sample (Figure 4d).

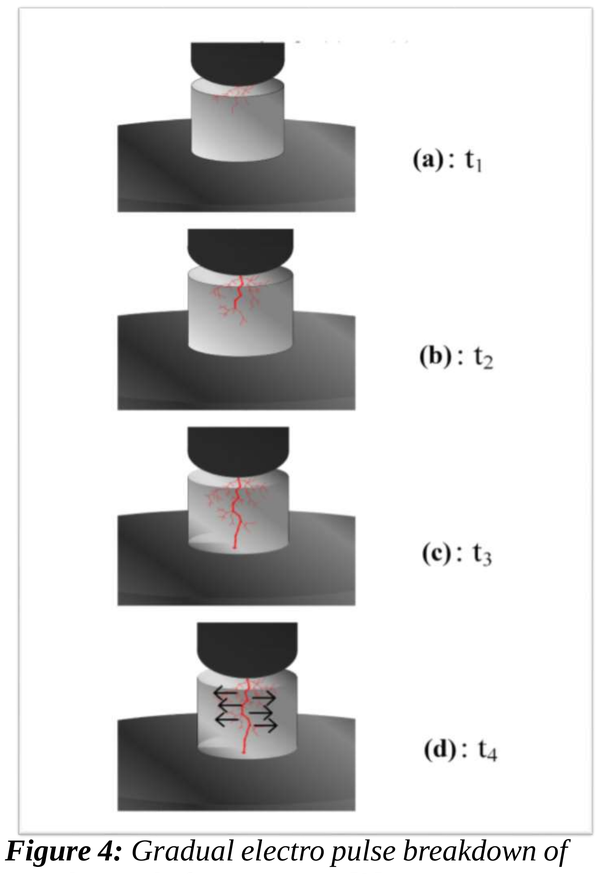

***Figure 4:** Gradual electro pulse breakdown of a rock sample from t_1 to t_4 [3]*

Objective:

- This work focuses on the understanding and mathematical modeling of the phenomena involved in the fragmentation process with the long-term objective of optimizing the conditions for the industrial implementation of this technique.
- This work consists in putting into equations the phenomena involved within the framework of an electro- hydro-thermo-mechanical approach and in identifying the modes of coupling between these different physics.

Methodology:

- **Mathematical Modeling:** Investigating the electro-hydro-thermo-mechanical mechanism by modeling the dielectric breakdown
- **Numerical Simulations:** Numerical simulations will be carried out to study the sensitivity of the process to the various factors involved in the fragmentation process
- **Experimental work:**
  - To better understand the role of the different parameters and define our model
  - To check the validity of the model by comparing the results obtained from the model and from the experimental setup

Conclusion:

This research work takes modeling the electrical fragmentation of rocks as a research target.

- First, the dielectric breakdown model should be introduced to describe the electric breakdown processes. The model and the model parameter settings should be validated.
- Then, numerical simulations should be carried out. In parallel with the numerical work, experimental tests should be performed followed by analysis and comparisons with numerical work.

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