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Discharge-mechanical method of rock breakage

V F Vazhov[1], S Y Datskevich[1], M Y Zhurkov[1], V M Muratov[1] and B Jeffryes[2]

[1] National Research Tomsk Polytechnic University, Tomsk, 634050, Russia
[2] Schlumberger Gould Research, High Cross, Madingley Road, Cambridge CB3 0EL, UK

Abstract. The electric discharge and mechanical technology of hard rock breakage was developed on the ground of mechanical and electrical pulse methods and it was tested for purposes of deep drilling. It was demonstrated that, due to breakage of the rock surface by electric discharges, the rock excavation volume (breakage performance) is significantly improved as compared to conventional mechanical methods.

1. Introduction

Rock breakage is the most labor-intensive and time and money-consuming operation when extracting and processing minerals. Inevitable shortcomings of main conventional mechanical methods of rock breakage are high specific energy consumption, strong dependency of the excavation volume on the rock strength, and rapid wear of a rock destruction tool. An electric discharge (ED) technology of breaking solid dielectric materials, that is invented and being developed in the Tomsk Polytechnic University (Russia), is seen to be promising [1, 2]. Such an ED technology provides the basis for its various applications including rock drilling, rock cutting, rock and ore breaking [3-5], surface processing and finishing [6] and other. The ED method is based on a phenomenon that the electric strength of liquid dielectrics and water is higher than that of solid dielectrics and rocks at a breakdown delay of 1 μs and less [1,7]. An electric breakdown results in a spark channel which penetrates into a solid body and converts the electric energy into energy of mechanical stresses and deformations (crack formation). The ED rock breakage principle allows preventing a lot of disadvantages of conventional mechanical methods due to following reasons: it is a breaking load that effects on the material and there is no need in any-kind mechanical rock destruction tools. When drilling a borehole, a rapid wear of a drill bit leads to significant increase in borehole drilling time and cost, especially it is true for deep and super-deep boreholes, and this retards the geothermal energy development [4].

Each rock breaking method is known to have its own shortcomings and disadvantages that limit fields of its application. Combining various rock breaking methods makes it possible to get new ones coming closer to a universal rock breaking technology [8].

Earlier we suggested an ED method of rock breakage by a continuously moving two-electrode system [9]. Such a method has a lot of advantages against to a fixed multi-electrode system [6] because it reduces the energy loss and the voltage pulse deformation at a pre- breakdown stage and significantly reduces the energy stored by a pulse generator. An ED method of rock breakage by a moving electrode system, when applied to drilling, allows one to implement a cooperative effect on rocks. A joint action of electric discharges and mechanical cutting would result in a higher rock excavation volume due to pre-breaking of rock by electric discharges and that makes its further mechanical disintegration easier.

The present paper shows, for the first time, results of studying the rock breakage by a joint electric discharge and mechanical method in order to determine the cutting forces when processing the surface of a granite unit mechanically and by an electric discharge method.

2. Experimental

In order to study the cutting forces we used a device equipped with a three-component elastic dynamometer with foil resistive strain gages. When processing a rock surface mechanically, cutters with an 8mm-wide main cutting edge and made of tungsten-cobalt hard alloy VK8 were used. A 4mm-deep and 8mm-wide trench was cut in a granite unit (the compression strength $\sigma = 160$ MPa), with a cutting depth of 0.07 mm per turn (Figure 1, a). A 1mm-thick layer of rock was removed off and a main constituent P_z of a cutting force and a normal constituent P_y (pressing-out force) were recorded at a final stage of surface layer removal (Figure 2).

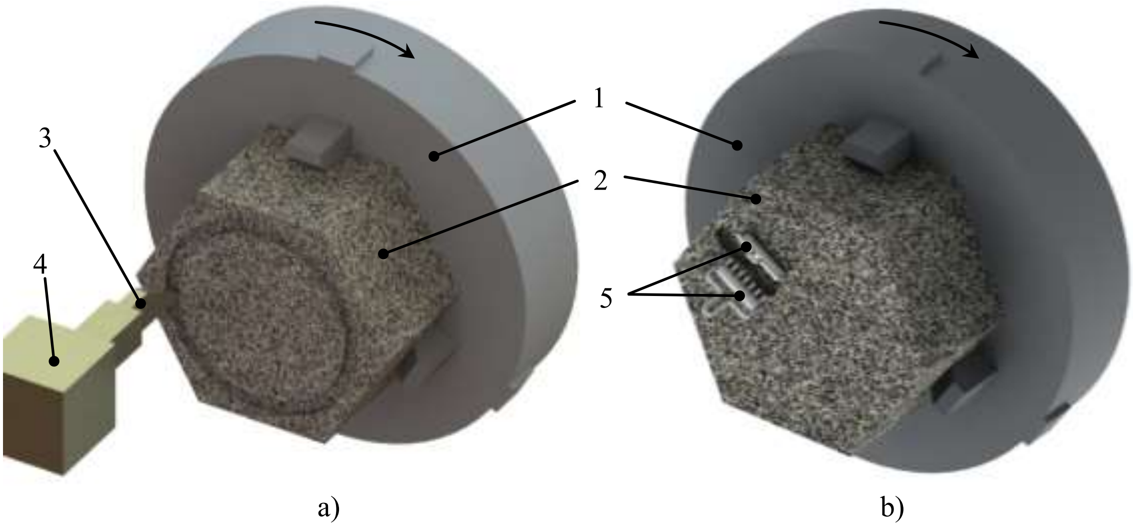

Figure 1. Processing of granite unit. a) mechanically, b) by electric discharges.
1 – rock unit holder; 2 – granite unit; 3 – cutter; 4 – elastic dynamometer, 5 – electrodes

When testing a pre-processed granite unit, a 20mm-gap two-electrode system was moving along the granite surface at a given speed (Figure 1, b). After having treated the granite unit with electric discharges, the rock was exposed to mechanical cutting according to the method described above.

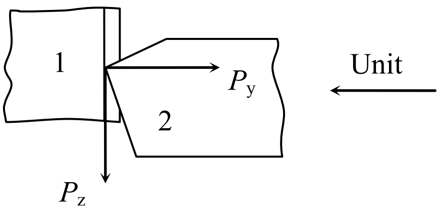

Figure 2. Diagram of forces applied to the cutter
1 – granite unit, 2 – cutter;
P_z – main constituent of cutting force,
P_y – normal constituent of cutting force

3. Results and discussions

Figure 3 shows granite units after being processed mechanically (a) and by a joint electric discharge and mechanical method (b).

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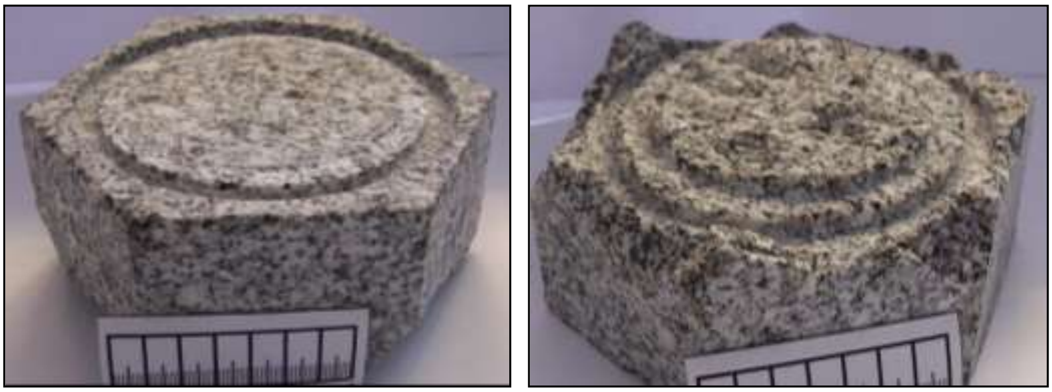

a) b)

Figure 3. Photos of granite units after processing. a) mechanically, b) by a joint electric discharge and mechanical method

Measurements of mechanical cutting forces are given in Table 1. When taking measurements of cutting forces on the rock surface before being exposed to electric discharges, it has been identified that, when 1mm-thick rock surface layers are successively, one after one, removed, the cutting forces do not practically depend on the depth of mechanical impact.

Table 1. Function of the cutting force and depth (without pre-processing by electric discharges)

Mechanical processing depth (mm)	P_z (N)	P_y (N)
1	2950	1550
2	2950	1550
3	2950	1490
4	2900	1530

Figure 4 illustrates results of measuring the cutting forces versus the cutting depth for a granite unit that has been pre-treated by electric discharges. The effect of electric discharge on the cutting forces is observed at a depth of 8 mm and less from the rock surface. Moreover, when removing the first layer off the pre-treated granite unit, the cutting forces appear to be approximately an order of magnitude less than those of when cutting the rock in its original state. The deeper we go, the higher the cutting forces are, because the material is getting less fractured. The depth of penetration of the discharge channel into a solid body is one of important parameters determining the degree and depth of crack formation after pre-processing the rock by electric discharges and the efficiency of rock breakage by the ED technology. Reference [2] states that, by theory, the depth of discharge channel penetration into a solid dielectric is $H = 0.32S$ (S – interelectrode gap). The breakdown channel path has a stochastic nature and the penetration depth, especially in rocks, varies in a rather wide range. Reference [9] covers experimental studies of a depth of discharge channel penetration into a granite unit at a wide range of the interelectrode gap. Whence it follows that an average penetration depth is $H = 6.1$ mm for $S = 20$ mm. Since the energy stored by the pulse generator is released inside the discharge channel as an electric burst, there occurs intensive crack formation inside the rock and rock pieces are split off. The crack length depends on a lot of factors and can reach tens of millimeters in case if cracks cannot come out on the free surface. In our case an average length of cracks is limited by a channel penetration depth since cracks can come out on a free surface. Plasma is released out of the discharge channel, the channel pressure reduces and the process of crack formation stops. Hence, cracks are able to develop inside a granite unit at a mean depth of 6.1 mm, thus, the total depth of rock fracture and crack formation can be 12.2 mm from the rock surface.

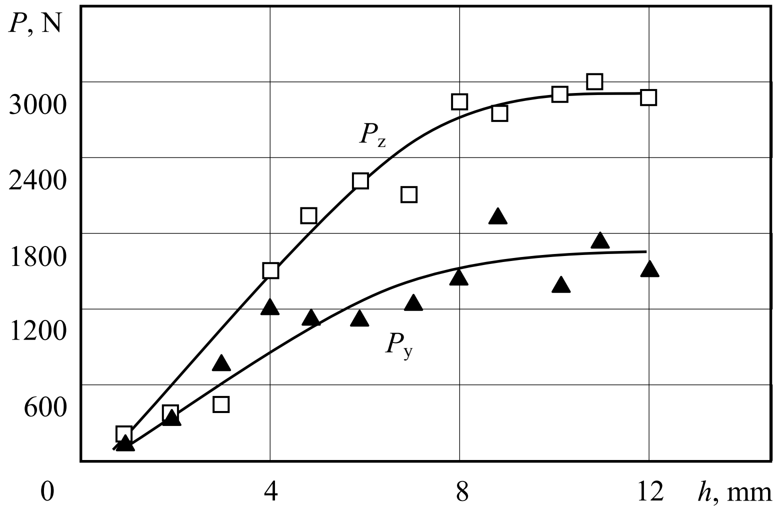

Figure 4. Function of cutting forces vs cutting depth for ED pre-processed surfaces

When cutting the rock at a depth of 8 mm and deeper, we observed the cutting forces corresponding to those of the rock initial condition given in Table 1. Thus, pre-processing of the rock surface by the electric discharge method significantly reduces forces of mechanical cutting that, in its turn, improves the mechanical disintegration performance when, for example, drilling.

More other advantages of the joint method of electrical discharge and mechanical drilling compared to the ED drilling only should also be mentioned. First, mechanical cutters both level an uneven surface of the bottomhole and, at the same time, increase the depth of penetration per turn by getting deeper into a fractured layer of the rock. Second, leveling the bottomhole surface increases the probability of discharge channel penetration into the rock and the depth of its penetration, and it also improves the excavation volume of the rock fractured by the ED method. A greater energy input to the discharge channel and the wider interelectrode gap are assumed to contribute to the greater efficiency of drilling by the joint electric discharge and mechanical technology [10].

4. Conclusion

This work covers research results that have been obtained for the first time and that allow us to make the following conclusion. An electrical burst inside the rock matrix significantly reduces its mechanical strength for shear that, in its turn, improves the mechanical rock breakage performance (excavation volume) by 2 times and more. A joint action of an electrical discharge technology and a mechanical method considerably improves the drilling depth and efficiency as compared to the mechanical drilling only. When drilling by an electrical discharge technology and by a joint, electrical discharge and mechanical, method, the rock strength has considerably less impact on the rock excavation volume than on that by the mechanical drilling only.

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References

[1] Vorob’yov A, Vorob’yov G and Chepikov A 1961 Regularities of solid dielectric breakdown at the interface with a liquid dielectric under the voltage pulse impact (Certificate of Invention **107**, 27.07.1999)

[2] Semkin B, Usov Y and Kurets V 1995 Principles of Electric Discharge Breakage of Rocks (Saint petersburg: Nauka) p 276

[3] Voigt M., Großmann S, Speck J and Anders E, 2012 Entwicklung und Erprobung eines Bohrkopfs für Tiefengeothermie basierend auf dem Elektro-Impuls-Verfahren 12. Symposium Energieinnovation (EnInnov 2012, Graz)
[4] Schiegg H, Rødland A, Zhu G and Yuen D 2015 *Journal of Earth Science* **26** pp 037–046
[5] Kurets V, Usov A and Tsukerman V 2002 Electrical Discharge Disintegration of Materials (Apatity: Krasnoyarsk Scientific Center of RAS) p 324
[6] Goldfarb V, Budny R, Dunton A, Shneerson G, Krivosheev S and Adamian Y 1997 11th IEEE International Pulsed Power Conference (Baltimore, USA) pp 1078–1085
[7] Vorob'yov G, Chepikov A and Vazhov V 1998 *Izvestiya vuzov. Fizika* **12** pp 110–113
[8] Protasov Y 2001 Rock fracture (Moscow: Moscow State Technical University) p 453
[9] Vazhov V, Zhurkov M, Lopatin V and Muratov V 2008 *Physical and Technical Issues of Rock Mining* **2** pp 70–77
[10] Vazhov V, Gafarov R, Datskevitch S, Zhurkov M and Muratov V 2010 *J. Appl. Phys.* **80** 8 pp 79–84