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INVESTIGATION OF THE EFFECT OF THE CAST BOOSTER WITH CUMULATIVE EFFECT ON ARRAYS WITH THE PRESENCE OF SOLID INCLUSIONS

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Abstract: The object of research in the present article is the intensification of the fragmentation of massifs with hard inclusions, by means of dispersed and additional drilling, using cast boosters with cumulative lining. The article presents the obtained dependences of the change in the depth of destruction of solid inclusions, depending on the length of the cumulative jet, its density and the strength of the solid inclusion, which allow to develop a methodology for engineering calculation of the parameters of the drilling-explosive works and the sequence of initiating the charges. The use of cast boosters with a cumulative -funnel, located in the lower part of the borehole, allows, at the expense of managing the action of the blast energy on the lower layers of the blasted massif, to reduce the average size of the fragments by 7.9% and by 1.6 times the resulting oversized fractions.

***Keywords*:** *cast booster, cumulative charges, blast hole, solid inclusions*

1. INTRODUCTION

The process of improving drillingś and blasting as the basis of most applied mining technologies is one of the main directions of modern research in the science of mining.

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To date, the quest for ways to improve the efficiency of drilling and blasting is mainly carried out in the direction of improving, automating and robotizing the processes of drilling and blasting works.

As far as the design of blast holes or boreholes is concerned, there have been no fundamental changes for a long time. In practically all cases, the blasting of the rock mass is carried out by borehole charges, based on the blast product expansion model, in which unfortunately a significant part of the blast energy concentration is dissipated well beyond the limits of the design contour. According to various estimates, approximately 50 to 70% of the total charge energy is expended in a technologically unnecessary and, most often, harmful manner, altering the state of the array outside the blasted volume.

In this regard, quite an intriguing prospect appears to be the creation of a method for the destruction of rock with a sharp asymmetry in the distribution of blast energy in space and its maximum concentration in the direction of the destroyed array. The development of such a method would be extremely useful when dealing with rock arrays of different strength, where the application of traditional drill-blasting methods does not ensure uniform crushing, leads to a large amount of oversized fractions and, consequently, increased costs for subsequent processing.

The feasibility of this idea is related to the use of the long-known principle of cumulating the blast energy depending on the shape of the charge (Belin and Mitkov 2015; Mitkov 2007).

The aim of the research is to enhance fragmentation and ensure uniformity in the fragmentation of solid inclusion arrays by using the directed blast energy of cumulative charges, over the entire height of the footing and developing methods and effective parameters for conducting drilling and blasting works in complex mining and geological conditions.

2. MATERIALS AND METHODS

In an effort to improve the parameters of the blasts, taking into account the research on the cumulative phenomenon and the current knowledge on the concentration of energy in a certain direction or location, we chose the method of cumulative charges.

Cumulative charges consist of an explosive with a detonator at one end and a cavity at the other end, which usually has the shape of a cone lined with a conical piece made of copper, steel, aluminum, or other material (Mitkov 2009). After detonation, a detonation wave occurs which, propagating towards the rear formation of the cone, causes the walls of the lining to collapse towards each other and collide with each other, whereby the pressure in the material increases rapidly and forms a cumulus jet. When the cumulus cavity is lined with metal, a compact cumulus jet is formed from the cumulus lining, directed along the axis of the cumulus charge in the direction opposite to the initiation of the explosive (Fig. 1).

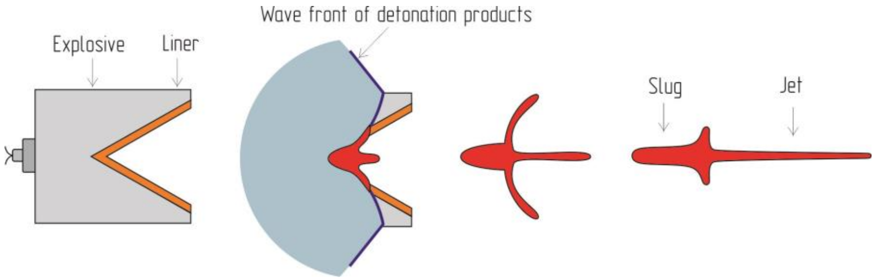

Fig. 1. Scheme of cumulative charge action with metal cladding

The impact of the compression of the PD on the metal lining of the cumulative recess and the action of the cumulative jet formed by the metal is calculated based on the hydrodynamic cumulative theory by Eq. (1) (Orlenko 2002):

$$V_k = V_0\left(\frac{1}{\sin\alpha} + \frac{1}{\operatorname{tg}\alpha}\right), \tag{1}$$

where:

α – angle between the forming of the cumulative lining (degrees),

V_o – velocity of expansion of detonation products (km/s).

When the cumulus jet moves in the air for a relatively short time, it is intensely destroyed and burned due to high friction. As the analysis of the literature has shown, jets with speeds of 6–10 km/s are the most stable. The cumulus jet, hitting the bottom of the blast hole or borehole, creates extremely high pressure on it, which can be calculated by Eq. (2) (Stoilova et al. 2014):

$$P_k = \frac{1}{4}V_k^2\rho_0, \tag{2}$$

where ρ_0 – metal density, lining (g/cm^3).

The penetration depth of the cumulus jet into the rock can be calculated by Eq. (3) (Zaid et al. 1971):

$$h_0 = L_e\sqrt{\frac{\rho_0}{\rho_{por}}}, \tag{3}$$

where:

L_e – effective cumulative jet length,

ρ_{por} – rock density, g/cm^3.

As shown by the analysis, the maximum penetration depth of the cumulus jet into the blast hole is achieved when the angles of the cone liner are equal to 40–50 degrees and the focal distance from the explosive charge to the bottom of the blast hole (borehole) is equal to: $f \approx 2L_m \approx 2d$ opening of cumulative liner (Mitkov et al. 2022).

Based on the research results, a cast booster design with a cumulative lined funnel was developed. A schematic and general view of the booster are given in Fig. 2. The material for the production of the articles TX – 40/60 has the following characteristics: composition: hexogen – 59.5%, TNT – 39.5%, ceresin or wax – 1%, detonation velocity D = 7920 m/s at density ρ_0 = 1.7 g/cm^3, heat of explosion Q = 5.02 MJ/kg and cone dissolution angle α = 50° (Mitkov 2009; 2014). The developed CF fly booster design was tested in industrial conditions and gave positive results (Fig. 2).

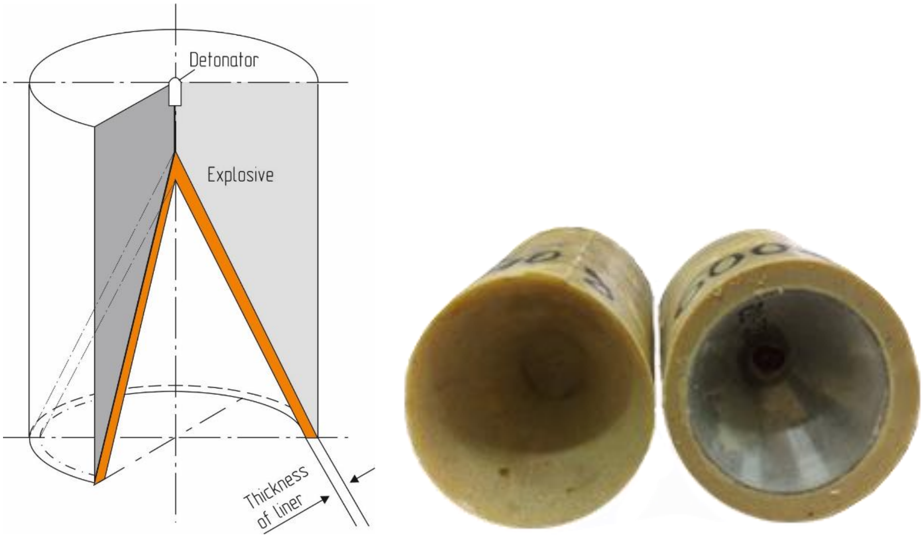

Fig. 2. Schematic and general view of cast booster with cumulative lining

3. RESEARCH METHODOLOGY

The research methods include theoretical and experimental studies, mathematical modeling methods, and also correlation analysis methods to process the obtained results.

Based on the experience of using charges with inert interstices, which shows that in all rocks, including very hard interbeds, a greater uniformity of fracturing is achieved and the amount of oversize fractions is reduced, in order to increase the efficiency of explosive fracturing, the developed method was implemented using dispersed main charges (Drukovannyy et al. 1978; Hagan 2013).

The physical nature of the phenomenon occurring in the borehole during the detonation of a charge with an inert gap can be represented as follows (Zharikov 1987; Zharikov 1986): the blast products of the main charge and the additional charge move against each other, and at a given moment of time they collide, resulting in the blocking of the detonation products (DP) of the main charge by the explosive gases of the additional charge. In this case, the drag of the mass, turns out to be much less than the back pressure of the explosion products of the additional charge, as a result of which the release of gases from the borehole is delayed and a more intense fracturing of the rock mass occurs. Following the collision of the shock waves and the slowing of the gas flows, a high-pressure source appears in the centre of the inert gap from which shock waves will travel in both directions. After the reflected contraction and rarefaction waves meet, a shock wave will go to the edge of the charge and a rarefaction wave to the centre of the inert gap. The shock wave will reflect off the end of the charge chamber and change its characteristics and direction again. The process will then repeat.

According to most researchers, the main reason for the increased efficiency of air--gap charges is precisely the result of the repeated media loading process implemented by a system of additional stress waves generated in the borehole. A characteristic feature of the repeated loading is the possibility of the subsequent development of a system of micro-cracks formed by the primary wave of contraction and an increase in the degree of fragmentation of the rock mass.

The sequence of implementation of the developed method is as follows (Fig. 5): for the block to be blasted, the drilling grid of the main boreholes is calculated, determined on the basis of the results of experimental blasting. The main boreholes are drilled to the full height of the footing to be blasted (Fig. 3).

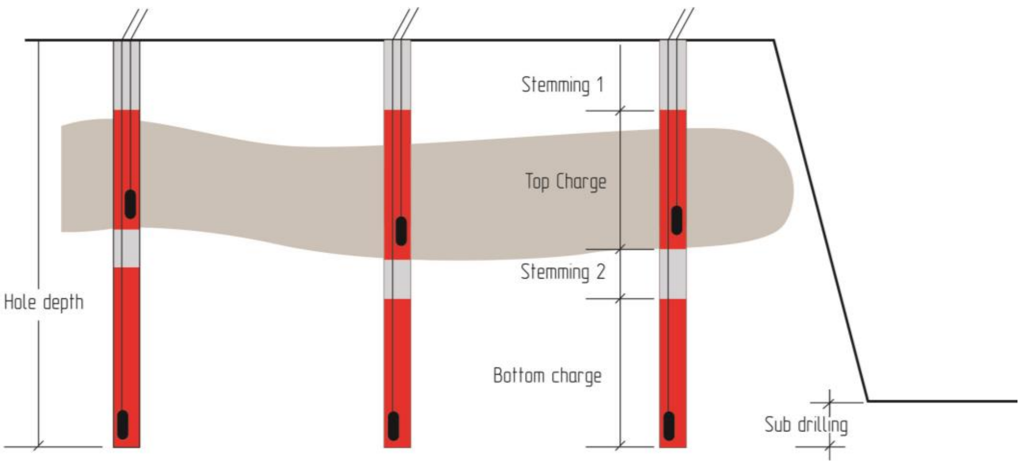

Fig. 3. Classical scheme of blast hole charges

When charged, they are dispersed by an inert gap which is placed in the weaker layers at the interface with the solid inclusion, and its height is determined by Eq. (4):

$$l_{ig} = (0.2 \div 0.3) l_b, \tag{4}$$

where l_b – height of the lower part of the charge (m).

During drilling, the presence and contour of solid inclusions is determined by changes in drilling rates and modes, colour and condition of the cuttings brought to the surface. Inside the contour with respect to the solid inclusions, additional boreholes are drilled which are located in the centre of the quadrangles formed by adjacent main boreholes.

The depth of the additional boreholes is determined by Eq. (5):

$$l_a = \frac{\sum_{i=1}^{n} l_1}{n} - (5...8) d_c, \tag{5}$$

where:

- l_1 – the end of the firm inclusion in relation to the length of the main boreholes between which the corresponding additional borehole is located (m),
- n – the number of main boreholes,
- d_c – is the diameter of the explosive charge in the additional boreholes (m).

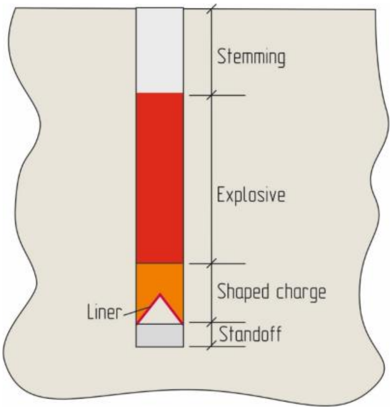

Fig. 4. Construction of an additional borehole

Loading of the additional boreholes was carried out as follows (Fig. 4):

1. A gap of inert material is placed to create the required focal distance ($f \approx 2L_m \approx 2d$;
2. A cast booster with cumulative lining is dropped;
3. Charging the boreholes with explosives, the mass of which is calculated according to Eq. (6):

$$Q = (3 \div 4)gh_{si}^{3}, \tag{6}$$

where:

q – relative consumption of explosives (kg/m^3) assumed for 0.5–0.6 kg/m^3,
h_{is} – power of solid inclusions (m).

The cast cumulate lined boosters, located in the additional boreholes, allow for uniform fracturing of the rocks due to the directed use of blast energy to the stronger intermediate layers. Placing and blasting charges within the solid inclusion reduces the scattering of blast products in the direction of weaker rocks, thus concentrating the blast energy from these charges on breaking the solid inclusions (Norov et al. 2016; Norov et al. 2013). This ensures efficient fracturing of the solid inclusion where oversized fractions are typically produced, thus minimizing the cost of fracturing them while reducing the relative consumption of explosives and increasing the spacing between drilled holes.

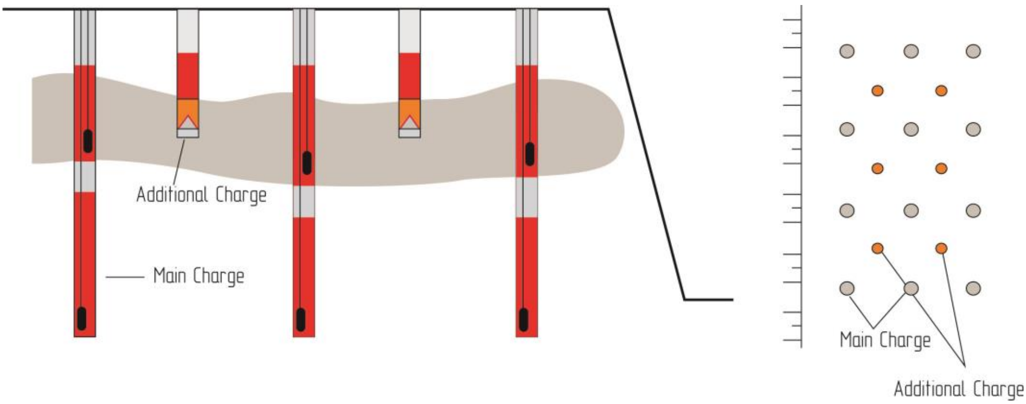

Fig. 5. A method for fracturing arrays of different rock strengths using main and additional charges with a cumulative effect

Blasting of the explosive charge in the additional boreholes is performed with a millisecond delay before the dispersed main borehole charges of 9 ms. to ensure the formation of initial cracks in the solid inclusions that develop and expand under the action of the main dispersed charges, which are initiated with a millisecond delay before the initiation of the top charge.

The delay interval between the different parts of the dispersed charges should provide anticipatory destruction of the solid inclusion, allowing a free surface to be prepared for the directed blast action of the lower explosive charge. As a result of the destruction of the weaker mass of the lower dispersed charge by the action of the blast products and the explosive displacement of the rock mass, further destruction of the strong inclusion takes place, thus increasing the blast efficiency.

The developed method for solid inclusion array destruction by blasting of dispersed and additional drill charges with cumulative effect, which can be successfully applied to mining practice, particularly in open pit mining.

4. RESULTS AND DISCUSSION

1. The effective parameters of drilling-explosive works at fragmentation of arrays with solid inclusions are determined, which allow to establish the length of the dispersed main charges, the effective depth of the additional boreholes and the mass of the charge in them, depending on the specific consumption of explosive and the power of the solid inclusion, on the basis of which the methodology for their engineering calculation is developed.
2. A method has been developed for studying the action of cumulative charges in arrays of different strength scales.
3. The dependences of the stress wave parameters when using drilling charges with cumulative effect, on the energetic properties of the explosive charge, the composition and the structure of the array with solid inclusions are studied.
4. The radius of action of a cumulative charge is determined, depending on the mass of the explosives in the additional boreholes, depth of rupture and jet density.
5. It was found that the use of cast boosters with a cumulative liner placed at the bottom of the additional boreholes, by adjusting the dynamic impact on the lower layers of the blasted mass, reduces the average size of the shards by 7.9% and reduces the amount of oversize fractions by a factor of 1.6.

5. CONCLUSIONS

The developed method for blast fracturing of arrays with solid inclusions with the use of dispersed and additional blast holes with cumulative effect, allows to carry out uniform fracturing of the rock over the entire height of the footing, at the expense of directed use of blast energy on solid inclusions, to increase the network of blastholes, to reduce the relative consumption of explosives and, accordingly, the cost of drilling.

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