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Technological applications of border effects by hole charges system explosion
Technologiczne wykorzystanie efektów granicznych wybuchu systemu ładunków otworowych

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Abstract: *The technique of blasting in a mining is based mainly on application of the systems of the prolonged charges, which provide the rational distributing of charges explosive in the destroyed volume of rock mass. Large majority of output volumes is provided by the opencut method which fully is practically based on application of the downhole charges systems. A downhole charge must execute a few functions. Main of them is destruction of rocks around the mining hole, bit also avoiding the problem of overdrill in mass explosions is very important.*
Reduction or complete liquidation of overdrill is possible by introduction of structural decisions, which create the reorientation of power stream of explosion in direction which coincides with the plane bench toe. Additional structural decisions for a control of overdrill size, capable to orient development of deformation process from the axis of downhole charge along the project bench toe, are needed. The article discusses the development of the deformation zone during the explosion, which allows to solve the problem of over-drilling.

Streszczenie: *W technika strzelniczej w przemyśle górniczym wykorzystuje głównie wydłużone ładunki wybuchowe, gdyż zapewnia to optymalne rozmieszczenie materiałów wybuchowych w obszarze, w którym niszczony jest górotwór. Zdecydowanie najczęściej stosuje się otwarte otwory strzałowe, gdyż ułatwia to ich elaborację. Ładunek materiału wybuchowego umieszczany w otworze strzałowym powinien spełniać kilka funkcji. Przede wszystkim, powinien efektywnie kruszyć górotwór wokół otworu strzałowego. Powinien także zabezpieczać przed wystąpieniem efektu nieprawidłowej fragmentacji górotworu wokół otworu strzałowego.*
Zmniejszenie lub całkowita likwidacja efektu nieprawidłowej fragmentacji górotworu jest możliwa w wyniku wprowadzenia rozwiązań strukturalnych, powodujących zmianę kierunku strumienia energii wybuchu w pożądany sposób. W omawianym obszarze nadal poszukiwane są nowe rozwiązania. W pracy przeprowadzono analizę rozwoju procesu deformacji górotworu w strefie wybuchu, w celu opracowania metody zabezpieczającej przed niewłaściwym przebiegiem fragmentacji materiału skalnego.

Keywords: *explosive, border effect, tamping, overdrill, modelling, cutter break, priming charge, conic charge, metallic laying, power stream*
Słowa kluczowe: *materiał wybuchowy, efekt graniczny, przybitka, nadmierne przebicie, modelowanie, perforacja, ładunek inicjujący, ładunek stożkowy, warstwa metaliczna, strumień energii*

Nomenclature:

PE products of explosion

1. Introduction

Known methods of increasing the efficiency of blasting in hard rocks are largely based on techniques for controlling the distribution of explosion energy during its initial period; from the moment of chemical decomposition of the explosive charge to the moment of transmission of energy to the rock mass. According to an analysis of well-known scientific developments and blasting practices, in recent years special attention has been paid to the possibilities of controlling the detonation process in elongated charge, as the most common in mining practice. The design features of the elongated charge include first of all its diameter and construction, parameters of overdrilling and tamping, a combination of different types of explosives in the charge, parameters and location of the intermediate initiator, *etc*. The method of controlling the configuration of the detonation wave front affecting the geometry and sequence of the interaction of stress fields in the broken array is less common.

In the work there are tasks of research related to justification of rational methods of control of mechanical effect of borehole charge explosion by formation of detonation front in elongated charge taking into account end phenomena caused by degeneration of cylindrical front of stress wave conditionally into spherical one in charge edges, which solve problem of overdrilling and loosening of rock mass in the area of tamping.

The aim of this paper is to study the processes of forming the mechanical effect of a mass explosion involving the edge effects of a limited-size borehole charge explosion.

2. Research problems

2.1. Controlling the detonation process

The main attention is paid to the specifics of designing and carrying out mass blasting at deposits lying in the conditions of mountain slopes. A feature of the conditions of development of such deposits is the difference of heights within one explosive unit, which dictates the need to reduce the height of the ledge to 6-10 m. At that charge, the length is reduced to 4-6 m accordingly, the role of the end part of the vertical hole charge in the formation of the force and deformation field becomes more essential. Part of the effect of this factor can be compensated for by reducing the charge diameter and grid parameters of the charges in the system. However, at a trend of application low sensitive ammonium-nitrate explosives in the diameter of the borehole should be assigned taking into account the value of the critical diameter characteristic of this type of explosives which approaches 80-100 mm. Edge parts of a borehole charge are both extreme sections of a short cylindrical charge which define the mechanical effect of explosion mainly in the axial direction:

– lower – in the field of overdrilling,
– upper – in the direction of tamping.

2.2. Overdrill problem in mass explosions

The explosion of the lower end of a borehole charge should prevent the raising of a sole of a ledge that appears owing to insufficient saturation of an array by explosion energy in a ground part of the borehole. As the lower end of a borehole, charge works in the most difficult conditions – in the clamped environment at a level and ledge soles are lower, it is necessary to increase the mass of the lower part of a charge due to its lengthening on overdrill value. This reception compensates for the deficit of energy of explosion in the lower end face. However, compensation involves an increase in the volume of drilling operations at least by 10%, and the corresponding increase in the consumption of explosives.

It is possible to reduce or completely to liquidate a well overdrill by the implementation of constructive solutions in the lower end face of a charge. The reduction of length of an overdrill is possible by the origin of a horizontal cutter break. The method based on the application of a conic neutral insert in the bottom of the borehole at the level of a sole of a ledge (Fig. 1) is known.

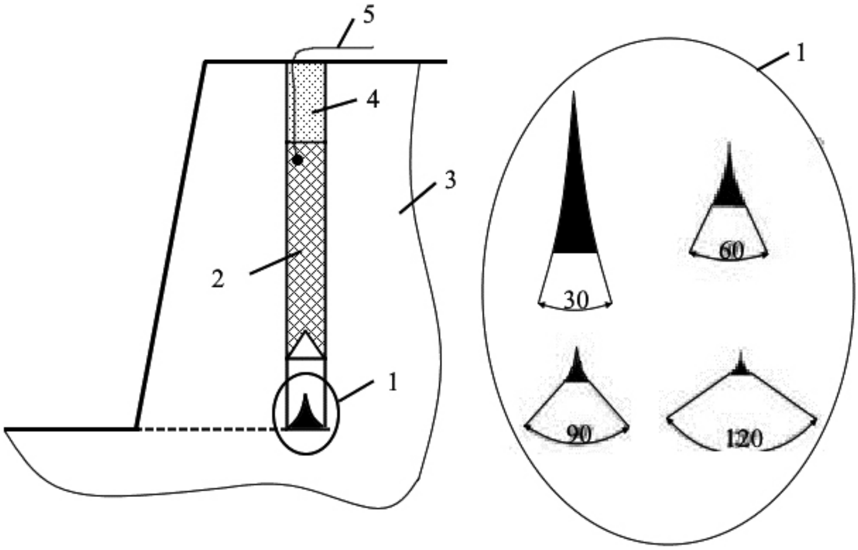


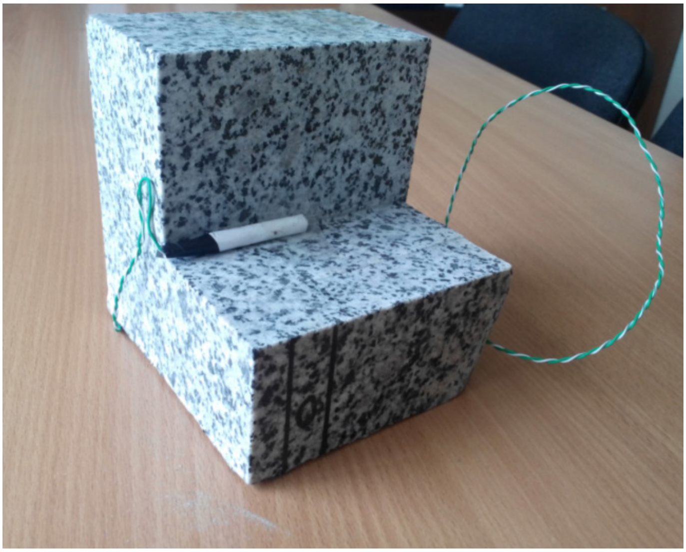
Figure 1. Construction of a charge with the rejecting insert: 1 – a form of inserts, 2 – explosive, 3 – rock (model), 4 – tamping, 5 – the initiating device [8]

Researches of efficiency of the rejecting conic insert [1-3] testify to a possibility of reduction of length of an overdrill, however completely do not solve the problem. According to researches presented in [1, 3], explosion using the rejecting conic insert with the angle of disclosure at top 60º leads to the formation of cutter break in an angular zone of the borehole at the level of the lower end face of a charge (overdrill). However, with removal from a charge axis, destruction zone depth sharply decreases. At the distance, equal to half of the distance between adjacent charges it reaches the ledge soles level. Actually, in an average zone between the influence of the next charge of a conic insert is not noted. At the same time, it is established that a combination of the conic insert to the preliminary cutter in a ground part of the borehole in space between wells almost ideal horizontal surface of splitting off at the level of the bottom of adjacent boreholes forms. The received result testifies to the possibility of the complete elimination of a problem of an overdrill. However, it should be noted that the offered way demands use of the special device – a conic insert and becomes a complicated preliminary creation of a cutter break at the bottom of the hole. The author does not discuss a way of creation of a cutter. However, proceeding from the results of researches, in the described combined method preliminary formation of the cutter break is the decisive factor.

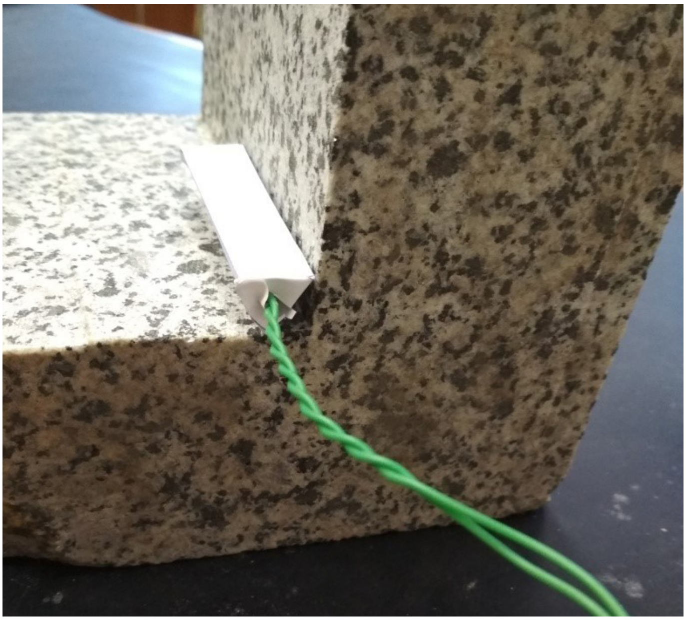
In the development of the stated results of researches the combined method based on the application of a way of the lower initiation of a borehole charge by the booster with conical shape is offered [4-6]. The explosion of the conic booster directed by top towards a borehole bottom creates an uneven force field in contact with the environment. In a cross-section, the force field has the pear-shaped form and power flows in a force field of the booster are generally oriented along an axis of a charge and on a normal, to a lateral surface of a cone in the direction of the ledge sole plane.

3. Materials and methods

Model experiments are executed on the creation of the primary cutter break by an explosion of an additional charge in an angular part of the bottom of the well. For simplification of experimental conditions, the borehole and a ring charge are replaced with a linear analog. In a granite sample rectangular notch which imitated operating conditions of the explosion in an angular part of the borehole (Fig. 2) was created. Several series of laboratory experiments have conducted on granite models. As a material of models, the granite of the Pokostovsky field differing in high strength and uniform fine-crystalline structure [7] is selected. By results of the microscopic analysis of samples were defined parameters of the deformed zone consisting of a zone of destruction (fall), a zone of crushing (crumple zone) (Fig. 3(a)) and a zone of microcracks (Fig. 3(b)).

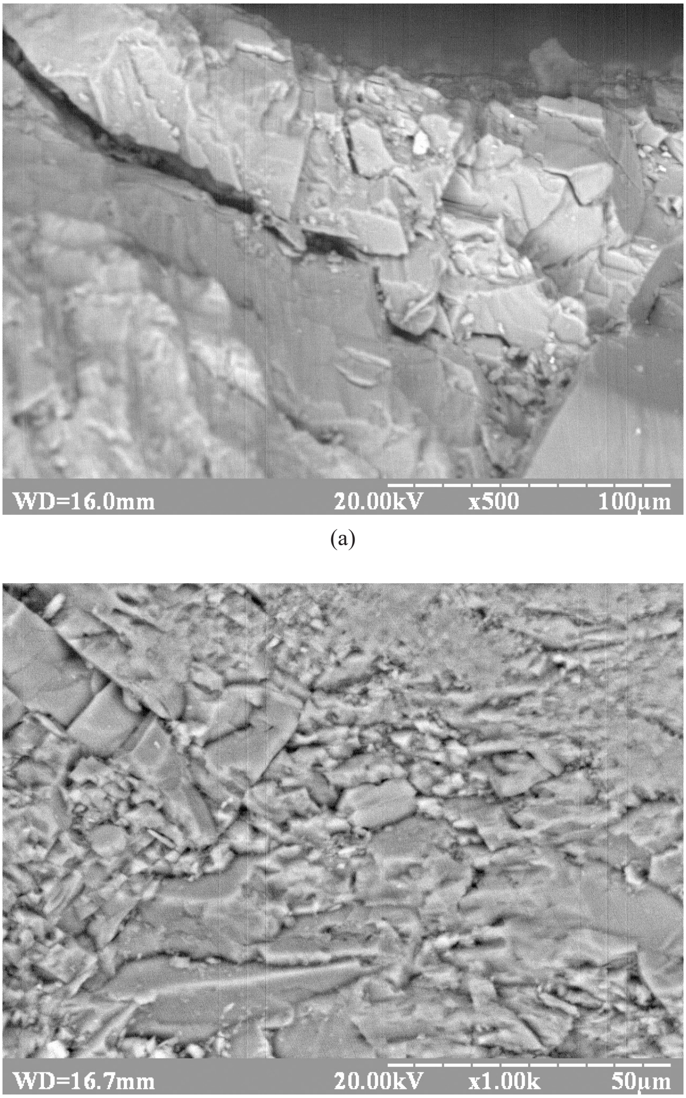


(a)



(b)

Figure 2. Scheme of experiments with model charges: a) cylindrical charge, b) wedge-shaped charge



(b)

Figure 3. Areas of crumpling (a) and microcracks (b)

The measured depth of a zone of crumpling h in the studied models is specified to relative units. Change of the specified depth of this zone, h_{sp} [mm·kg$^{-0.5}$], with an increase in the mass of a charge is defined by Equation 1:

$$h_{sp} = h \cdot \sqrt{m_з} \qquad (1)$$

where $m_з$ is an increase in the mass of a charge [kg]. Assuming that h = 20.81 mm, Equation 1 can be expressed as:

$$h_{sp} = 20.81 \cdot m_з^{1/2} \qquad (2)$$

According to Equation 2, weighing booster about 0.5 kg the maximum depth of a zone of crushing in the lower angular zone of the borehole can be approx. 1.5 cm that taking into account the zone of microcracking following it is capable to define unambiguously the direction of development of a crack of a splitting off in the ledge sole plane.

4. Discussion of results

4.1. Analysis of the intermediate initiator

It is known that in the end faces of a cylindrical charge of limited length the axisymmetric nature of the development of the field getting directly at the level above an edge part of a charge the form close to a sphere is broken. In [8], explosion of a cylindrical charge from the acetylene-air mixture with its initiation in point (0; 0) (Fig. 4) *i.e.* in origin of coordinates is theoretically investigated. The made calculations for a cylinder with a ratio of 1:1 of its heights to diameter showed that the front of a shock wave practically in a form approaches the sphere. However, the increase in this ratio changes the nature of the expiration of explosion products. So, at a ratio of the height in charge to its diameter of 4:1 (Fig. 4) from the center of the explosion the front of the shock wave (SW), similar to cylindrical, according to the advance of a detonation wave from an initiation point, *i.e.* from the beginning of coordinates (0; 0).

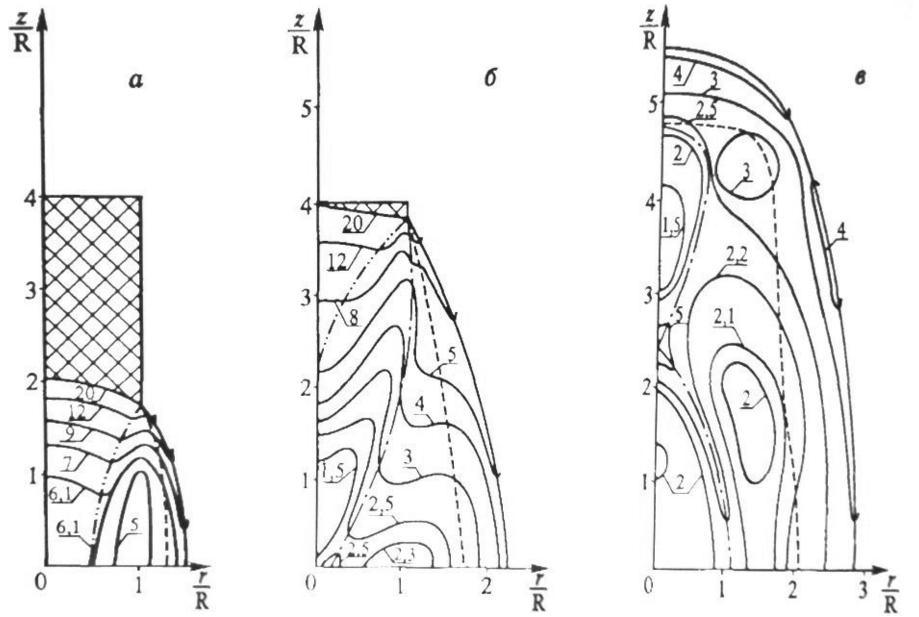


Figure 4. Dynamics of development of a force field at the explosion of a short cylindrical charge

At the initial moments, the force field looks like it is central symmetric (Fig. 4(a)). However, at the subsequent moments (Fig. 4(b)) it is extended towards an upper-end face of a charge, probably, as detonation speeds along *Z*-axis prevails over exhaust speed on the environment of explosion products in the direction of *R*-axis, *i.e.* in the neutral environment. Further with the development of process and its exit over an upper-end face of a charge (Fig. 4(c)), the field form in the axial direction gets a sphere form. At the same time, the wave front in the axial direction after an exit out of limits of an end face of a charge loses 35-40% of energy in comparison with the radial direction [8]. Therefore, if the extended charge is shorter with a constant diameter, the more intensively the general dissipative losses of the energy of explosion in the field of an end face due to the transition of the edge area of a field to central symmetry.

It is necessary to consider the difference and features of manifestation and development of these effects in the lower and upper-end faces of a charge. The lower face part of a charge is responsible for a zone of an overdrill, *i.e.* for maintenance of a level of a sole of a ledge on the required horizon. Here an end face of a borehole charge, being in most cramped conditions, tests the largest resistance of a rocky array to destruction and respectively requires first-priority attention in researches. The upper face part is in more favorable conditions – in the array layer at the level of tamping, which is partially weakened by the previous mass explosion when developing an upper ledge. Generally upper edge part of a borehole charge should provide the required extent of destruction of an array at the level of tamping with the explosion in the mode of weak loosening or the strengthened camouflet at an indicator of action of explosion within n = 0.3-0.7.

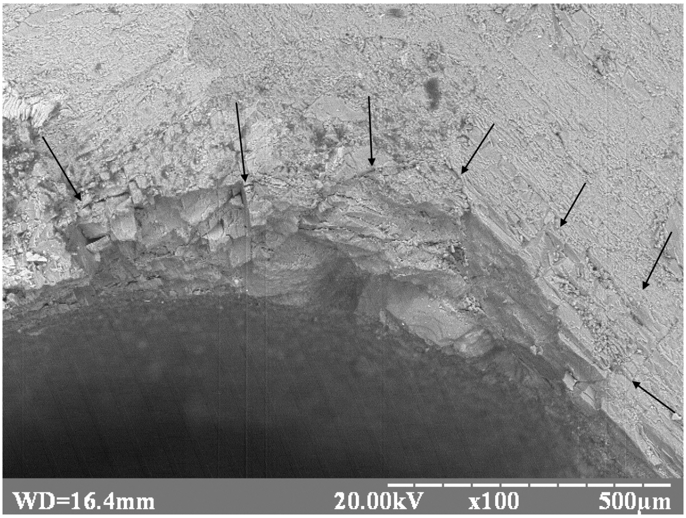
The tasks facing the lower and upper edge sections and the main part of a cylindrical charge, technologically integrate by one purpose. The explosion should provide the necessary quality of crushing of mountain weight within the prism falling on one charge. However, edge portions of a borehole charge work in unequal mining conditions and perform additional functions. Therefore, it is necessary to consider the mechanism of space forming of the mechanical effect of explosion separately longwise of a borehole charge.

The task of a charge is carried out in several consecutive stages, detonation decomposition of the "initiating device – the intermediate initiator – an industrial charge" system. The first stage is fundamental. At this stage during the first microseconds after initiation management by edge effects of the explosion is possible only at the expense of constructive solutions within a borehole charge, and first of all due to the choice of the place of initiation. With the advent of modern not electric means of initiation like Nonel became widely available a method of the lower initiation of a borehole charge. This method does not influence the status of the blown-up borehole charge, provides a more rational distribution of energy of explosion on charge height thanks to the development of process from a ledge sole to the tamping locking products of explosion (PE). In this option of the reverse detonation of a borehole charge tamping delays PE in the borehole before completion of secondary reactions of explosive decomposition. At the same time, it provides completeness of a charge detonation until a departure of residual products of the explosion in the atmosphere. However, the lower initiation does not exhaust ways of management by edge effect in a ledge sole. For a decrease in length of overdrill, it is offered to change a form of a priming cartridge or booster.

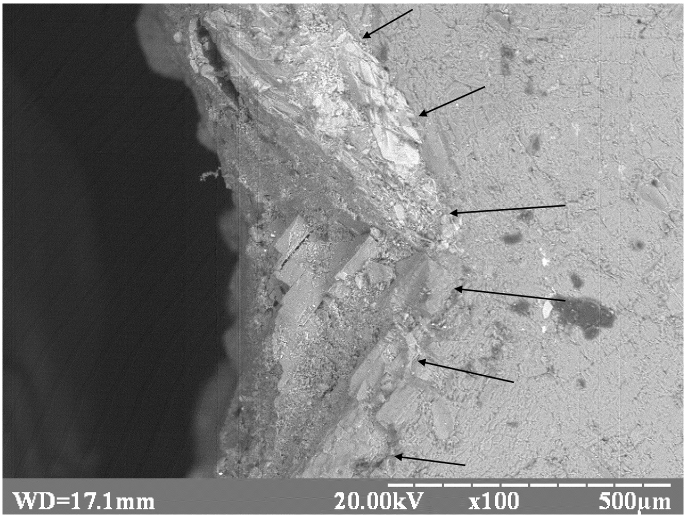
As a result of mathematical modeling [4], it is established that the booster can give more irregular shape for orientation of a force field energy along the ledge sole plane. The booster in the form of a truncated cone can be such an intermediate initiator.

4.2. Analysis of deformation mechanism

In experiments is noted the influence of a form of a charge on the nature of deformations in an angular zone of the well (Fig. 5(a)). Irrespective of a form of charges at pictures except for a zone of fall there are almost equal zones of crushing and microcracking. In the technical sense, a wedge-shaped charge is more accented defines the direction of development of a zone of deformations in the angular area (Fig. 5(b)).



(a)

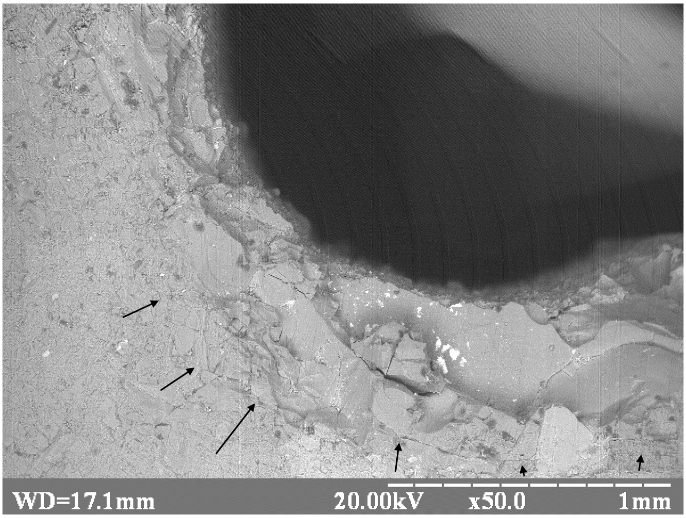


(b)

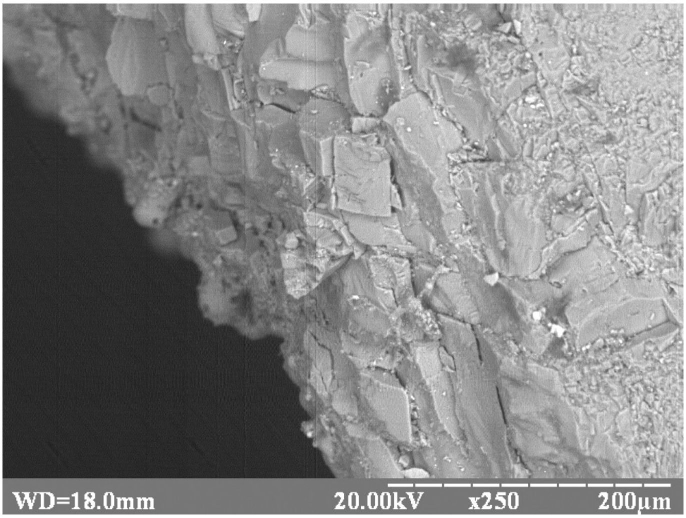
Figure 5. Crumpling zone from the explosion of model cylindrical (a) and prismatic charge (b)

As one of the efficient controls, the mechanical effect of the explosion of the extended charge the ground passive laying allowing orienting an axial energy flow of explosion towards the horizontal plane can serve in a ground part of a spur or the borehole. In model experiments for this purpose metallics laying [7], which in the real borehole can be or be replaced with disks from concrete or a granular material like sand or drilling slame are used [8]. In the experiment are used plates 1-3 mm thick.

It is experimentally established, that when using plates as laying depth of a formation zone of crumpling and microcracks increases on value from 400 µm when using a plate 1 mm thick up to 700 µm when using a plate 3 mm thick. The deformation phenomena are observed on a lateral surface of the model (Fig. 6) and are practically absent under metallic laying. Such nature of deformation of an angular zone favors to side development of temper in the cutter of the bottom of charging development.



(a)



(b)

Figure 6. The deformed zone in model with a plate 2 mm thick: (a) the nature of deformation in an angular zone of a ground part of the well (50-fold increase), (b) crumpling zone (250-fold increase)

The deformation mechanism in an angular zone depending on plate material is of interest. According to the known researches of Haponenko [8], even the layer of drilling slame left in the borehole provides a reduction of depth of an overdrill, which leads to a reorientation of energy flow in a ground part.

5. Conclusions

Results are studied on models of the forming of the mechanical effect of the explosion in edge bottom pane of a borehole charge of the limited sizes.
By results of the microscopic analysis of samples parameters of the deformed zone consisting of a zone of

destruction, a zone of crumbling and a zone of microcracks are determined.
It is offered to implement the idea of the device of a side source of dynamic perturbations in the bottom of the borehole of a laying join path in borehole flax with an obligatory structural element of a borehole charge – the intermediate fighter. Changing the primers form, it is possible to achieve reorientation of energy flow at its explosion in the set direction. The primer in the form of a truncated cone is established in a ground part of a borehole charge and is guided top to a borehole bottom coaxially with a charge. Side scattering of products of the explosion used as the initiator of the deformation phenomena in an angular zone of the borehole, and the axial impulse directed towards a ledge sole will be transformed on laying and strengthens horizontally oriented force field.
It is established that a wedge-shaped charge is more accented defines the direction of development of a zone of deformations in the angular area of the borehole.

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