doi: 10.56761/EFRE2024.S4-P-043201

Comparison of electrohydraulic and electro-pulse effects under similar experimental conditions

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Abstract. The comparison of two mechanisms of hard rock fracture – electrohydraulic and electro-pulse – has been carried out. By means of computational studies it is shown that the electro-pulse effect leads to more intensive cracking in the material volume than the electrohydraulic one. Experimental studies show that with comparable energy input into the discharge channel, the volume of rock broken off due to the electro-pulse effect is much higher than the volume of rock destroyed by electrohydraulic effect.
Keywords: electrohydraulic effect, electro-pulse effect.

1. Introduction

In a number of medical and industrial technologies, electric discharge is used as a means of destroying solids [1–7]. Destruction is performed by applying electrodes to an object located in a liquid medium (Fig. 1). A high voltage impulse is applied to the electrodes located at a distance *d* relative to each other.

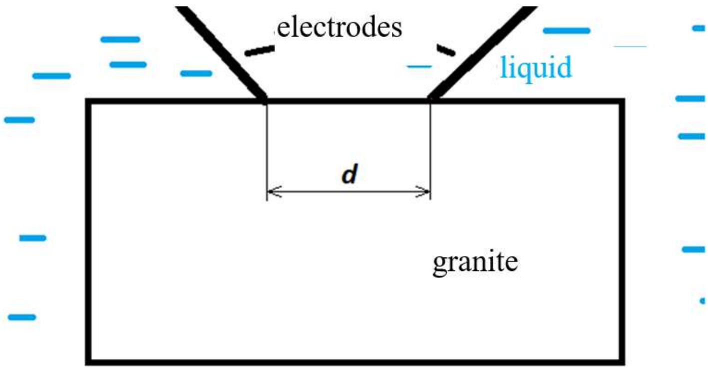


Fig. 1. Solid destruction by electrical discharge.

Under the influence of a high-voltage impulse, a discharge channel is formed between the electrodes, leading to the destruction of rock fragments. The destructive effect of solid is produced by two mechanisms. The first, electrohydraulic effect (so called "Yutkin effect"), is the action of shock-wave disturbances from an electrical breakdown channel formed in a liquid or at a liquid-solid interface [1, 2]. The second mechanism – the electro-pulse effect (so called "Vorobyevs` effect") – is the action of shock-wave disturbances from the breakdown channel formed inside a solid body immersed in a liquid media [3, 4].

It can be assumed that at the same energy input into the discharge channel the efficiency of electro-pulse fracture will be higher, because in this case the strength of the material is overcome mainly in tension, not compression, as in the case of electrohydraulic action. There are papers that consider both these phenomena simultaneously, for example [6, 7]. However, in such works either the scale of energy and specimens are rather small, or the modes of the process are not specified, or the conditions of the discharge formation and energy release are different, which does not allow a direct comparison. This article is an addition to already executed researches and aims to carry out a comparative test of granite specimen destruction in conditions of electro-pulse and electrohydraulic effects with the same mode of the energy release into the discharge channel.

2. Calculation

The computational studies were carried out using a two-dimensional mathematical model. In the model the structure imitating mechanical properties of granite taking into account its heterogeneous composition is used (Fig. 2).

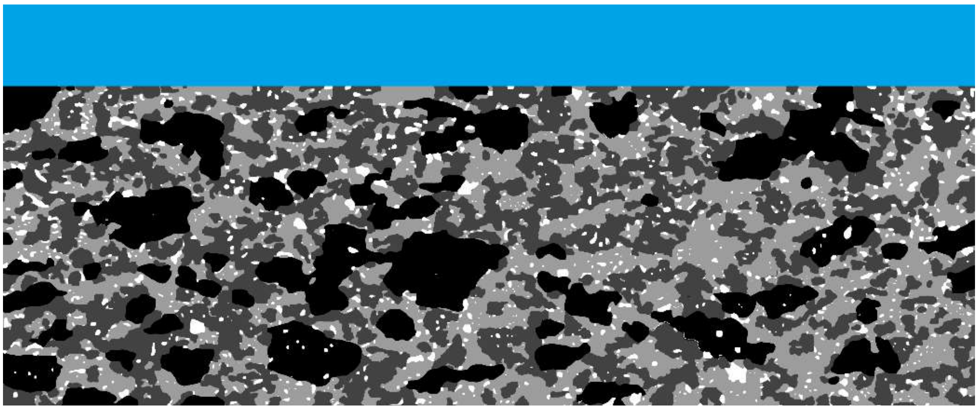


Fig. 2. Structural map of the computational volume. The homogeneous region in the upper part is water.

The granite structure was specified explicitly using a photo of a real sample slice. Data on the physical and mechanical properties of the main structural components: quartz (light gray); plagioclase (dark grey); feldspar (black); and micas (white) were taken from literature [8, 9].

The pressure in the discharge channel was used as a disturbing action on the discharge channel wall (Fig. 3).

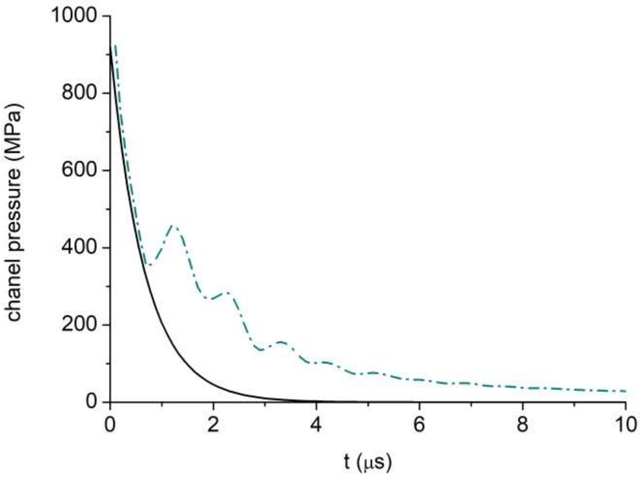
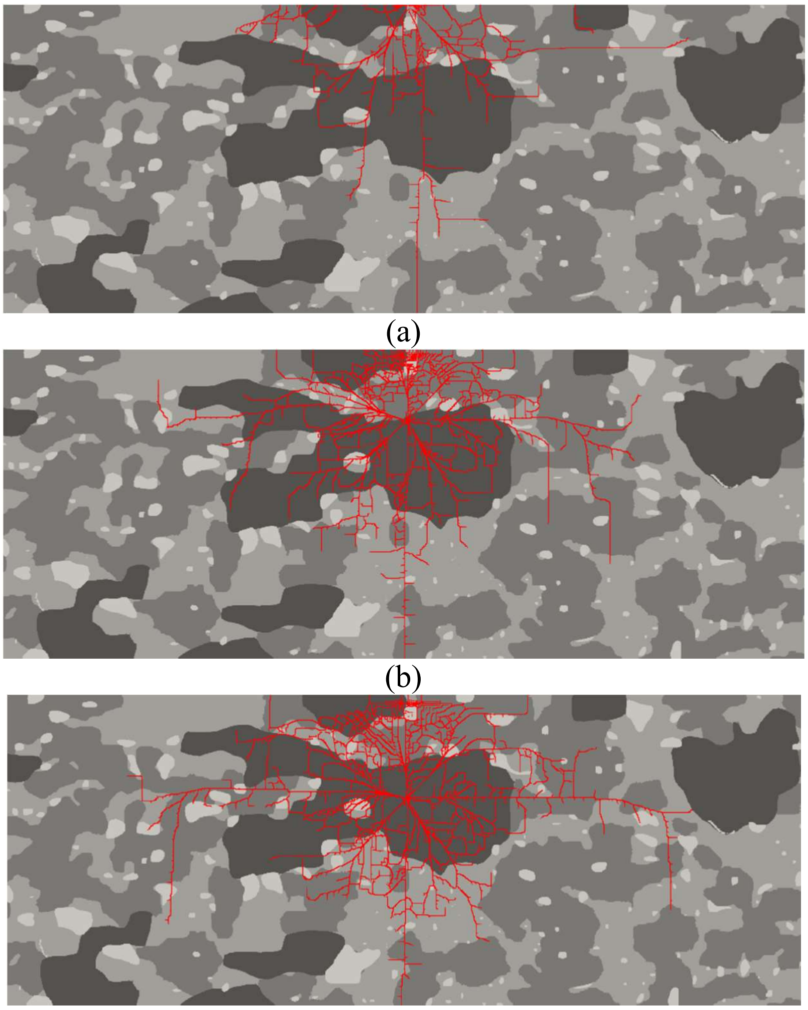


Fig. 3. Discharge channel pressure: calculated curve – dashed-dotted line, approximated profile – solid curve.

The pressure (dashed-dotted line) was determined on the basis of the discharge circuit parameters due to the self-consistent model that we had previously developed [10] and then approximated (solid curve) to set it as the initial condition in the crack calculation model [11]. The deformation and pressure in the medium were calculated by finite element method.

The simulation was performed for the three points of the discharge channel location. The first case, corresponding to the impact of the Yutkin effect, assumes the formation of electrical discharge channel on the surface of a solid, i.e., the depth of channel penetration was zero. In the second and third cases, the impact of the electro-pulse effect, i.e., the discharge channel penetration into the solid material was investigated. Based on the experimental data, the depth of discharge channel penetration was assumed 7 and 10 mm. The calculation results are shown in Fig. 4.



(a)

(b)

(c)

Fig. 4. Crack distribution at time 11.25 μs for the depths of channel penetration of 0 (a), 7 (b) and 10 (c) mm.

Calculations show the more active cracking process in the case of discharge channel penetration. At the same time, no significant difference is observed between the cases of discharge channel penetration in solid at 7 and 10 mm. It can be noted that in the second and third cases (Fig. 4b and 4c), the orientation of the cracks facilitates the separation of part of the material and the formation of a spall cavity, while in the first case (Fig. 4a), the separation of the spalled material is difficult and only small fragments are possible. Nevertheless, in all cases, it is possible to note the formation of a through crack along the entire depth of the sample. This indicates the possibility of sample splitting, which happened in several cases during our physical experiments.

3. Laboratory experiments

Experimental studies were carried out using granite specimens in the deionized water. The source of high-voltage pulses was a generator of pulse voltages on the basis of a pulse transformer EG350 [12]. The interelectrode distance was 25 mm. To prevent rock breakdown and implement the electrohydraulic effect, it was necessary to reduce the voltage on the electrodes. For this purpose, in these experiments, the output of the generator was shunted with a 50 Ohm resistor brand TVO-60. At the same time, to compensate for the losses, the generator stored energy was doubled. At the moment of the electrical discharge formation the photographing of the formed discharge channel was performed (Fig. 5). It was applied 6 pulses in each experiment. Typical voltage and current waveforms for both cases are presented in Fig. 6.

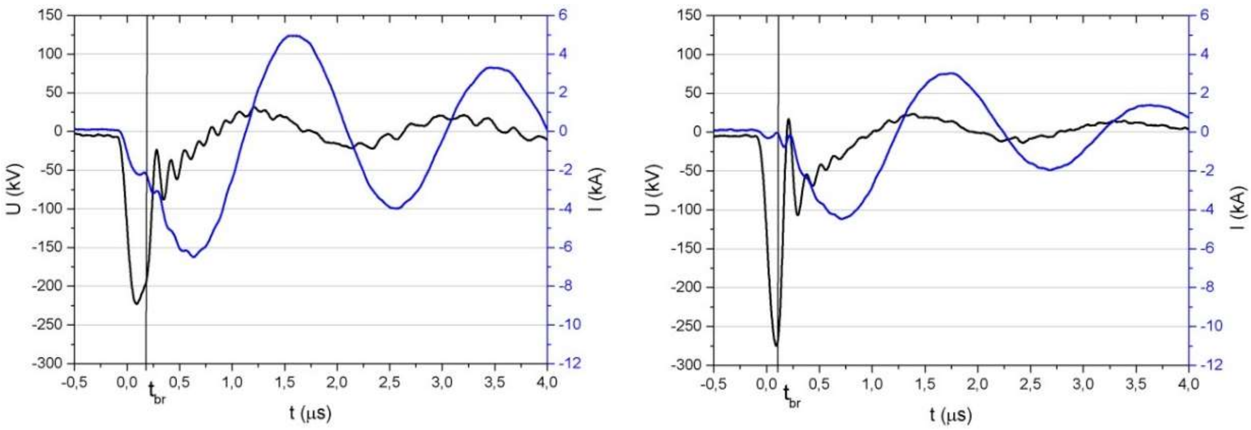
a b

Fig. 5. Electrohydraulic (a) and electro-pulse (b) effects and results of their action on granite surface.

The specific energy for the destruction of material for the electro-hydraulic effect was 8565 J/cm^3, which is significantly higher than for the electro-pulse effect (202 J/cm^3). At the same time, the broken-off volume of material per pulse is higher for the electro-pulse effect – 1 cm^3/pulse versus 0.05 cm^3/pulse for the Yutkin effect. The results of the experiment are summarized in Table 1.

Table 1. Experimental results.

	Electrohydraulic effect	Electro-pulse effect
Stored energy, J	414	209
Voltage amplitude, kV	225	275
Average volume of fractured rock after 6 pulses, cm^3	0.29	6.2
Volume of spalled rock per pulse, cm^3/pulse	0.05	1
Specific energy for splintering, J/cm^3	8565	202



a b

Fig. 6. Voltage and current waveforms for electrohydraulic (a) and electro-pulse (b) effects.

One can notice the presence of a significant pre-breakdown current due to the voltage drop across the resistor, a lower amplitude of the output voltage and a longer breakdown delay time in the case of the electrohydraulic regime (Fig. 6a). At the same time, the energy released after breakdown moment t_{br} in the discharge channel in this case is slightly greater than during electric pulse action, this can be judged by the maximum current amplitude of 6 kA and 4 kA for electrohydraulic and electro-pulse effects, respectively. The period of energy release in both cases is the same, which provides comparable conditions for shock wave dynamics after the breakdown.

4. Discussion

The electrohydraulic effect is realized in the formation of a shock wave by the expanding discharge channel. The discharge channel in this case is formed either in the liquid medium or at the interface between the liquid and solid media. The resulting shock wave has a very high pressure in its front, which, however, decreases very rapidly with increasing the distance from the discharge channel. If a solid is in the vicinity of the discharge channel, the shock wave has a deforming effect, resulting in cracking and solid material fracture. It is assumed that the main failure mechanism is the formation of compression regions and exceeding the compressive strength of the solid material.

According to the photographs of the breakdown moment (Fig. 5b), it can be seen that in the first experiment the discharge channel is embedded in the rock volume, since there is practically no frame illumination, except for the places where the discharge channel is bound to the electrodes, and the discharge channel passes inside the rock volume. Thus, the solid splitting off occurs due to the electro-pulse effect (Vorobyevs` effect). In the second case (Fig. 5a) the developed field strength is insufficient for the discharge channel penetration into the rock volume and the breakdown occurs on its surface in water, the discharge channel can be seen visually. The rock destruction in this case occurs due to hydro shock (Yutkin effect).

For the specified experiment, the specific volume of rock spalled by the electro-pulse effect averages 1 cm^3/pulse, which is significantly higher than the volume of rock spalled due to the electrohydraulic effect (0.05 cm^3/pulse).

5. Conclusion

Thus, the results of experiments and simulation of granite fracture at electro-pulse and electrohydraulic action with the same energy input mode into a discharge channel have shown the advantage of electric pulse action expressed in the greater specific volume of the rock splitting off. Computational studies shown, that the electro-pulse effect leads to the more intensive cracking in the material volume than the electrohydraulic one. For a number of experiments, the efficiency of granite destruction differed about 20 times.

Acknowledgement

The computer simulation part of the work was performed under the government statement of work for ISPMS SB RAS, Project FWRW-2021-0002.

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