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QUALITY CONTROL OF PREPARATION OF ROCK MASS EXPLOSION IN GRANITE OPEN PIT

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Abstract. The increased intensity of rock crushing using blast energy is a live problem for mining companies in Ukraine engaged in the extraction of hard rocks. The solution to this problem is to increase the share of blast energy spent on rock mass destruction.

The paper presents the results of pilot studies of the efficiency of rock breaking in the massif using a new design of borehole charge with variable cross-section for the development of resource-saving and environmentally friendly technologies of extraction of construction raw materials at non-metallic open pit. For substantiation of rational parameters of explosive destruction of rocks experimental researches on studying of structure of a rock massif were carried out. The main characteristics of fracturing of granite massif were determined using the method of stereo photo shooting of exposed faces at horizons selected for industrial tests of the developed method of explosive rock breaking. The influence of cracks on the character of explosive fracture of anisotropic massif was determined and the anisotropy coefficient was calculated. A nomogram was developed, which was used to adjust the parameters of the borehole grid in the experimental site of the block. The quality of rock mass crushing in result of explosion was assessed by the average diameter of pieces with measurements of particle size distribution. The method of oblique photoplanimetry was used for measurements. The results were processed using a computer program. The software makes it possible to determine the granulometric composition of blasted rock mass based on image processing. The results of industrial experiments shown that the use of charge designs with variable cross-section leads to a 30% decrease in the average diameter of pieces of broken rock and a 10–15% decrease in the consumption of industrial explosives. The use of the proposed designs of combined borehole charges of different shapes allows increasing their length at a constant mass of charges. In turn, this allows forming a multidirectional stress field in the rock massif after detonation of the borehole charge. In such a force field, the role of tensile and shear stresses increases, contributing to more uniform rock crushing. It is established that the new technology of rock breaking with the help of combined borehole charges allows to reduce the consumption of industrial explosives without degrading the quality of rock crushing, and to reduce the negative impact on the environment.

Keywords: borehole, explosion, borehole charge, ledge surface, fracturing.

1. Introduction

The increased intensity of rock crushing using blast energy is a live problem for mining companies in Ukraine, which are engaged in the destruction of strong rocks with complex structure. The solution to this problem is to increase the proportion of blast energy used to destroy part of the massif.

Improving the design of borehole charges is one of the ways to increase the efficiency of blast energy use, as well as to reduce the cost of blasting operations.

Mechanical methods of borehole drilling allow creating cylindrical cavities of constant diameter along the entire length of the borehole. At the same time, this form of blast holes is not optimal in the end zone of cylindrical borehole charge due to small radii of massif destruction.

From the point of view of overcoming the resistance at the bottom of the ledge, it is more reasonable to use a spherical shape in the lower part of the concentrated borehole charge [1].

Creation of a spherical-shaped cavity along the length of the borehole charge is carried out by forming chamber expansions in the specified parts of the borehole using a mechanical expander and by the borehole springing. Insufficient efficiency of the second method is due to the heterogeneity of physical and mechanical properties of rocks, which leads to the formation of irregularly shaped chamber cavities. At the same time, mechanical expansion of boreholes is associated with the complexity of design of mechanical reamers and their unreliability.

As a result of searching for rational designs of borehole charges, a method of rock breaking with borehole charges with variable diameter along the height of the ledge was developed and introduced [1]. This method was first implemented in conditions of the Southern Mining and Processing Enterprise (Krivbass), when boreholes with chamber expansions along the height of the ledge were created with the help of the flame-jet drilling rigs. It was shown in [1] that the replacement of a borehole charge with a constant cross-section by a system of concentrated charges located in chamber expansions along the axis of a small diameter borehole and with radial gaps [2], allows reducing the specific consumption of explosive by 10–15% [3] without degrading the quality of rock crushing. However, because flame-jet drilling is selective with respect to rock type (rocks with quartz content), a new method of borehole charge formation in a polyethylene sleeve of variable diameter was developed [4]. The efficiency of this method was first tested in industrial conditions of Poltava Mining and Processing Plant at formation of borehole charges from aquatol T-20G. Tests were also carried out at flux quarries in Donbass using explosive of PVS-1U type.

Subsequently, new methods of forming borehole explosive charges with variable and different cross-sectional shape were developed, which were implemented in methods of breaking locally fractured and fractured rocks with complex structure [5-8].

The purpose of the work is to evaluate the efficiency of using new designs of borehole charges for breaking rock massifs with complex structure at non-metallic open pit.

2. Research methods

In the article the method of stereo photo shooting for definition of the basic characteristics of fracturing of granite massif and the method of oblique photoplanimetry for definition of granulometric composition of the blasted rock mass were used.

3. Experimental part

For substantiation of rational parameters of blasting destruction of rocks of complex structure, which are granites, industrial tests of new ways of rock breaking based on the change of constructive features of a borehole charge [5–8] were carried out on the open pit of the LLC "Uman granite open pit".

The nature of destruction of rocks with complex structure is determined by their microstructure and macrostructure of the rock mass. In this regard, when selecting the main parameters of drilling and blasting operations (geometry of location and size of the borehole grid), these features should be taken into account. This allows obtaining a uniform crushing of rock with a minimum output of fine fractions, which are the losses of minerals in the production of crushed stone. Therefore, the availability of comprehensive data on the initial fracturing of the rock massif allows us to predict the nature of fracture development during the detonation of explosive charges [9, 10] and simplifies the calculation of rational parameters of drilling and blasting operations.

To determine the main characteristics of fracturing of the granite massif within the mine take of the open pit of the LLC "Uman granite open pit", stereo photo shooting of exposed faces was carried out on the horizons selected for industrial tests of the developed method of blasting breaking of rocks with complex structure (block # 1, horizon +108 m). The main characteristics of hydraulic fracturing were determined in accordance with the method [11].

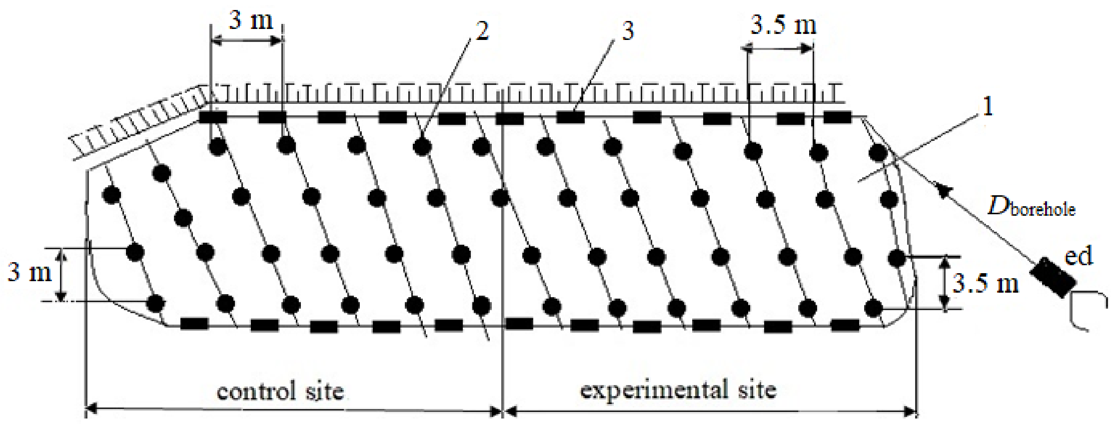
To determine the influence of cracks on the character of blasting destruction of anisotropic massif along the face line, boreholes with diameters from 36 mm to 43 mm and depths from 1.0 m to 1.5 m were drilled and blasted. Patronized Anemix-70 was used as the explosive.

According to the known values of the large a and small b of axes of the explosion funnel, as well as its orientation to the sides of the world, the anisotropy coefficient K = a/b = 1.16 was calculated. Taking into account the value of the coefficient K, the parameters of the borehole grid were adjusted in accordance with the blasting pattern in the experimental site of the block. Instead of the grid 3×3 m, 3.5×3.5 m was adopted. In accordance with the changed parameters of the borehole grid, as well as taking into account zones of increased fracturing (oriented orthogonally to the bottom borehole line) identified on one of the experimental blocks, 110 mm diameter and 16 m deep boreholes were drilled in the massif on the ledge of the 18 m high block (according to the blasting pattern). As a result, 149 to 161 boreholes were drilling. The borehole charge length was 13 m and the tamping length was 3 m.

The blasted blocks were divided into experimental and control sites. In the control sites, the boreholes drilled on the grid 3×3 m were charged in the usual way with the formation of a continuous structure of borehole charges. In the experimental sites, the boreholes were charged on a grid of 3.5×3.5 m with the formation of combined borehole charges with variable cross-section in the zone of monolithic rocks. At the block boundary from the rear side of the block, the borehole charges alternated between each other and had the form of triangular and square prisms.

Figure 1 shows the scheme of the borehole layout and switching of charges on the ledge of the open pit of the LLC "Uman granite open pit".

The technology of forming a combined extended borehole charge with different cross-section shape provides the following operations. In the lower part of the boreholes drilled in the zones of monolithic block rocks with pronounced local fracturing, emulsion explosive substance (EES) Anemix-70 is fed in portions. Feeding of the EES is carried out with the help of a hose. Then a borehole charge with variable cross-section is formed with uniform placement on the column of spherical hollow spheres (spheres) with a diameter of 0.8Dborehole, where Dborehole is diameter of the borehole. The spheres are connected to each other in a chain by means of twine. The distance between the spherical cavities is equal to the active part of the cumulative charge lengths [5, 6].



1 – ledge surface; 2 – blast boreholes; 3 – borehole retarders

Figure 1 – The scheme of borehole layout and charge switching on the open pit ledge LLC "Uman granite open pit"

After that, the first intermediate detonator made of TNT checker T-400G (2 pcs.) is installed. Then, a section of DKRP-4 type conversion EES with pyroxylin powder is installed in the remaining central part of the borehole. In the gap between the surface of the borehole and the charge, the next portion of EES is fed and the second (upper) detonator T-400G (2 pieces) is installed.

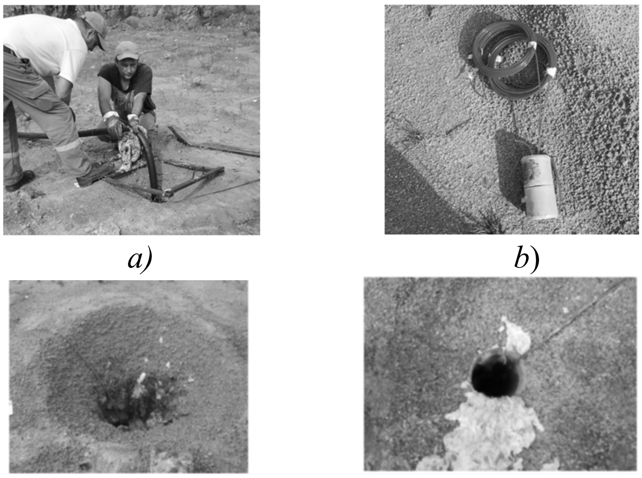
At the final stage, the borehole is sealed by tamping of granite screenings. Then, in the boreholes drilled in the rear part of the ledge of a massif in the area with extended zones of increased fracturing, extended charges in the form of square and triangular prisms are formed. The profile of borehole charges is made of dense polyethylene. The boreholes are charged in the same sequence as for charges with variable cross-section (Fig. 2).

Charge initiation was carried out using the "Impulse" SNI non-electrical system, and internal borehole decelerations were carried out using devices such as ED 8Zh, UNS-S-500-16, UNS-PA-25-10, UNS-PA-40-10, UNS-PA-0-10 and DSHE-9. The devices were connected to the main detonating cartridge using waveguides of the non-electric SNI "Impulse". The charges on the rock block ledge were switched into groups connected in a diagonal pattern using counter initiation.

During the mass explosion, the total mass of EES (Anemix-70) was 23250 (planned value 23500 kg). The saving of EES was 250 kg.

During the industrial tests of the blasting technology at the LLC "Uman granite open pit", 19003 m3 of rocks were broken off. Thus, the yield of rock mass was made 8.4 m3 from 1 m of the borehole, and volume of drilling works was made 2260.5 m3.

Based on the results of mass explosions (11.05.2019 and 30.09.2022) in the experimental and control sites of the block, the quality of crushing of the broken-off rock mass was assessed (Fig. 3).



a) b)

c) d)

a – charging of EES borehole; *b* – detonation preparation; *c* – charging of EES borehole and installation of an intermediate detonator; *d* – charging the boreholes with EES and installing the top detonator in the boreholes (a priming cartridge from a T-400 TNT checker)

Figure 2 – Sequence of the boreholes charging on the block ledge

Figure 3 – Measurement of granulometric composition of the blasted rock mass on the ledge of the granite open pit

4. Results and their discussion

Table 1 presents the results of processing the data of stereo photo shooting for determining the main characteristics of fracturing of the granite massif within the mine take of the open pit of the LLC "Umansky granite open pit".

Table 1 – Characteristics of the main systems of cracks at the open pit of the LLC "Uman granite open pit"

Name of cracks (Kloos nomenclature)	Fracture coefficient	Distance between crack walls, mm	Distance between individual cracks, m	Width of the zone of increased fracturing, m	Distance between the centres of the zones, m
Longitudinal compression cracks – cracks *S*	2–4	0.012–0.16	0.15–2.9	50–70	50–76
Transverse breakaway cracks – cracks *Q*	2–5	1.2–4.5	1.3–6.8	60–80	65–80
Horizontal unloading cracks – cracks *L*	4–8	0.05–0.15	0.5–1.5	none zone of increased fracturing	-

The quality of rock mass crushing after the explosion was assessed by the average diameter of pieces with measurements of particle size distribution. The method of oblique photoplanimetry was used for the measurements. The obtained results were processed by using a computer program "WipFrag". The software product allows measuring the particle size distribution of blasted rock mass based on image processing. The rock mass is transformed into a network of fragments, which are measured in semi-automatic mode, and fragments of separations are selected. As a result, a histogram of rock mass particle size distribution and an integral curve of separation distribution are constructed [12] (Fig. 4).

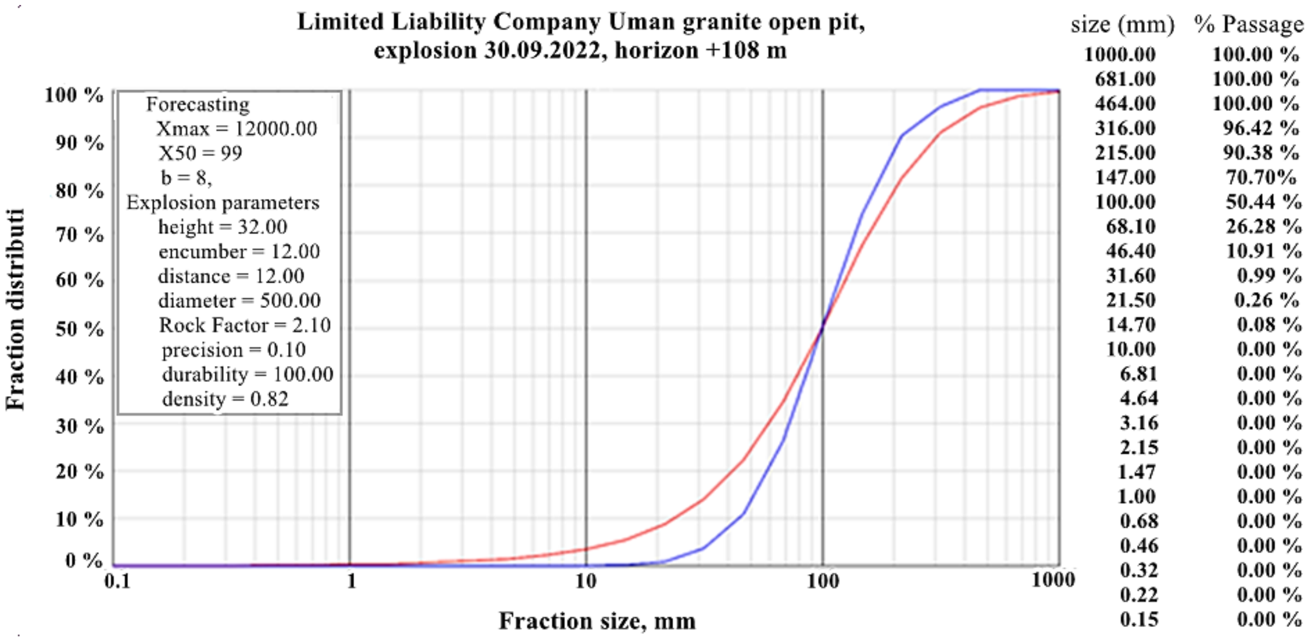


Figure 4 – Granulometric composition of blasted rock mass broken off from the open pit ledge

Table 2 shows the results of determining the average diameter of a piece of rock mass after experimental explosions on the open pit ledge.

Table 2 – Determination of the average diameter of a piece of rock mass

Experimental site				Control site			
Coarseness classes, mm	Average piece size by class d_i, mm	Fraction yield W_i, mm	$d_i \times W_i$	Coarseness classes, mm	Average piece size by class d_i, mm	Fraction yield W_i, mm	$d_i \times W_i$
0–200	100	41	4100	0–200	100	26.7	2670
201–400	300	34	10200	201–400	300	24.5	7350
401–600	500	17.3	8650	401–600	500	20.6	10300
> 600	700	7.7	5390	> 600	700	28.2	19740
Total value			28340	Total value			40060
$d_{cp} = \Sigma d_i W_i /100 = 283.4$ мм				$d_{cp} = \Sigma d_i W_i /100 = 400.6$ мм			

It follows from the analysis of the obtained results that the use of modified parameters of drilling and blasting operations with the use of combined designs of charges with variable cross-section leads to a 30% reduction in the average diameter of a piece of broken rock mass, as well as to a 10–15% reduction in the consumption of industrial explosives. At the same time, the yield of the conditioned piece with an average diameter of 201 to 600 mm increases by 10%.

5. Conclusions

The conducted research allows us to formulate the following conclusions:

1. Application of modified parameters of drilling and blasting operations with the use of combined designs of explosive charges of different shapes with variable cross-section leads to a 30% decrease in the average diameter of a piece of broken rock mass and a 10–15% decrease in the consumption of explosives. At the same time, the yield of the conditioned piece increases by 10%.
2. The proposed methods of breaking of strong, locally fractured and fractured rocks with complex structure allow improving the quality of crushing of blasted rock mass and increase the technical and economic performance of mining enterprises.
3. Increasing the efficiency of rock mass crushing is achieved by adjusting the main parameters of drilling and blasting operations, using new designs of combined borehole charges with different cross-sectional shape, taking into account the direction and intensity of fracture systems of different morphology in the destroyed block. This makes it possible to increase the length of the explosive charge at a constant mass and to distribute it more evenly over the height of the ledge.
4. Implementation of the proposed technology of blasting at open pits when breaking rock massifs with complex structure allows providing effective and high quality crushing of rocks. At the same time, the saving of explosive substance for one borehole makes up to 30 kg. This allows to reduce the specific consumption of explosives on average by 15% and to maintain the design reference mark of the ledge footing.

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КЕРУВАННЯ ЯКІСТЮ ВИБУХОВОЇ ПІДГОТОВКИ ГІРНИЧИЙ МАСИ НА ГРАНІТНИХ КАР'ЄРАХ

Новіков Л.А., Коновал В.М., Іщенко К.С., Кінаш Р. І., Малєєв Є. В.

Анотація. Підвищення інтенсивності дроблення гірських порід з використанням енергії вибуху є актуальною проблемою для гірничодобувних підприємств України, які займаються видобуванням міцних гірських порід. Вирішення цієї проблеми полягає у збільшенні частки енергії вибуху, що витрачається на руйнування гірського масиву.

У статті представлені результати дослідно-промислових досліджень ефективності відбійки гірських порід у масиві з використанням нової конструкції свердловинного заряду змінного перетину для розробки ресурсозберігаючих та екологічно безпечних технологій видобутку будівельної сировини на нерудних кар'єрах. Для обґрунтування раціональних параметрів вибухової руйнування гірських порід проведено експериментальні дослідження щодо вивчення структури гірничого масиву. Визначено основні характеристики тріщинуватості гранітного масиву з використанням методу стереофотозйомки оголених вибоїв на горизонтах, вибраних для промислових випробувань розробленого способу вибухової відбійки гірських порід. Визначено вплив тріщин на характер вибухового руйнування анізотропного масиву та розраховано коефіцієнт анізотропії. Розроблено номограму, за якою скориговано параметри сітки свердловин на експериментальній ділянці блоку. Якість дроблення гірничої маси в результаті вибуху оцінювалося за середнім діаметром шматків із вимірюванням гранулометричного складу. Для вимірювань використовувався метод косої фотопланіметрії. Отримані результати оброблялися за допомогою комп'ютерної програми "WipFrag". Програмний продукт дає змогу на основі обробки зображень визначати гранулометричний склад підірваної гірничої маси. Результати промислових експериментів показали, що застосування конструкцій зарядів зі змінним поперечним перетином призводить до зменшення на 30% середнього діаметра шматків відбитої породи та зниженню на 10-15% витрати промислових вибухових речовин. Використання запропонованих конструкцій комбінованих зарядів свердловин різної форми дозволяє при постійній масі зарядів збільшити їх довжину. У свою чергу це дозволяє сформувати різноспрямоване поле напружень у масиві гірських порід після детонації свердловини. У такому силовому полі зростає роль напружень, що розтягують і зрушують, що сприяє більш рівномірному дробленню порід. Встановлено, що нова технологія відбійки гірських порід за допомогою комбінованих свердловинних зарядів дозволяє зменшити витрату промислових вибухових речовин без зниження якості дроблення гірських порід, а також знизити негативний вплив на довкілля.

Ключові слова: свердловина, вибух, свердловинний заряд, поверхня уступу, тріщинуватість.