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O. K. Ishchenko[1], Cand. Sc. (Tech.),
orcid.org/0000-0003-2449-5258,
V. M. Konoval[2], Cand. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0002-6740-6617,
K. S. Ishchenko[3], Cand. Sc. (Tech.), Senior Research Fellow,
orcid.org/0000-0003-2237-871X

1 – National Mining University, Dnipro, Ukraine, e-mail: ishchenkook@gmail.com
2 – Cherkasy State Technological University, Cherkasy, Ukraine
3 – M. S. Polyakov Institute of Geotechnical Mechanics, NAS of Ukraine, Dnipro, Ukraine, e-mail: ishenko_k@i.ua

EFFICIENCY OF PREPARATION OF MOUNTAIN MASS AT CAREERS OF BUILDING MATERIALS

Purpose. To conduct an assessment of the effectiveness of rock breaking in a complex array using a new design of borehole charges to develop a resource-saving and environmentally safe method of mining construction materials on non-ore quarries.

Methodology. To substantiate the rational parameters of explosive destruction of rocks with complex structural features, such as granites, in the conditions of the "Sivach" quarry, experimental studies were carried out to study the structure of the rock massif – orientation of microcracks of different morphology and anisotropy of physicomechanical properties of rock-forming minerals and their spatial position on the block. The main characteristics of the fractured structure of the granite massif are studied using the method of stepler imaging of exposed faces at horizons chosen for industrial tests of an explosive rock breaking method.

Findings. Experimental studies have determined the effect of cracks on the nature of explosive destruction of an anisotropic massif. To achieve the goal, holes were drilled at along the bottom line with a diameter 43 mm to a depth of 1.0–1.5 m and charges with a cartridged explosive material (EM) – ammonite № 6 GV – were undermined.

In terms of the dimensions of the large *a* and small *b* axes of the explosion funnel and its orientation relative to the sides of the light, the coefficient of anisotropy was calculated from the expression $K = a/b$, which averaged 1.14. Using the developed nomogram and taking into account the data of the anisotropy coefficient, the parameters of the well grid of the valid blast design were corrected at the experimental section of the block equal to 4.5×5.5 m instead of 5×5 m. Using the changed parameters of the blast design, mass explosions were carried out in the experimental and control sections and the results of crushing the broken rock mass with the use of the oblique-planed photographic planimetric method were estimated. The results of industrial experiments have shown that the use of modified blast design parameters using variable-charge designs reduces the diameter of the average chunk by about 30 % and the consumption of industrial explosives by 10–40 %. The output of the conditioned piece (201–600 mm) increases by 10 %.

Originality. The scientific novelty of the proposed explosive technology of crushing hard rocks of complex structure, realized in a new method of breaking up locally-fractured rocks involves:

- considering the identified zones of increased fracturing in the control and experimental sections the directions of local cracks and the extent of zones of increased fracturing in the block array which are oriented relative to the sides of the world were determined whose parameters were used to calculate the anisotropy coefficient;
- according to the anisotropy coefficient, a nomogram was constructed to correct the blast design;
- based on the changed parameters of the blast design in the holls drilled in the massif with a pronounced local fracturing, combined charges of variable cross section were formed, which made it possible to improve the results of crushing the broken rock mass.

Practical value. The presented results of industrial tests of the proposed design of a combined borehole charge implemented in the new method of destruction of strong locally fractured rocks allow for a constant charge weight to increase its length and, more evenly distribute the explosive over the height of the ledge, as a consequence. At the same time, the conditions for the transfer of explosion energy from explosive charge to destroyed array change with the formation of a different-grade and multidirectional stress field. As a result, the role of tensile and shearing stresses contributing to a more even crushing of the rocks increases.

Key words: *borehole, explosion, borehole multicharge, shoulder surface, fracture density*

Introduction. The problem of intensity increase in rocks crushing with the use of blast energy of explosive material (EM) is relevant for the experts dealing with destruction of rocky formations. The solution of this problem is inseparably associated with increase in explosion energy transformed to destructed part of the massif.

Unsolved aspects of the problem. It is known that the considerable part of explosion energy is expended in the zone, which is directly adjacent to charge cavity (usually 2–3 radiuses of a charge) where the medium is overgrinded that leads to losses of minerals in pits of nonmetallic construction materials.

As noted in the paper by Efremov E. I., control of the size of the rock re-milling zone and reduction of fine fractional yield can be achieved due to both reduction of the contact area of borehole charge of explosive material

(EM) with the destructed rocks, and creating of conditions providing reduction of explosion dynamic impact on charge cavity surface.

Thus, during failure of rocks, it is possible to increase the useful effect of explosion by various means, in particular, by regulation of value of specific energy of EM due to use of constructions of borehole charge of a variable diameter.

It should be noted that in case of explosion control, it is necessary to consider that the tensile strength of rocks is approximately 10 times less than compressive strength of rocks. As the energy capacity of the solid media destruction is proportional to a square of their strength in case of a specific loading, energy capacity of solid media destruction by tensile stresses is 100 times less than energy capacity of destruction in case of compression stresses. From this, it follows that the increase in a role of tensile stresses in solid media destruction by explosion can be reached when using extended charges of a variable diameter.

There are some methods for extended charge formation with different configuration of both its length and cross-section.

In particular, it is:

- creation of expanded sections, whose diameter is bigger than the diameter of initial cavity, in the drilled cylindrical cavities [1, 2];
- placing inside the charging cavity of a continuous column of explosives in polyethylene shells of a variable diameter [3], with an air gap and a reflector of blast waves [4], in the form of a cone with a step-down diameter to the wellhead [5], cumulative charges [6], combined charges for the destruction of rocks of complex structure [7, 8] and with a different configuration of the cross-section [9, 10];
- layout of hollow figures from inert materials in charge cavities [11].

The above-mentioned constructions of extended borehole charges make it possible to create the multidirectional and multigradient field of stresses in the massif and at the same time, to reduce the dynamic impact of explosion on the surface of the charge cavity, due to reduction of the direct contact area of EM with rocks.

Objective of the article. The objective of the research is evaluation of blasting efficiency of massif with complex structure in non-metallic pits with use of new construction of borehole charge.

Tasks, methodology and presentation of the research results. For grounding of rational parameters of explosive failure of the rocks with complex structure (granites developed in pit "Sivach" of PrJSC "Ukragrovzryvprom"), the industrial tests of the new blasting method [11], based on change of design features of a charge were carried out.

The rocks in pit are gray highly water-flooded end compact-grained granites with red inclusions of strength of f = 12–16 grades on scale of Professor M. M. Protodyakonov. The level of flowing waters in pit reaches 1.0–2.0 m in case of massif average water content of 15–20 %.

The nature of failure of rocks of complex structure is affected by their microstructure – orientation of microcracks and anisotropy of physical mechanical properties of rock-forming minerals, as well as massif macrostructure – spatial position of cracks of different morphology which partition the exploded unit. Therefore, in case of selection of parameters of drilling-and-blasting operations (DBOs) – the specific consumption EM, geometry of layout of boreholes and blasting – such features of micro- and macrostructure should be considered. It will allow obtaining uniform rocks breaking in case of the minimum yield of fractions, which are losses of minerals in course of crushed stone production.

In this regard, the comprehensive data on nature of massif fracture density in the destructed unit of granite massif considerably simplifies calculation of rational parameters of DBOs.

In order to determine the main characteristics of fracture pattern of granite massif within mining lease of "Sivach" pit of Uman Quarries Management using the method explained in paper [11], free faces on horizons, which were selected for industrial tests of the developed method of blasting of rocks with complex structure (unit 01/12, mount. +56 and unit 04/11, mount. +68 m) were stereo photographed.

The separate photography of the same object (part of shoulder) was conducted from two camera angles using a digital camera for obtaining a stereo pair in the experimental area along the face line. The static rod was used for scaling of stereograms.

The stereo pair is oriented in case if the angle θ at the vertex of dihedral angle formed by the direction of photography rays and the spatial position of camera angles are known. In this case, in the stereomodel investigated by means of a stereoscope, it is possible to determine the basic characteristics of the natural macrocracks partitioning the massif, i. e. elements of their formation (angle of slope and its azimuth), and intensity (number of the cracks per 1 m of face length).

Processing of deciphered stereo pairs was maintained with use of standard programs of image processing "Photoshop" and "CorelDraw 11". In this case, the vertical and horizontal macrocracks, which can be seen in the picture, are usually represented in the form of lines of various thickness with the subsequent projection to the static rod for determination of crack density.

After data processing, the distribution parameters of crack systems at the "Sivach" pit were obtained. They are shown in Table 1.

In order to determine the cracks influence on the nature of explosive breaking of anisotropic massif along the face line, the blast-holes were drilled and exploded (the diameter is 36–43 mm, depth is 1.0–1.5 m, EM is stick powder ammonite No 6 liquid hydrogen). According to the specified sizes of big a and small b axes of breaking bell-hole caused by explosion of charge of EM and its orientation in parts of the world, coefficients of massif anisotropy were calculated according to expression $K = a/b$, which is equal to 1.14 on average. With use of data of anisotropy coefficient, a nomogram (Fig. 1) was developed. Due to this nomogram, the parameters of borehole pattern of valid blast design in the experimental field of the unit (the borehole pattern is equal to 4.5 × 5.5 m instead of 5 × 5 m) were corrected. Its long side coincides

Table 1

The characteristics of the main crack systems at the "Sivach" pit

Name of joints (Kloos nomenclature)	Coefficient of fracture density, m	Distances between walls of joint, mm	Distance between separate joints, m	Width of zone of the higher fracture density, m	Distances between centers of zones, m
Longitudinal joints of compression – S-joints	3–5	0.01–0.15	0.1–2.6	40–60	45–66
Transversal joints – Q-joints	1–3	1.0–3.5	1.0–5.8	50–60	60–75
Horizontal joints of unloading – L-joints	3–7	0.05–0.15	0.5–1.5	zones of higher fracture density are absent	–

with the direction of maximum values of vect or of explosion energy flow in the destructed massif $\vec{F}_{max}$.

According to the changed parameters of borehole pattern (a = 5.5 m – distance between boreholes in a row and b = 4.5 m – distance between rows of boreholes), and considering revealed zones of high fracture density (focused orthogonally to the face line) in of experimental units, the boreholes of a diameter of 150 mm and a depth of 10.0–11.0 m with the subdrill of 0.6–1.5 m were

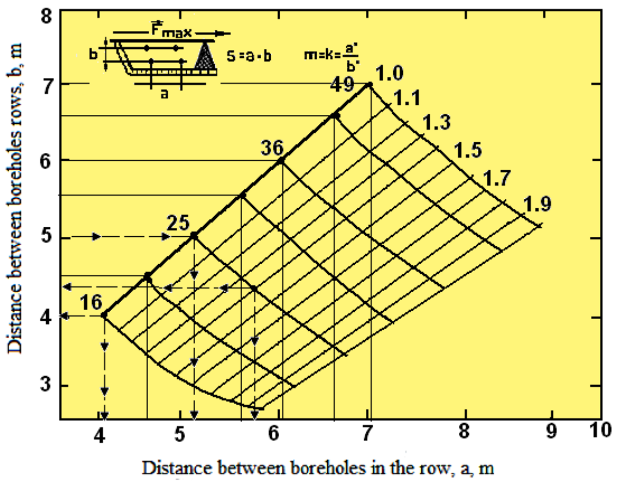

Fig. 1. The nomogram for correction of boreholes considering anisotropy coefficient

drilled according to valid blast design the massif in the shoulder of 12.0 m high. The diagram of the experimental unit is shown in Fig. 2.

After drilling-off, the boreholes were charged (Fig. 3). The borehole multicharges were formed in the test area according to approved standard blast design for mass explosion for the unit. For this purpose, 2.0–2.4 m was left for tamping in the borehole, and another part of the borehole was divided into two equal sections. The mixed explosion of trotyl (hydrocarbon gas + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix were placed in the lower part of the borehole, the booster explosive of two trotyl blocks T-400 connected by wave guide with plain detonator by non-electric system of initiation "Impuls" or "PRIMA-ERA" was installed.

After that, the top part was filled with conversion explosive material (charge section is DKRP-4 with plastid) and the top booster explosive was installed. The space between walls of borehole and section DKRP-4 was filled up with mixed EM – trotyl (hydrocarbon gas + ammonium nitrate). The mouth of borehole was encapsulated by tamping of stone screening dust (fraction of 3–5 mm).

At the experimental site, the formation of charges was carried out taking into account the isolated zones of increased fracturing. Thus, in the block rock mass in the direction of the extended zones with pronounced local fracturing in the drilled wells, extended combined

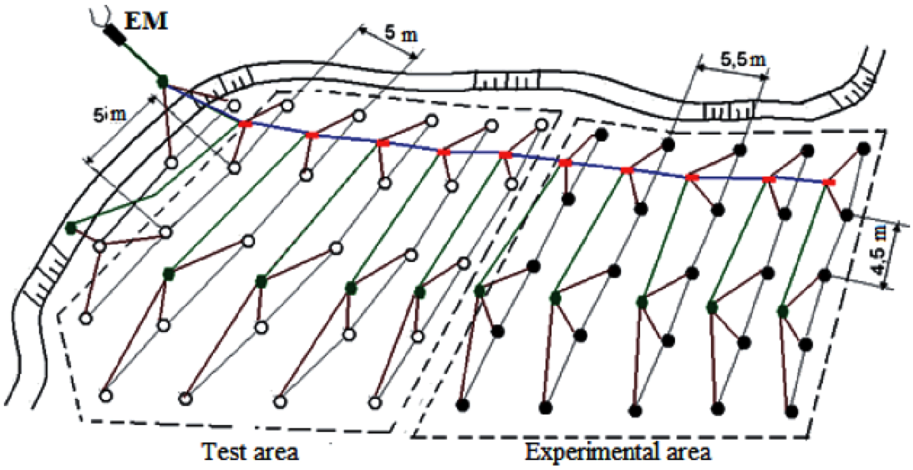

Fig. 2. The diagram of placement of boreholes and charges commutation in pit shoulders of "Sivach" unit 01/12, mount. +58.0 m

a b c d

Fig. 3. Charge of wells on the block:

a – appearance of the unit with a charging machine; b – emulsion EM such as Anemix; c – conversion EM-charge section is DKRP-4; d – installation of the cartridge-thriller from the TN-TNT in the well

charges of the variable cross section were formed. The design of the developed variable-charge explosive of the variable cross-section is shown in Fig. 4.

Formation of charges of the variable section in the boreholes was carried out by installation of the EMs,

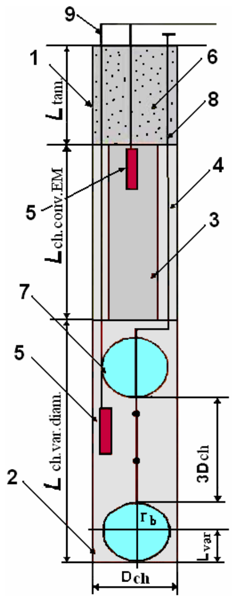

Fig. 4. Structure of the borehole multicharges variable diameter:

1 – borehole; 2 – charge of mixed EM – HG + AN; 3 – section of conversion EM – DKRP-4; 4 – pyroxylin powder; 5 – primed blasting cartridge; 6 – tamping; 7 – spherical cavities; 8 – binder for connection of spherical cavities; 9 – non-electric system of initiation "Impuls"

which were connected in a chain by means of binder in a spherical cavity, in the lower section of explosive column. The spherical cavity diameter is $0.8D_{bor.}$, where: $D_{bor.}$ is a borehole diameter. The distance between spherical cavities was accepted as equal to active part of the length of a cumulative charge [11]

$$H_{\text{lim.}} \geq \ell_{c.ch.} \geq 2d_{sph.cav},$$

where $d_{sph.\,cav.} = 0.5d_{ch}$. is the diameter of spherical cavity; $\ell_{c.ch.}$ is the length of the cumulative charge.

Charges of variable diameter with spherical cavities are formed in zones of monolithic block rocks, and charges of continuous structure are formed in jointing zones. The lower section of charge was filled with the mixed EM of trotyl (hydrocarbon as + granulated ammonium nitrate in a proportion 65/35) or emulsion EM such as Anemix; the top section was filled with conversion EM – DKRP-4 with plastid, and the top booster was installed. The space between walls of borehole and section DKRP-4 was filled up with mixed EM – trotyl (hydrocarbon gas + ammonium nitrate) or pyroxylin powder.

Commutation of borehole charges of EM in the rocks shoulder was carried out by the groups connected by lattice network. The linear delay elements of UNS-S and UNS-PA were placed between groups of charges in each level, and explosions were carried out starting with the charges located on the flank of. destructed unit with the use of non-electric systems of initiation "Impuls", NONEL, and "PRIMA-ERA".

According to results of mass explosions, the evaluation of results of crushing of the blasted mined rocks was carried out in experimental and test areas. Quality of

Table 2

Calculation of sizes of average piece of blasted mined rocks on experimental explosions*

Experimental area				Test area			
Classes of fineness, mm	Average size of piece on class, d_i, mm	Fractions output, W_i, mm	$d_i \times W_i$	Classes of fineness, mm	Average size of piece on class, d_i, mm	Fractions output, W_i, mm	$d_i \times W_i$
0–200	100	41.0	4100	0–200	100	26.7	2670
201–400	300	34.0	10 200	201–400	300	24.5	7350
401–600	500	17.3	8650	401–600	500	20.6	10 300
> 600	700	7.7	5390	>600	700	28.2	19 740
Σ			28 340	Σ			40 060
$d_{cp} = \Sigma d_i W_i / 100 = 283.4$ mm				$d_{cp} = \Sigma d_i W_i / 100 = 400.6$ mm			

* average values on experimental explosions

crushing was evaluated by the diameter of an average piece with measurement of particle size distribution of blasted mined rocks with application of a method of oblique-angled photoplanimetry. The calculation results are presented in Table 2

Conclusions and recommendations for further research. The analysis of results of industrial experiments has shown that the application of changed blast design parameters with use of structures of charges of variable section (Table 2) reduces diameter of an average piece approximately by 30 % and consumption of industrial EM by 10–40 %. The output of standard piece (201–600 mm) increases by 10 %.

The suggested methods for blasting strong complex structural local-jointed rocks allow improving the quality of crushing of blasted mined rocks and increasing technical and economic indicators of work of the mining enterprises. High-quality crushing of blasted mined rocks is achieved due to adjustment of key parameters of blast design, namely, geometrical arrangement and sizes of boreholes pattern, application of new structures of borehole multicharges of various cross-sectional shapes, and accounting of direction and intensity of crack systems of various morphology (opening degree) in the destructed rock unit.

The use of suggested structures of borehole multicharge of a variable section makes it possible to increase charge length at its constant mass and, as a result, to distribute EM along the shoulder height more uniformly.

Thus, conditions of energy transmission from explosion of EM charge are changed in case when multigradient and multidirectional field of stress is formed in the destructed massif. The role of extension and shearing stress providing more uniform crushed of rocks increases in such force field.

In course of industrial tests during 2012–2017, about 1500 thousand m^3 of mined rocks were blasted in granite pits of PrJSC "Ukragrovzryvprom" according to the developed recommendations. The average economy of industrial EM in one borehole is 40 kg, thus, the general economy for one mass explosion (only under section "explosive materials") exceeded 30 thousand UAH. The comparative analysis has shown that at preservation of rocks blasting quality, the use of suggested technology allows cutting specific consumption of EM and volume of drilling operations on average by 15 % with preservation of design elevation of face toe.

Industrial tests have shown that introduction of the suggested technology of explosive works conducting in pits at blasting massifs of complex structure makes it possible to provide effective and high-quality crushing of rocks.

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Ефективність підготовки гірничої маси на кар'єрах будівельних матеріалів

О. К. Іщенко[1], *В. М. Коновал*[2], *К. С. Іщенко*[3]

1 – Державний вищий навчальний заклад „Національний гірничий університет“, м. Дніпро, Україна, e-mail: ishchenkook@gmail.com

2 – Черкаський державний технологічний університет, м. Черкаси, Україна

3 – Інститут геотехнічної механіки імені М. С. Полякова НАН України, м. Дніпро, Україна, e-mail: ishenko_k@i.ua

Мета. Провести оцінку ефективності відбивання гірських порід у масиві складної будови з використанням нової конструкції свердловинного заряду для розробки ресурсозберігаючого та екологічно безпечного способу видбійки будівельної сировини на нерудних кар'єрах.

Методика. Для обгрунтування раціональних параметрів вибухового руйнування порід складної будови, якими є граніти, в умовах кар'єру „Сівач“ проведені експериментальні дослідження із вивчення структури породного масиву – орієнтування мікротріщин різної морфології та анізотропії фізико-механічних властивостей породоутворюючих мінералів і їх просторове положення на блоці. Досліджені основні характеристики тріщинної будови гранітного масиву з використанням методу стереофотозйомки оголених забоїв на горизонтах, обраних для промислових випробувань розробленого способу вибухової відбійки гірських порід.

Результати. Експериментальними дослідженнями визначено вплив тріщин на характер вибухового руйнування анизотропного масиву. Для цього уздовж лінії забою були пробурені шпури діаметром 43 мм на глибину 1.0–1.5 м і в них підірвані заряди патронованих вибухових речовин (ВР) – амоніт № 6 ЖВ. За розміром великої a і малою b осей воронки вибуху та її орієнтуванні відносно сторін світу, був розрахований коефіцієнт анізотропії з виразу $K = a/b$, що склав у середньому 1.14. Із використанням розробленої номограми та урахуванням даних коефіцієнту анізотропії були скориговані параметри сітки свердловин діючого паспорта буропідривних робіт (БПР) на експериментальній ділянці блоку рівній 4,5 × 5,5 м замість 5 × 5 м. Із використанням змінених параметрів паспортів БПР проведені масові вибухи на експериментальній та контрольній ділянках і оцінені результати дроблення відбитої гірської маси з використанням методу косокутної фотопланіметрії. Результати промислових експериментів показали, що застосування змінених параметрів БПР з використанням конструкцій зарядів змінного перерізу зменшується приблизно на 30 % діаметр середнього шматка, а витрата промислових ВР на 10–40 %. Вихід кондиційного шматка (201–600 мм) збільшується на 10 %.

Наукова новизна. Наукова новизна запропонованої вибухової технології дроблення міцних гірських порід складної будови, реалізована в новому способі відбійки локально-тріщинуватих гірських порід, полягає в наступному:

- з урахуванням виявлених зон підвищеної тріщинуватості на контрольній та експериментальній ділянках встановлені напрямки локальних тріщин і протяжність зон підвищеної тріщинуватості у блоковому масиві відносно сторін світу за параметрами яких був розрахований коефіцієнт анізотропії;

- за даними коефіцієнту анізотропії побудована номограма для коригування чинного паспорта БПР;

- за зміненими параметрами паспорта БПР у свердловинах, пробурених у масиві з вираженою локальною трещинуватістю, формували комбіновані заряди змінного перетину, що дозволяють поліпшити результати дроблення відбитої гірської маси.

Практична значимість. Представлені результати промислових випробувань запропонованої конструкції комбінованого свердловинного заряду змінного перетину, реалізованого в новому способі руйнування міцних локально-тріщинуватих гірських порід, дають можливість при постійній масі заряду збільшити його довжину і, як наслідок, більш рівномірно розподілити ВР за висотою уступу. При цьому змінюються умови передачі енергії від вибуху заряду ВР руйнуючому масиву із формуванням разноградієнтного й різноспрямованого поля напружень. У такому силовому полі зростає роль розтягуючих і зсувних напружень, що сприятимуть більш рівномірному подрібленню гірських порід.

Ключові слова: *свердловина, вибух, комбінований свердловинний заряд, поверхня уступу, тріщинуватість*

Эффективность подготовки горной массы на карьерах строительных материалов

А. К. Ищенко[1], *В. Н. Коновал*[2], *К. С. Ищенко*[3]

1 – Государственное высшее учебное заведение „Национальный горный университет“, г. Днепр, Украина, e-mail: ishchenkook@gmail.com

2 – Черкасский государственный технологический университет, г. Черкассы, Украина

3 – Институт геотехнической механики имени Н.С. Полякова НАН Украины, г. Днепр, Украина, e-mail: ishenko_k@i.ua

Цель. Провести оценку эффективности отбойки горных пород в массиве сложной структуры с использованием новой конструкции скважинного заряда для разработки ресурсосберегающего и экологически безопасного способа добычи строительного сырья на нерудных карьерах.

Методика. Для обоснования рациональных параметров взрывного разрушения пород сложной структурны, какими являются граниты, в условиях карьера „Сивач" проведены экспериментальные исследования по изучению структуры породного массива – ориентировка микротрещин различной морфологии и анизотропии физико-механических свойств породообразующих минералов и их пространственное положение на блоке. Исследованы основные характеристики трещинного строения гранитного массива с использованием метода стереофотосъемки обнаженных забоев на горизонтах, выбранных для промышленных испытаний разработанного способа взрывной отбойки горных пород.

Результаты. Экспериментальными исследованиями определено влияние трещин на характер взрывного разрушения анизотропного массива. Для этого вдоль линии забоя были пробурены шпуры диаметром 43 мм на глубину 1.0–1.5 м и в них подорваны заряды патронированного взрывчатого вещества (ВВ) – аммонит № 6 ЖВ. По размерам большой *a* и малой *b* осей воронки взрыва и ее ориентировке относительно сторон света, был рассчитан коэффициент анизотропии из выражения $K = a/b$, который составил в среднем 1.14. С использованием разработанной номограммы и учетом данных коэффициента анизотропии были скорректированы параметры сетки скважин действующего паспорта буровзрывных работ (БВР) на экспериментальном участке блока равной 4.5 × 5.5 м вместо 5 × 5 м. С использованием измененных параметров паспортов БВР проведены массовые взрывы на экспериментальном и контрольном участках и оценены результаты дробления отбитой горной массы с использованием метода косоугольной фотопланиметрии. Результаты промышленных экспериментов показали, что применение измененных параметров БВР с использованием конструкций зарядов переменного сечения уменьшается примерно на 30 % диаметр среднего куска и расход промышленных ВВ на 10–40 %. Выход кондиционного куска (201–600 мм) увеличивается на 10 %.

Научная новизна. Научная новизна предложенной взрывной технологии дробления крепких горных пород сложной структуры, реализованная в новом способе отбойки локально-трещиноватых горных пород, заключается в следующем:

- с учетом выявленных зон повышенной трещиноватости на контрольном и экспериментальном участках установлены направления локальных трещин и протяженность зон повышенной трещиноватости в блочном массиве относительно сторон света по параметрам которых был рассчитан коэффициент анизотропии;
- по данным коэффициента анизотропии построена номограмма для корректировки действующего паспорта БВР;
- по измененным параметрам паспорта БВР в скважинах, пробуренных в массиве с выраженной локальной трещиноватостью, формировали комбинированные заряды переменного сечения, позволяющие улучшить результаты дробления отбитой горной массы.

Практическая значимость. Представленные результаты промышленных испытаний предложенной конструкции комбинированного скважинного заряда переменного сечения, реализованного в новом способе разрушения крепких локально-трещиноватых горных пород, дают возможность при постоянной массе заряда увеличить его длину и, как следствие, более равномерно распределить ВВ по высоте уступа. При этом изменяются условия передачи энергии от взрыва заряда ВВ разрушаемому массиву с формированием разноградиентного и разнонаправленного поля напряжений. В таком силовом поле возрастает роль растягивающих и сдвигающих напряжений, способствующих более равномерному дроблению пород.

Ключевые слова: *скважина, взрыв, комбинированный скважинный заряд, поверхность уступа, трещиноватость*

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