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INFLUENCE OF SURFACTANT ON THE EXPLOSIVE DESTRUCTION OF POLYMINERAL ROCKS

[1]Ishchenko O., [2]Novikov L., [2]Ishchenko K., [2]Lohvyna L., [3]Kinash R.

[1]Dnipro University of Technology
[2]M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine
[3]AGH University of Science and Technology

Abstract. Explosive destruction of rocks depends on their composition, the nature of mineral grain distribution, microcrack concentration and orientation, presence of gaseous and liquid phases. Surfactants are used to increase the efficiency of rock destruction by means of dynamic and explosive loads. The increase in destruction efficiency is achieved by adsorption reduction of the solid's surface energy, which leads to the formation of microcracks and a decrease in rock strength. Rock saturation with surfactant solutions is determined by the degree of solution acidity, rock porosity, content of liquid and gaseous components, and stress state. It is well known that surfactant solutions can lead to a 20–50% reduction in rock strength and the concentration of suspended dust particles. The decrease in strength occurs when the enthalpy of chemical reactions of a solid with an active substance is several tens of kilojoules per mole. The paper presents a method of experimental modelling of explosive rock destruction taking into account the influence of surfactants. It was found that the microcracking of granites is characterised by a high density of internal structure defects in the form of microcracks in quartz grains. In particular, the finely dispersed destruction products of pegmatoid granite samples, which are not treated with surfactants, mainly consist of elongated acute-angled fragments of quartz and feldspars (microcline and albite). As a result of studying the products of destruction by explosion of granite and ferruginous quartzite samples treated with a concentrated solution of sodium carbonate and 10% solution of sodium bicarbonate, it was found that quartz prevails in the composition of finely dispersed solid particles, which has a more rounded shape compared to quartz particles for dry samples. That is, sharp-angled fragments are practically not observed in the destruction products. It has been established that explosive destruction of granite and ferruginous quartzite samples treated with a sodium carbonate solution results in a significant increase in the average size of fine particles, as well as their median and quartile sizes. It has been established that the nature of the destruction of uranium and iron ores can be changed by treating them with surfactants. In addition, the formation of fine particles in the destruction products can be reduced by using explosive charges with different cross-sectional shapes.

Keywords: rock, surfactant, explosive destruction, microcracks, fine particles, particle size distribution.

1. Introduction

Currently, the process of dynamic destruction of anisotropic polymineral rocks is not well understood. These rocks are characterised by the presence of a large number of internal defects: intergranular contacts of minerals that make up the rock base; intragranular and intergranular microcracks; and adhesion planes. The methods of dynamic destruction of these rocks should provide not only the necessary crushing and appropriate rock composition, but also the concentration of dynamic energy in the specified directions. This allows to exclude the impoverishment of mineral resources during intensive mining operations on the surface, as well as to control the destruction of rocks during sinking of workings with different technical purposes and stripping of mineral resources in a complex stress-strain state.

Almost all technological processes associated with the separation and further crushing of rock blocks involve crack formation [1]. For strong anisotropic rocks, this process is one of the most energy-consuming. Therefore, the search for new and improved methods of rock destruction continues in this area.

The use of surfactants is a promising means of increasing crack formation and, consequently, rock destruction. The action of surfactants is based on the adsorption reduction of the surface energy of bodies (Rehbinder effect). Surfactants have long

been successfully used in various industries [2, 3]. However, despite the obvious effectiveness of their application, they are not widely used in mining practice due to poor development of theoretical and methodological bases.

Currently, rock destruction is considered a complex physical and chemical process, the nature of which depends on the magnitude and speed of load application, the stress state of the object, its strength and structural properties. In this regard, it is an urgent task to study this process at the microscopic level. At this level, fracture occurs at the point of contact between destructive element and the rock and is accompanied by the breakage of bonds between grains or the disruption of chemical bonds in the crystal, the appearance of microcracks, and displacement along the sliding surfaces. The system of defects, even in the most well-formed crystals, creates germs on which microcracks develop under the slightest deformation. The size of the crack mouths continuously increases with deformation. At the same time, the adsorption effect increases. For example, surfactants contained in the environment surrounding a solid body, when it is deformed, are adsorbed on its outer surface and penetrate the mouths of microcracks. This facilitates their development to active sizes and contributes to the formation of plastic shifts.

The saturation of rocks with active solutions is determined by the size and nature of rock porosity, their initial moisture content, type of surfactant solution, stress state of the massif, and other factors [4]. It should also be noted that the penetration of surfactants contributes to the development of microcracks and changes in their parameters [4].

Recently, surfactants have been used as a filler for inserts in the packing material, in the form of a shell around the explosive charge. The rock is saturated with surfactant solutions immediately before drilling and blasting operations [5, 6]. However, this does not always take into account the fact that the surfactant solution can enter the rock during the drilling process, since drilling fluids, as well as lubricating and cooling fluids often contain surfactants (e.g., emulsion flushing fluids) [7].

Studies have shown [8, 9] that the use of surfactants leads to a decrease in the strength of rocks and a decrease in the energy intensity of their destruction. At the same time, an important direction in rock mining is the use of surfactants in combination with pulse loads.

Papers [10, 11] considered the effect of surfactants on the fractional composition of dust during the explosive destruction of samples of strong fine-grained sandstone (Ternivska and Dniprovska mines of DTEK Pavlohradvuhillia, Pavlohrad). They showed that after the samples were treated with alkaline surfactant solutions, the strength of the samples decreased and the average diameter of fine dust particles at the explosive-rock contact increased. The analysis of the destruction products of strong sandstone showed [11] that its particles treated with surfactants are represented by quartz grains of rounded shape, and without surfactant treatment, the particles have an acute-angled shape. The surfactants used were 10% solutions of sodium bicarbonate and soda ash, magnetised water, and lime milk. In destruction products of the carbonaceous mass samples treated with lime milk, there are no quartz fragments, which are usually present when no surfactant is used.

It has been experimentally proven [12] that surfactant solutions can reduce the strength of rocks by 20–50%. The decrease in strength is directly proportional to the area of the treated surface. With the decrease in the strength of the rock being destroyed under the action of surfactants, the diameter of the dusty particles increases due to the targeted reduction of the strength properties of the medium at the contact "destructive tool-rock" or "explosive-rock". For example, for quartz, such substances are solutions with an alkaline reaction, in particular, Na_2CO_3 (sodium carbonate or soda ash) and $NaHCO_3$ (sodium hydrogen carbonate or bicarbonate of soda), in the presence of which the fracture resistance of this mineral is sharply reduced.

The main source of dust in rock blasting is the process of release of gaseous detonation products of explosives and a mixture of dust particles with the packing material. The dust particles are formed in the fine crushing zone at the explosive-rock contact. In addition, fine particles in the area near the blast wellhead are additionally involved in the dust due to the influence of the injection air flow [13].

Efremov E.I. et al. [14] found that the intensity of dust emission and the dispersion of dust particles are influenced by the following factors: mining and geological features of the massif (fracturing and water cut); specific consumption of explosives and their detonation rate; fractional and mineralogical composition and strength characteristics of the rock being destroyed; microstructural features of the environment. Of these factors, the greatest influence on the formation of fine particles during the destruction of polymineral rocks is exerted by the properties of the medium, i.e., the strength characteristics of rock-forming minerals and the density of defects in their structure.

Most rocks (igneous and metamorphic) contain quartz, which is the strongest rock-forming mineral. Kratkovsky I.L. [15] notes that this mineral is represented by elongated aggregates consisting of several dozen small isometric grains with a large density of structural defects.

Rocks containing quartz, which are subject to destruction by dynamic loads (explosion, impact), are the main source of fine non-hazardous dust (up to 100 μm), consisting of 75–90% or more quartz. In an explosion at the explosive-rock contact, the median diameter of dust particles (the average diameter of 50% of particles of the dusty fraction up to 100 μm) does not exceed 2–4 μm, and for dust in drill cuttings this limit is 8–10 μm. Therefore, dust particles with such properties can remain in the atmosphere for a long time after the explosion due to the influence of turbulent pulsations.

For rocks without quartz content (peridotites, gabbro, basalts) or rocks with a quartz content of less than 10% (gabbro-diabases), the median size (diameter) of fine particles of rock destroyed by an explosion is usually in the range of 30 to 40 μm with a weighted average diameter of 65 to 75 μm. During the explosive destruction of such rocks, the resulting dust and gas cloud quickly dissipates and settles in the area of the rock drainage due to the intensive fall of large particles under the influence of gravity.

Considering that uranium ore deposits belong to rocks of igneous and metamorphic origin (granites, migmatites, albites, etc.), the structure of which includes quartz,

an urgent task is to study the mechanism of explosive destruction of rocks containing uranium, weakened by the action of surfactant solutions, including the process of release of the smallest (dispersed) dust particles.

Various liquid analysers are used to determine and substantiate the physical properties of surfactants. In particular, "Yokogawa" analysers that allow measuring hydrogen index (pH), conductivity and resistivity [16].

The Fluorat-02-4M liquid analyser is designed for rapid analysis of liquids by fluorometry and photometry. In addition, the analyser is used as a fluorometric detector as part of the LUMACHROM liquid chromatograph [17].

For pH measurements, a pH meter HI 5222 is used [18]. The device has built-in software that allows you to control the measurement process, collect experimental data, process, store and transfer the results to a computer.

The purpose of the work is to analyse the effect of surfactants on the mechanism of explosive destruction of rock containing uranium, and to analyse the grain size and fractional composition of rock destruction products.

2. Methods

According to the article, the results of the study were carried out using the method of explosive rock destruction experimental modelling under the influence of surfactants. When analysing the fractional composition of rock samples destruction products, the relations were used to determine the main grain size distribution characteristics of fine particles.

The qualitative indicators of the yield of fine dust fractions during the destruction of rock samples containing uranium treated with surfactants were evaluated by polarisation-optical and X-ray diffraction methods, and the selection and determination of physical properties of surfactants were carried out by fluorometry and photometry.

3. Experimental part

The experiments study the effect of surfactants on the distribution of the fractional composition and structure of rock destruction products. The surfactants used were substances with an alkaline reaction, namely a 10% solution of sodium bicarbonate $NaHCO_3$, a 10% solution of soda ash Na_2CO_3, magnetised water and lime milk, which was obtained by diluting 1 part of quicklime in 9 parts of water.

A methodology was developed to conduct the research. According to this methodology, rock samples were taken from the workings and mining blocks of the Inhulska ore mine of the Central Uranium Ore Deposit (Eastern Zone, Kropyvnytskyi), as well as an exploration core of quartzite with iron content, 43 mm in diameter, well H-445, open pit No. 3, Central Mining and Processing Plant, Kryvyi Rih.

The samples collected at Inhulska mine consisted of cube-shaped stufas with a linear edge size of ≈ 350 mm and cores with a diameter of 55–75 mm. They have a fractured structure with faults and a northward orientation of the ore deposit. Sampling was carried out in the areas not affected by blasting operations in the treatment blocks 1a-2-10t, 1a-5-1, 1a-2-1t, 1b-2-3t, 1a-9-1 of the Inhulska mine, Eastern Mining and Processing Plant.

Inhulska mine develops lenticular albite ore deposits up to 20 m thick with an angle of dip of 60 to 85° and strength of 10 to 15 points according to the Prof. M.M. Protodyakonov scale. The rocks are presented as a monolithic granite rock massif of complex tectonic structure containing biotite gneisses, migmatites and albites, which are difficult to blast, medium fractured, with strength from 12–18 to 20 points.

The description of rock samples treated with surfactants is given in Table 1.

Table 1 – Data on samples of surfactant-treated rocks selected for the study of physical and mechanical properties and explosion failure mechanism

No	Sampling location	Type of rock	Rock characteristics
1	Ingulska mine, Eastern Mining and Processing Plant, Central deposit, Eastern zone, mining blocks 1a-2-10t, 1a-5-1, 1a-2-1t, 1b-2-3t, 1a-9-1, area No. 3, 200-350 m altitude	Gneisses biotite	Complex structure with inclusions of quartz grains, difficult to blast, medium fracture, durable
2		Migmatites large and medium grain size	Migmatites, dark grey, coarse and medium grained, layered, strong
3		Granites pegmatoid	Pegmatoid granites of light pink to dark brown colour, massive texture, crystal structure with quartz, durable
4		Albitites on granites	Albitites on granites, pink, fine-grained structure with quartz, strong, tough, difficult to blast
5	Central Mining and Processing Plant, open pit No. 3, core diameter 43 mm, well H-445, Kryvyi Rih	Quartzite containing iron	Thinly laminated, fine-grained, fine-striped texture, durable

The models for the lab tests were manufactured on a stone cutting machine using a 450 mm diamond disc. For the tests, 15 cubic models with an edge size of 40 ± 2 mm were prepared (3 models for each type of rock). The faces of samples were processed with grinding powder, while their curvature did not exceed 0.05 mm. The control of the end surfaces (faces) of the samples was carried out with an indicator (caliper) along two mutually perpendicular faces. The deviation of the faces from parallelism was ±0.1 mm.

Tests of the physical and mechanical properties of the rocks of the ore deposit were carried out in accordance with the current State Standards [19–22], the results of which are presented in Table 2.

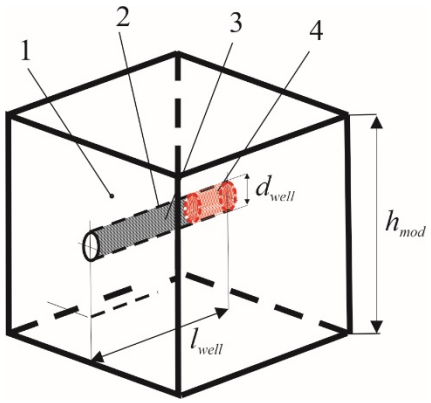
After producing the cubic models with sides h_{mod}, a cavity was formed in the centre of one of the surfaces (faces) – a well, where a charge of highly splashy explosive from a mixture of shadow and solid rocket fuel (SRF) of a solid structure with an initiator with a diameter d_{well} = 5 mm to a depth l_{well} = 2/3 h_{mod} was placed. The wellhead of the charge well is sealed with packing. The mass of explosive in the charge cavity was 0.150 g.

Fig. 1 shows the experimental model for laboratory tests.

Table 2 – Physical and mechanical properties of rocks from the Central uranium ore deposit (Ingulska mine, Kropyvnytskyi, Eastern Mining and Processing Plant) and quartzite with iron content (Central Mining and Processing Plant, open pit No. 3, Kryvyi Rih)

No series tests	Rock type	Density $\rho \cdot 10^{-3}$, kg/m^3	Uniaxial compressive strength σ_{st}, MPa	Extended wave velocity C_p, m/s	Transverse wave velocity C_s, m/s	Poisson's ratio, ν	Young's modulus E MPa	Strength coefficient f
*1	Gneisses biotite	2.72	150.7	4800	3300	0.07	10.0	14–20
*2	Granites pegmatites	2.6	150	6300	3600	0.25	17.6	11–14
*3	Migmatites coarse-grained and medium-grained	2.30	155	5300	3500	0.11	12.1	14–15
*4	Albites on Igmatites	2.75	245	6250	3750	0.2	2.95	16–20
*5	Albitites on granites	2.98	255	6380	3800	0.23	3.05	16–20
*6	Quartzite with content of iron	3.0	300.0	5600	2750	0.39	94.0	16–20

* Average results for each series of tests are given.



1 – cubic model; 2 – cavity simulating a well; 3 – packing; 4 – charge of explosives; h_{mod} – model height, m; d_{well} – well diameter, m; l_{well} – well length, m

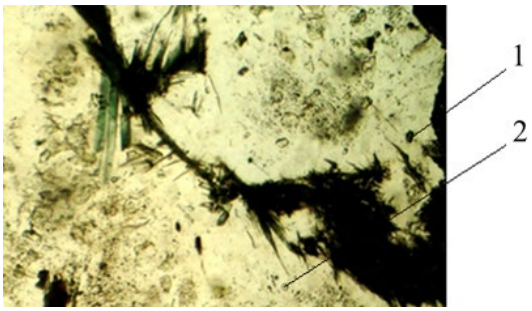
Figure 1 – Experimental model

Prepared samples were placed in different surfactant solutions for 24 hours. One of experimental samples was saturated with magnetic water. The control samples, which were not affected by surfactants, were dried in a laboratory drying oven at a temperature of 50º C for 24 hours. The prepared models were placed in an explosion chamber and remotely detonated by a capacitor explosive device – PIV-100M.

For the granulometric analysis of the destruction products, sets of laboratory sieves СЛ-200 №58 with holes with a diameter of 0.25 to 80 mm in diameter and a sieve analyser A30 according to the methods of Baron L.I. After separation of destruction products into fractions, the mass concentration of each fraction was determined using an electronic balance. The DRON-3 device was used for X-ray structural analysis of dust

particles (up to 100 μm) in the explosive destruction products. The structural features and mineralogical composition of rocks containing quartz (pegmatoid granite and ferruginous quartzite) were studied on transparent grinds using an electron microscope AD315 (maximum magnification 2000X).

Fig. 2 shows a microphotograph of the structure of pegmatoid granite with uranium content (Central deposit, Kropyvnytskyi)

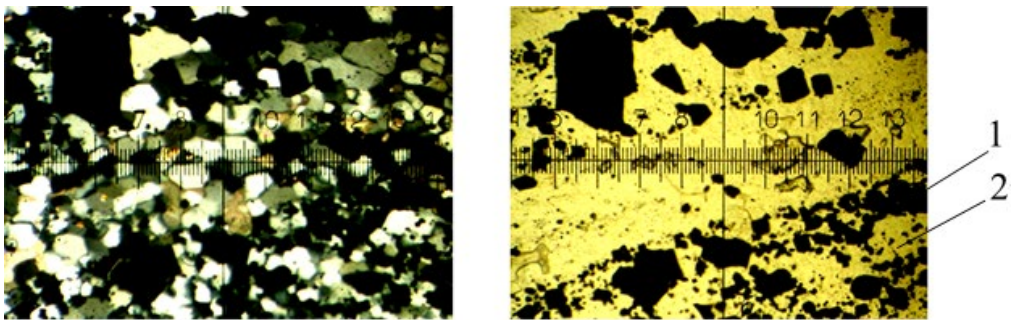


1 – uranium resin (dark grains); 2 – quartz (transparent grains)

Figure 2 – Structure micrograph of a light pink to dark brown granite with fine and medium-grained uranium (transparent grinding at 150X magnification)

The mineralogical composition of granite (Fig. 2): primary minerals - acidic plagioclase (albite-oligoclase No. 20–30) - 40–45%; alkaline amphiboles of green-brown ribecite group – 16%; colourless amphiboles of tremolite-actinolite group - 4%; quartz of mosaic structure with traces of granulation and healed microcracks in the form of subvertical strips of gas-liquid inclusions - 20–25%; secondary minerals - calcite in the form of pelitomorphic grains in feldspars, apatite (often located in the middle of accessory minerals), a small amount of dark brown biotite - 15%; accessory minerals - orthite (all in the middle of amphibole clusters), thorite in microcracks of plagioclase, sphene (all in the middle of accessory orthite and thorite) - 5%.

Fig. 3 shows a micrograph of a transparent grind of the structure of magnetite quartzite (Central Mining and Processing Plant, Kryvyi Rih)



a) *b)*

1 – magnetite (dark grains); 2 – quartz (transparent grains)

Figure 3 – Transparent grinding micrograph (150X magnification) of the structure of magnetite quartzite with thin stripes under polarised light (*a*) and through which light passes (*b*)

In Fig. 3, magnetite quartzite has a layered fine-grained texture. The strips of quartz grain aggregates are 300 to 400 μm thick, and individual quartz grains in a strip are 30 to 100 μm thick. There are no continuous strips of magnetite. Individual grains of magnetite ranging in size from 20 to 300 μm are wrapped in small quartz grains (20–50 μm).

Quartz and magnetite make up approximately 95% of quartzite minerals in a 1:1 ratio. Separate transparent ferrocalcite grains (no more than 0.5–1.0%) can be observed in the microscope field of view. There are no secondary changes.

The weighted average size of fine particles in the destruction products (μm) is determined by the formula

$$\bar{d} = \sum_{i=1}^{N} d_i \cdot f_i ,$$

where d_i = 0, 10, 20,…,100 μm - average diameter of the fraction (with an interval of 10 μm); f_i - fraction frequency.

The particle size sorting coefficient and the asymmetry coefficient are determined by the following formulas, respectively [18]:

$$S_0 = \sqrt{Q_{75} / Q_{25}} ;$$

$$S_k = Q_{75} \cdot Q_{25} \cdot Q_{50}^{-2} = Q_{75} \cdot Q_{25} \cdot Md^{-2} ,$$

where Q_{75}, Q_{25} and Q_{50} – are the quartile values of fine particle sizes, which make up 75, 25 and 50% of the total volume of fractions in the range from 0 to 100 μm, respectively; Md is the median particle size, μm.

The sorting coefficient S_0 varies in the range from 1 to 3 and characterises the uniformity of the medium's destruction when subjected to shock and blast loads. The asymmetry coefficient S_k characterises the symmetry of the distribution of particles with respect to their weighted average size.

3. Results and discussion

The results of a macrostructural study of granites containing uranium from the Central deposit showed that the intensity of microcracking of granites averages 60–75 microcracks per centimetre and they are characterised at the micro level by a high density of internal structure defects in the form of microcracks in quartz grains (Fig. 4).

The results of experimental studies on the destruction of pegmatoid granite and magnetite quartzite samples, dry and treated with surfactants, are given in Table 3 and Table 4.

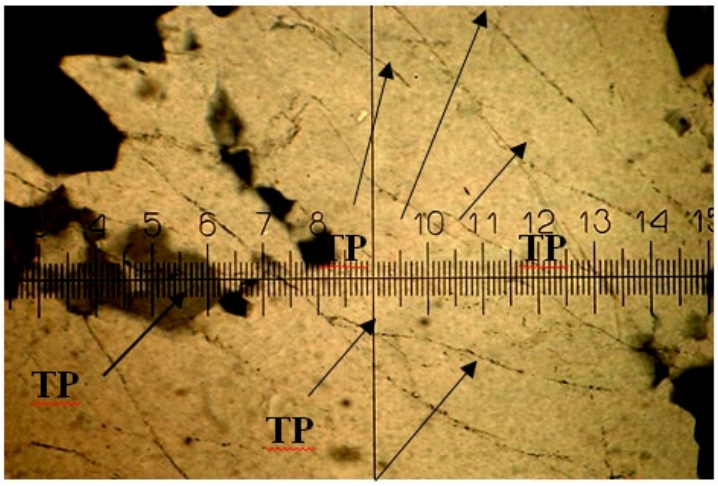


Figure 4 – Crack micrograph in quartz grains of light pink granite with uranium content at 240X magnification

Table 3 – Grain-size characteristics of explosive destruction products of pegmatoid granite samples treated with surfactants

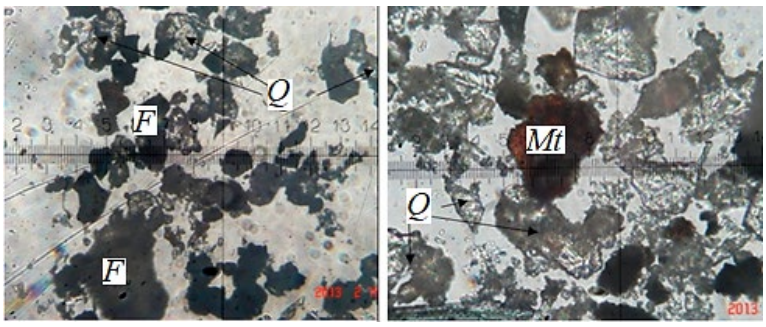
Surfactants	$\bar{d}$, μm	*Md*, μm	Q_{75}, μm	Q_{25}, μm	S_0	S_k
Dry samples	18.17	5.24	14.61	1.79	2.86	0.95
Magnetic water (pH= 7)	17.64	4.72	13.11	1.62	2.84	0.95
10% $NaHCO^3$ solution	16.82	3.56	10.36	1.20	2.94	0.98
10% Na_2CO^3 solution	27.62	12.22	31.57	4.31	2.71	0.91
Lime milk	17.36	4.56	12.94	1.57	2.92	0.98

Table 4 – Grain-size characteristics of explosive destruction products of magnetite quartzite samples treated with surfactants

Surfactants	$\bar{d}$, μm	*Md*, μm	Q_{75}, μm	Q_{25}, μm	S_0	S_k
Dry samples	16.21	3.68	10.46	1.25	2.89	0.97
Magnetic water (pH= 7)	18.98	5.12	14.56	1.74	2.89	0.97
10% $NaHCO^3$ solution	18.09	5.18	14.30	1.78	2.83	0.95
10% Na_2CO^3 solution	41.43	50.96	96.47	21.10	2.14	0.78
Lime milk	16.36	5.56	14.94	2.57	3.92	0.88

The microgranulometry data were processed by fitting the ex-experimental curves to two-parameter dependencies. Histograms of the fractional composition were constructed based on the sieve analysis data.

In the process of studying the fractional and mineralogical composition of the destruction products of quartz rocks (granites and ferruginous quartzites), it was found that the finely dispersed destruction products of pegmatoid granite samples (fraction up to 100 μm), untreated with surfactants, consist of 90–95 % elongated acicular fragments of quartz and feldspars (microcline and albite) (Fig. 5)



a) *b)*

Q – quartz, *F* – feldspar, *Mt* – magnetite

Figure 5 – Micrograph of destruction products of granites (*a*) and ferruginous quartzites (*b*) at 300X magnification

Small fragments of quartz and feldspar are present in the analysed samples in approximately equal proportions (Fig. 5, a).

The finely dispersed destruction products of untreated surfactant ferruginous quartzite consist of 95–99% quartz fragments. Fragments and grains of ore minerals, as well as mica, hydrochloride and amphiboles (magnetite, biotite, chlorite, etc.) are rarely observed in the microscope field of view. Their content in the destruction products of this rock does not exceed 1–5% (Fig. 5, b).

The microscopic study of the destruction products of granite and ferruginous quartzite samples treated with a concentrated Na_2CO_3 solution and a 10% $NaHCO_3$ solution revealed that quartz prevails in the composition of fine-dispersed particles of the fraction up to 100 μm, which is characterised by a more rounded shape compared to quartz particles of the same fraction for dry samples. That is, there are practically no sharp-angled fragments in the destruction products (Fig. 6).

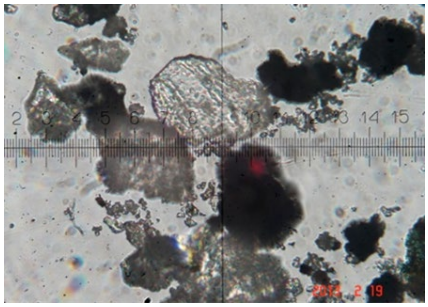
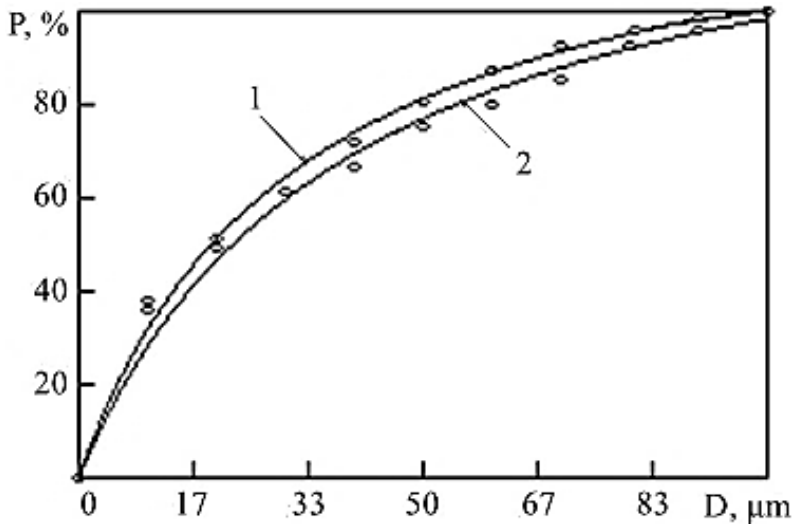


Figure 6 – Micrograph of ferruginous quartzite products treated with saturated Na_2CO_3 solution at 300X magnification

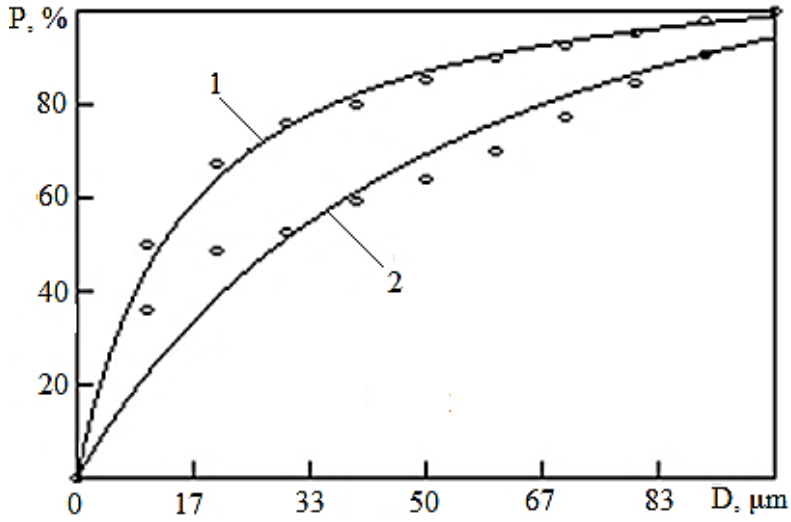
In Fig. 6, quartz is represented by light grains and magnetite by dark grains.

The granulometry of destruction products containing quartz (granites and ferruginous quartzites) allowed us to establish a significant increase in the average size of fine particles, as well as their median and quartile sizes for rocks treated with surfactants (saturated Na_2CO_3 solution).

Fig. 7 shows the results of destruction product distribution of rocks with quartz content, dry and after surfactant treatment.



a)



b)

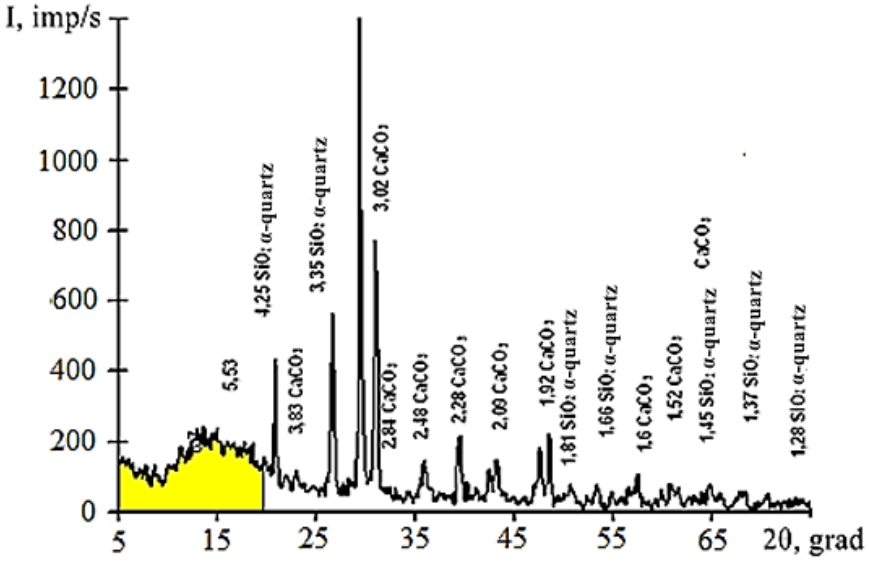
1 – dry samples; 2 – samples weakened by the action of surfactants (Na_2CO_3)

Figure 7 – Cumulative curves of grain-size distribution (up to 100 μm) of granite (*a*) and ferruginous quartzite (*b*) samples, destroyed by explosion

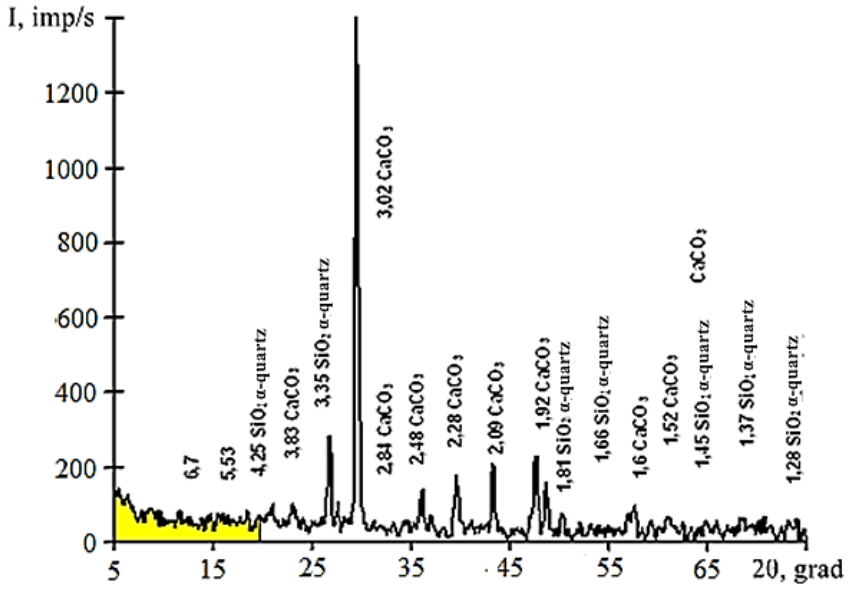
A qualitative assessment of fine particles in the destruction products of polymineral rocks (dry pegmatoid granite and surfactant-treated granite) was performed by X-ray diffraction analysis [23]. This method was used to study the smallest crystalline particles of quartz dust.

It was proved that the level of dissipative losses of explosive energy at the "explosive-polymineral medium" contact during the destruction of rock samples treated and untreated with surfactants is determined by a comparative analysis of total intensity of reflected X-ray beam in the "amorphization" zone, which is in range of angles

2θ = 5÷20º. The value of the total intensity I (imp/s) was determined from the diffractograms created in MS Excel (Fig. 8).



a)



b)

Figure 8 – X-ray diffractograms of fine granite particles pegmatoid granite (Ingulska mine at Cu-Kα radiation) for the explosion-damaged dry sample (*a*) and sample saturated with surfactant (*b*)

In Fig. 8, the darkened area represents the "amorphisation" zone. The more finely dispersed particles are present in the analysed sample, the higher the intensity of the measurement, the pulses delivered per second and the X-ray beam reflected from the particle.

The study and analysis of the granulometric and mineralogical composition of dynamic load destruction products of rocks exposed to surfactants (soda ash, sodium

bicarbonate, and magnetised water) indicate a change in the nature of polymineral fracture due to the treatment with surfactants. In addition, the formation of the smallest (dispersed) particles in the products of polymineral rock destruction (uranium and iron ores) can be reduced by using charges of different cross-sectional shapes. This creates conditions for differential rock loading along the length of the charge column. As a result, uniform crushing of limestone rocks is achieved due to the predominance of shear and tensile stresses, the contact area of the explosive with the surface of the blast drill bit is reduced, and larger dust particles are formed in the destruction products.

4. Conclusions

The research allows us to draw the following conclusions:

1. The intensity of microcracking in granites averages from 60 to 75 microcracks per centimetre. Microcracks are mainly formed in quartz grains.

2. The finely dispersed destruction products of pegmatoid granite samples not treated with surfactants consist of elongated acute-angled fragments of quartz and feldspar by 90–95%. At the same time, small fragments of quartz and feldspar are present in the analysed samples in approximately equal proportions.

3. The finely dispersed destruction products of untreated surfactant ferruginous quartzites consist of quartz fragments by 95–99%. The content of fragments and grains of ore minerals, as well as mica, hydro-mica and amphibole in the fracture products does not exceed 1–5%.

4. In the explosive destruction products of granite and ferruginous quartzite samples treated with a concentrated solution of Na_2CO_3 and 10% $NaHCO_3$ solution, there are finely dispersed quartz particles (up to 100 μm), which are characterised by a more rounded shape compared to quartz particles of the same fraction for dry samples.

5. During the explosive destruction of granite and ferruginous quartzite samples treated with Na_2CO_3 solution, a significant increase in the average size of fine particles, as well as their median and quartile sizes, occurs.

6. The nature of polymineral media fracture can be changed by treating them with surfactants. In addition, the formation of the smallest particles in the destruction products of uranium and iron ores can be reduced by using explosive charges of different cross-sectional shapes.

7. The level of dissipative losses of explosive energy at the contact "explosive - polymineral medium" is determined by a comparative analysis of the total intensity of the reflected X-ray beam in the "amorphization" zone, which is in the range of angles $2\theta = 5 \div 20^{o}$.

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About the authors

Ishchenko Oleksii, Candidate of Technical Sciences (Ph.D.), Associate Professor in Department of Construction, Geotechnics and Geomechanics, Dnipro University of Technology, Dnipro, Ukraine, ishchenkook@gmail.com, ORCID ***0000-0003-2449-5258.***

Novikov Leonid, Candidate of Technical Sciences (Ph.D.), Researcher in Department of Geomechanics of Mineral Opencast Mining Technology, M.S. Poliakov Institute of Geotechnical Mechanics of the NAS of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, lnov710@gmail.com, ORCID ***0000-0002-1855-5536.***

Ishchenko Kostiantyn, Doctor of Technical Sciences (D.Sc.), Senior Researcher in Department of Geomechanics of Mineral Opencast Mining Technology, M.S. Poliakov Institute of Geotechnical Mechanics of the NAS of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, ishenko_k@i.ua, ORCID ***0000-0003-2237-871X.***

Lohvyna Liudmyla, Junior Researcher in Department of Geomechanics of Mineral Opencast Mining Technology, M.S. Poliakov Institute of Geotechnical Mechanics of the NAS of Ukraine (IGTM of the NAS of Ukraine), Dnipro, Ukraine, ludmilalogvina2024@gmail.com, ORCID ***0000-0001-9910-6865***.

Kinash Roman, Doctor of Technical Sciences (D.Sc.), Professor, Doctor in Department of Geomechanics, Civil Engineering and Geotechnics, AGH University of Science and Technology (AGH UST), Krakow, Poland, rkinash@agh.edu.pl ORCID ***0000-0001-6715-9583.***

ВПЛИВ ПОВЕРХНЕВО-АКТИВНИХ РЕЧОВИН НА ПРОЦЕС ВИБУХОВОГО РУЙНУВАННЯ ПОЛІМІНЕРАЛЬНИХ ГІРСЬКИХ ПОРІД

Іщенко О., Новіков Л., Іщенко К., Логвина Л., *Кінаш Р.*

Анотація. Процес вибухового руйнування гірських порід залежить від їх складу, характеру розподілу мінеральних зерен, концентрації мікротріщин та їх орієнтації, присутності газоподібної та рідкої фази. Поверхнево-активні речовини використовуються для підвищення ефективності руйнування гірських порід за допомогою динамічних і вибухових навантажень. При цьому підвищення ефективності руйнування досягається за рахунок адсорбційного зниження поверхневої енергії твердого тіла, що призводить до утворення мікротріщин та зниження міцності гірських порід. Насичення гірських порід розчинами поверхнево-активних речовин визначається мірою кислотності розчинів, пористістю гірських порід, вмістом рідких та газоподібних компонентів, а також напруженим станом. Відомо, що розчини поверхнево-активних речовин можуть приводить до зниження міцність гірських порід на 20–50% та концентрації зважених частинок пилу. При цьому зниження міцності виникає, коли ентальпія хімічних реакцій твердого тіла з активною речовиною становить кілька десятків кілоджоулів на моль. В роботи наведено метод експериментального моделювання вибухового руйнування гірських порід з урахуванням впливу поверхнево-активних речовин. Встановлено, що мікротріщинуватість гранітів характеризується високою щільністю дефектів внутрішньої будови у вигляді мікротріщин в зернах кварцу. Зокрема, дрібнодисперсні продукти руйнування зразків граніту пегматоїдного, які необроблені поверхнево-активними речовинами, переважно складаються з витягнутих гострокутних уламків кварцу та польових шпатів (мікрокліну та альбіту). В результаті дослідження продуктів руйнування вибухом зразків гранітів та залізистих кварцитів, оброблених концентрованим розчином карбонату натрію та 10% розчином гідрокарбонату натрію встановлено, що у складі дрібнодисперсних твердих частинок превалює кварц, якій має більш округлу форму в порівнянні з частинками кварцу для сухих зразків. Тобто в продуктах руйнування практично не спостерігаються гострокутні уламки. Встановлено, що при вибуховому руйнуванні зразків гранітів та залізистих кварцитів, оброблених розчином карбонату натрію, відбувається істотне збільшення середнього розміру дрібнодисперсних частинок, а також їх медіанного та квартильних розмірів. Встановлено, що характер руйнування уранових і залізних руд може бути змінений шляхом їх обробки поверхнево-активними речовинами. Крім цього, утворення дрібнодисперсних частинок у продуктах руйнування можуть бути зменшені при використанні зарядів вибухової речовини з різною формою перерізу.

Ключові слова: гірська порода, поверхнево-активна речовина, вибухове руйнування, мікротріщини, дрібнодисперсні частинки, гранулометричні характеристики