Explosive Preparation of Rocks in Career with Well Retarders

E B Shevkun¹, A V Leshchinsky¹, Yu A Lysak²

¹Pacific University, st. Pacific, 136, Khabarovsk-680035, Russia
²LLC AVT-Amur, Lenin's street, 140/1, Blagoveshchensk-675000, Russia

E-mail: 000399@pnu.edu.ru

Abstract. The article deals with improving the quality of fragmentation of rocks by blast due to increase in intervals of delay. It shows the change in understanding of the mechanism of rock destruction under the influence of blast loads in recent decades. The mechanical effect of blast loads is manifested not only in crushing of rocks, but also in the weakening of their strength in remote distances from a charge. In the area of the blast wave compressive and tensile loads lead to the development of existing micro-defects and micro-cracks. The rock mass changes its strength properties, passes into a new state, called pre-destruction. The increase of delay time between blasts of charges increases the overall time of the blast, contributes to the merging of cracks and a gradual decrease in the sizes of the structural elements of the rocks. Impact on rocks alternating loads up to 20 or more times allows to increase the distance between the charges.

1. Introduction

Currently, in the practice of blasting there are several different methods of controlling the processes of explosive crushing of rocks. However, despite the significant differences in the methods of controlling the effect of the explosion, the method of exploding charges with air gaps should be distinguished as one of the effective [1,2]. Practice confirms that the separation of the downhole charge of explosives into several parts by the air gap significantly changes the dynamics of the explosion. This increases the time of the explosion on the rock mass, reduces the peak pressure of the detonation products, there is an interference wave pattern in the array. The total influence of these factors leads to an increase in the uniformity of crushing rock mass – reduced yield of both large and small fractions. The practice of using such charge structures has shown that, along with improving the quality of crushing, the consumption of explosives is simultaneously reduced, in some cases up to 30 %.

In recent years, due to the sharp rise in the cost of explosives and drilling, interest in air gaps arose again precisely because of economic advantages. New design for creation of the air gaps can be grouped into two classes: suspended type, with a variety of spacer devices, or polypropylene (plastic) sleeve and the thrust device in the form of paddles on the racks. Depending on local conditions of the enterprise used various designs on creation of air intervals of this or that class. However, the improvement of the range of explosives and the means of initiation has brought new challenges to the use of air gaps.

Almost all designs for creating air gaps are based on the mechanical retention of the overlying charge by various spacers or suspension devices. This approach is based on the factor of spreading
loose explosives into the walls of the well at a length of 4-6 of its diameters – the weight of the overlying part is held by this "cork" of the bulk explosive. With the transition to fluid emulsion explosives, the problem arose of the influence of the entire weight of the overlying charge on the spacer or suspension device forming the air gap. Therefore, the use of air gaps in the charges of emulsion explosives has become difficult.

Powdered explosives detonate from a string of detonating cord. With the transition in the last century to granular explosives, the initiation of which requires an intermediate detonator in the form of a cartridge or a powerful explosive checker, it became necessary to install an intermediate detonator in each part of the dispersed charge of granular explosives or emulsion explosives. When they were placed on the detonating cord, there were no problems, and the transition to waveguide systems with a moderator in each intermediate detonator due to variations in its response time caused the problem of incorrect operation of well charges in the presence of more than one detonator.

Thus, the improvement of the types of explosives and the means of initiation proved to be an obstacle to the use of the progressive design of the charge with air gaps.

2. Problem statement
Currently, the technical revolution in the field of blasting in mining enterprises is actually being completed. The problem of water resistance of explosives solved radically – waterproof, but dangerous to humans, the TNT pure in mining is only used in the form of checkers-detonators and in certain proportions in the composition of the bulk composite explosives of the type of grammonites.

The main volume of water-resistant explosives are fluid emulsion explosives. The issue of their production at modular plants at mining enterprises and delivery to the places of application in mixing and charging machines has been resolved. At large distances to the quarries, the mixing and charging machine is refueled on Board the quarry, which significantly increases its performance. The whole process of manufacturing and charging emulsion explosives in the well is fully mechanized; by charging under a column of water, the loading performance of waterlogged and dry wells is almost the same.

Legally excluded from the practice of mining the fire and the electro-flame blasting methods as unsafe and fails to provide a clear compliance with the defined intervals of delay in multi-row short-delay blasting. The major share of funds initiation of borehole charges are non-electric systems based on waveguides and electronic systems.

The main advantage of such systems is the separate charge initiation of each well, which allows to reduce the seismic impact of mass explosions on the infrastructure of carriers and adjacent settlements. The second important advantage is the presence of large-scale well slows-down from 500 MS and above, which allows to initiate the ground network before the wells. This eliminates damage to the surface network of flying pieces of rock mass during the explosion. However, this advantage caused a crisis in the development of methods for obtaining the optimal granulometric composition of crushed stone mass, which directly affects the performance and reliability of all mining equipment.

Experimental mass explosions in JSC "Urgalugol" with air space in well charges showed the possibility of financial savings of more than 5 rubles/m³. At the same time, in some places there were areas with a reduced quality of crushing the rock mass and working out the sole of the ledge. The analysis showed that these areas are confined only to wells with air space and two militants. At the same time, charges with air gaps were used earlier, but with the initiation system by a detonating cord with pyrotechnic relays on the surface without retarders in the wells, and then there were no such problems.

Had a suspicion that the moderators of the blast hole charges Iskra-C a range of decelerations cause incorrect triggering of borehole charges if you have more than a single detonator [3]. This assumption was verified and confirmed in [4, 5].

The above actualizes the use of high-precision digital deceleration blasting systems to initiate well charges, but their cost is many times higher than waveguide systems, requires highly qualified
personnel – the electronic detonator of each well is configured on the block by an engineer using a laptop. Not every mining company can afford it.

The kinetics of destruction of heterogeneous fractured rocks (and all rock massifs are represented by such rocks) is significantly affected by the rate and depth of crack germination associated with the mechanism of natural cracks and their embryos existing in the environment, as well as the conditions of the transition of the energy of the explosion into the energy of formation of new surfaces. Under the influence of cyclic alternating load there is a flow of energy to the top of the crack. In this case, the same in absolute magnitude tensile and compressive stresses create equal flows of energy, but their effect on the growth of the crack is exactly the opposite: the energy of compressive stresses has a strengthening effect, and the tensile stresses are aimed at breaking the bonds at the top of the crack. Crack growth cannot occur at the stage of the compressive load, despite the flow of energy to the top of the crack. The process of brittle destruction of rocks by explosion from the physical point of view is characterized by one type of destruction – separation under the action of tensile stresses from the action of the compression wave in the dilution phase.

This feature corresponds to the physical nature of the mechanism of breaking bonds only under the action of tensile stresses or tangents, and not all the energy of tensile stresses is spent on the growth of the crack, but only its excess over the energy of deformation of the medium. After the crack reaches the maximum increment, which occurs at the stage of the tensile load, the crack length remains constant (not healed) for a subsequent time [6]. Therefore, it is the time between the impact pulses that is of fundamental importance: the next pulse should follow only after the compression process, in which there is no crack growth, and the passage of the tensile wave, in which the crack growth takes place.

Therefore, it must go through a full cycle of "compression – tension" in the stress wave, and the time of removal of matter from the state of rest is always less than the time of its return to this state. Moreover, the crack growth undergoes with constant velocity and under dynamic loading, the ultimate crack development rate from the stress wave velocity in the array is according to [7] 0.34–0.51, and according to [8] only 0.10–0.13 – in the experiments in Dolomites the crack development rate was 550 m/s at the compression wave propagation velocity of 4500 m/s.

In [9] suggested that the effect of cyclic loads on the disclosure of grains of useful component. Significant dispersion of elastic and strength properties of minerals, physical and mechanical properties of ores with different structural parameters and fracture characteristics can be significantly manifested in the cumulative nature of damage accumulation, i.e. under cyclic loading. The peculiarity of this type of loading is the gradual growth and accumulation of cracks moving in the field with a complex structure of micro-stresses, formed in the ore containing minerals with different strength and different deformation characteristics. The pattern and nature of destruction is determined by the accumulation of violations from cycle to cycle and the formation of multiple structures of destruction.

During the compression tests of the samples, it was found that the destruction of the sample was largely dependent on the nature of the loads applied. Thus, when loading the sample with increasing load, there is an intensive accumulation and development of violations (cracks and microcracks) – irreversible damage accumulates. The magnitude of the destructive load in these experiments was 20-30 % lower than in conventional single loading.

Especially active are the processes of softening in the last cycles, when there is a mass accumulation of microfractures, a multiple grid of microcracks is formed (the intensity and the total acoustic emission sharply increases). As a result of such effects, multiple destruction is observed with the formation of a surface several times greater than with conventional (non-cyclic deformation), while the energy stored (or required for destruction) under cyclic exposure is reduced by 1.3–1.4 times.

The same conclusions are drawn from numerous simulations of the dynamics of cracks development in rocks when external influences change [10-14]. If to solve the problem of increasing the degree of crushing of rock mass to increase the productivity of the mining and transport complex, it is necessary to move to large intervals of deceleration [15].
3. Theoretical substantiation
In recent years, as a result of a number of theoretical and experimental studies, it was found that the mechanical effect of the explosion is manifested not only in the fragmentation and destruction of rocks, but also in the softening at remote distances from the charge [16]. In this area, the stress waves passing from the explosion lead to the development and increase of the concentration of existing microdefects, microcracks, weakening of intergranular and intergranular bonds. The rock mass changes its strength and deformation properties, goes into a new state, called-the pre-destroyed.

In [17], a change in the tensile strength of rocks at a distance of (150-200) $R_{exp}$ was found to be 2–3 times. The zone of preliminary destructive action of the explosion is characterized by a relatively small range of velocity changes, but a significant - on average 1.5-2 times - decrease in strength at large distances from the charge - up to 200 $R_{exp}$.

The paper [18] presents the fundamentals of a theoretical approach to the study of the features of wave pre-failure of rocks, in which it is believed that microcracks in the elastic deformation develop under the action of a tensile pulse in an elastic wave. The determining parameters are the magnitude of the tensile pulse, its duration and the rate of onset of microcracks. At a certain ratio of the values of these parameters, natural germ microcracks can grow by some value.

Thus, in the work [6] it is shown that the increment of the crack length in one cycle of "compression-stretching” is 10 mm, which is phenomenologically interpreted as a pre-fracture of the rock. The latter is extremely important for increasing the degree of rock crushing by explosion, because the microstructural parameters of the rock in the elastic de-formation can vary significantly with a series of explosive effects, since they have a cumulative effect [19].

It follows that the size of the area of preliminary destruction can increase with the continuing dynamic effects on the array, and this factor of anthropogenic impact on the rock should be taken into account.

Let us consider the dynamics of loading a conventional rock mass with the most common parameters of the sound velocity in it, equal to 3-4 km/s – it is with this speed that the voltage wave moves along such an array. With an average sound velocity of 3.5 km/s per 1 ms, the compression wave passes 3.5 m. Consider the scheme of blasting wells with a diameter of 200 mm, located on a grid of 6x6 m, with a slowdown of 25x42 ms.

Consider two options – the growth of cracks with speed 0.4 and 0.1 of the speed of sound. In the first case, in 1 ms the crack will grow by 1.4 m, in the second – by 0.35 m. Taking the size of the fracture zone radius of 40 charge radii (4 m), and the radius of the preliminary fracture zone of 200 charge radii (20 m). We obtain the time for the formation of the zone of collapse $\approx 5$ ms and the zone of preliminary destruction – 14 ms in the first case, in the second, respectively 11 ms and 57 ms.

This simplified calculation demonstrates that the formation of a zone of preliminary destruction even if the rate of growth of cracks of 0.4 the speed of sound, possible delays of more than 14 ms between bursts of successively exploding wells. Is-the pacing of these assumptions, it is clear that the scheme slowdowns 25x47 ms may not provide sufficient time for the completion of the growth and merger of micro-cracks in the cracks, forming a separate array. Only schemes with decelerations above 100 ms can provide sufficient time to form not only a zone of destruction, but also a zone of preliminary destruction.

4. Experimental study
On August 21, 2016, at quarry No. 5 (Vostok), a horizon of + 200 m, an experimental mass explosion was carried out with video shooting in rocky rocks of an average fortress. In a block with a volume of 71,600 m³, 221 wells with a diameter of 215 mm were drilled along a grid of 6.0 × 6.0 m, the depth of the wells was 11 m, the height of the step was 10 m, and the mass of the well charge was 300 kg. The block was divided into two approximately equal parts: one part with clogging of wells with drill cuttings, the second part without clogging. We used a non-electric initiation system RIONEL with a slowdown between the wells of the surface network in a row of 200 ms, between rows - 150 ms. The downhole network is slowed down to 750 ms. The surface network of borehole charges of the block...
was initiated from the middle of the block along the third row from the rear according to the “explosion in clamp” pattern.

A frame-by-frame scan of the video of the explosion established a regular decrease in the amount of gas and dust emission from wells without stemming and bottom-hole material from wells with stemming as the explosion develops in time and space.

The radius of the crack formation zone can reach a limit of 40 charge radii, and the radius of the preliminary fracture zone, according to various estimates, reaches from 60 to 250 charge radii. For an approximate graphical construction of the dynamics of the explosion in time and space, we take the value of the zone of cracking up to 9 m, and the zone of preliminary fracture - 44 m.

Before the explosion of subsequent wells, the stress wave produces cracks in the full volume of the zones of crack formation and preliminary fracture in the phases of compression and extension. At the same time, there is enough time for the formation of cracks in both zones by stress waves and their full opening by penetrating highly compressed explosion products.

Stress waves are absorbed in the crack formation zone of the blasted wells, which must be taken into account when constructing subsequent zones of preliminary fracture. They look like sectors of circles of various configurations. Wells falling into the overlapping zone of sectors of the pre-fracture zone are twice exposed to stress waves.

By 950 ms, a well appears with a 20-fold exposure to stress waves. The impact of each pulse causes a certain number of fractures, both as a result of the development of fractures existing in the rock, as well as the formation of new stresses in the places of concentration, dislocations, and weakened strength under the action of a stress wave in the rarefaction phase [20]. At large intervals of deceleration, there is the necessary time for crack propagation to full depth, corresponding to the quasistatic stage of fracture under the action of the bursting action of detonation products of subsequent charges.

Hino [20] claims that in the case of multi-row short-term explosions as a result of the explosion of the charges of the previous stage, additional impact surfaces are formed in which the bursting effect of the gases lasts from 10 to 100 ms.

5. Discussion
The repeated repetition of alternating compressive and tensile stresses and the long bursting effect of detonation products in the cracks of previous explosions lengthens and expands them, including outside the block. This makes it possible to form steep boards quarry without breaking beyond the separation line with good crushing quality. A better spallation of the rock from the massif and a steeper slope of the ledge indicate that most of the energy of the detonation products was transferred to the destroyed massif [21].

Thus, there is a real way to improve the quality of crushing rock mass explosion almost without any additional costs. After all, the use of borehole charges with air gaps is accompanied by additional operations to form an air gap with real time and material resources. In addition, it is necessary to use intermediate detonators in all parts of the separated charge, which is problematic in waveguide systems with a pyrotechnic moderator in the well or requires the use of more expensive electronic retarders.

Blast control using increased slowdowns does not entail any additional costs, since detonators of a surface network of different slowdown ratings have the same cost, but can significantly reduce the cost of drilling and blasting due to the increased distance between the wells.

6. Results
In general, the following conclusions can be drawn from the results of eight years of using explosive loosening of rocks with extended deceleration intervals up to 150-200 ms.

The extended retardation intervals during downhole blasting allow a 5–7-fold increase in the total duration of the action of multiple sign-variable loads on the rock massif, primarily tensile stresses. The length and expansion of cracks in the crushing zone and their number in the prefracture zone increase.
In the first case, the possibility of penetration of highly compressed explosion products into cracks and their active wedging increases, which is expressed by a decrease in the action of the explosion products towards the wellhead during the explosion of the following charges. A growing number of them go into cracks arising from previous explosions, contributing to their development. This makes it possible to abandon the use of clogging while maintaining the quality of crushing rocks. Smooth stable slopes of the ledges are formed, the duration of the preservation of such slopes in fact reached 8 years.

In the second case, the total destruction of the massif increases, which contributes to an increase in the number of weakened regions serving as the nucleation centers of the fracture points, since the strength of the entire system is determined by the strength of the weakest spot.

In combination with a wedge cut in the depths of the block, which provides the blasting regime “in clamping”, quality indicators at the quarries of the Petropavlovsk group of companies are characterized by compact laying of loose rocks with a calm surface topography. This helps to reduce losses and mixing of minerals with waste rock, and practically ensure the absence of large fractions of the rock mass.

The productivity of mining equipment has increased, the specific consumption of explosives has been reduced while improving the quality of working on the bottom of the ledge and reducing the seismic effect.

References
[1] Zharkov I F 2018 Improving the efficiency of crushing rocks of deep quarries Blasting Issue 121/78 pp 48-56
[2] Leschinsky A V, Shevkun Ye B 2009 Dispersion of borehole charges Haba-rovsk: Publishing House of the Pacific. state University 154 p
[3] Shevkun Ye B, Gomanyuk D S 2017 Downhole charges with air gaps Electronic scientific publication "Scientific notes of PNU" vol 8 4 pp 520–531 http: //ejournal/articles-2017/TGU_8_340.pdf
[4] Galimyanov A A 2016 Substantiation of the parameters of an open technology for the development of adjoining gentle and inclined coal seams: diss ... cand. Tech Sciences (Khabarovsk) 162 p
[5] Andreev A A 2014 About the features of short-blown blasting Explosive business 112/69 pp 220–223
[6] Karkashadze G G, Larionov P V, Mishin P N 2011 Modeling of crack growth under the action of cyclic loading GIB 3 pp 258–262
[7] Kutuzov B N et al 1988 The reference book of the detonator Under the general editorship of B.N. Kutuzov (M.: Nedra) 511 p
[8] Baron V L, Cantor V Kh 1989 Technique and technology of blasting in the USA (M.: Nedra) 376 p
[9] Hopunov E A 2013 Selective destruction of mineral and industrial raw materials (in enrichment and metallurgy) (Yekaterinburg: LLC “UIPC”) 429 p
[10] Momeni A, Karakus M, Khanlari G R, Heidari M 2015 Effects of cyclic loading on the mechanical properties of a granite International Journal of Rock Mechanics and Mining Sciences vol 77 pp 89–96
[11] Xiaodong Fu, Qian Sheng, Yonghui Zhang, Jian Chen 2015 Application of the discontinuous deformation analysis method to stress wave propagation through a one-dimensional rock mass International Journal of Rock Mechanics and Mining Sciences vol 80 pp 155–170
[12] Akande J M, Lawal A I 2013 Optimization of Blasting Parameters Using Regression Models in Ratcon and NSCE Granite Quarries (Ibadan, Oyo State, Nigeria) Geomaterials vol 3 1 pp 28-37
[13] Haeri H, Shahriar K, Fatehi Marji M, Moreno V 2014 Experimental and numerical study of crack propagation and coalescence in pre-cracked rock-like discs International Journal of Rock Mechanics and Mining Sciences vol 67 pp 20–28
[14] Liu T, Cao P, Lin H 2014 Damage and fracture evolution of hydraulic in compression-shear
rock cracks *Theoretical and Applied Fracture Mechanics* vol 74 pp 55–63

[15] Shevkun E B, Leshchinsky A V, Lysak Yu A, Plotnikov A Yu 2017 Features of explosive cultivation at increased intervals of deceleration *GIAB* 4 pp 272–282

[16] Lupiy S M 2016 Pre-fracture zones during the blasting method of mine workings and their influence on the parameters of anchor fastening *Blasting* (M.) 115/72 pp 226-232

[17] Mindeli E O et al 1978 The study of stress waves during an explosion in rocks (M.: Nauka) 122 p

[18] Kochanov A N, Odintsev V N 2015 Theoretical estimation of the radius of the area of pre-fracture of rocks in a camouflage explosion *Explosive business* 113/70 pp 41-54

[19] Novikova M A 1984 Development of a method for the production of mass explosions with associated mining of granite blocks. Abstract. ... cand. tech. sciences *Moscow Mining Institute* (M.) 23 p

[20] Hino K 1956 Fragmentation of rock through blasting and shock waves, theory of blasting (Quarterly of the Colorado School of Mines, Golden) 51 pp 189-209

[21] Yurovskikh A V 2003 Development of a model of rock destruction at the quasistatic stage of the explosion: Diss. ... cand. tech. Sciences: 25.00.20 (St. Petersburg) 119 p