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SUBSTANTIATION OF RESEARCH RESULTS ON ENERGY EFFICIENCY OF BASALT CRUSHING

Purpose. To experimentally determine the main design and operational parameters of the influence of rock mass properties on the Roller Crusher performance when processing basalt rock mass.

Methodology. The crushing and grinding of basalts are studied by the methods of mathematical statistics in order to identify the results obtained and determine the dependences of technological parameters on the mechanical impact factors. Experimental studies are carried out on the example of basalts from the Rafalivskyi quarry in the Rivne region.

Findings. It has been revealed that the elemental composition of rocks in the benches of basalt quarries has a different mineral composition. Experimental studies of the rock crushing results have determined the efficiency of using screening for crushing basalts. The experimental dependences of the roller crusher performance in crushing and grinding modes on the properties of the rock mass have been obtained.

Originality. The value of crushed rock fractal joints has been found, when using cone and centrifugal crushers, which is characterized by the shape factor and fractal dimension *D*. For cone crusher $K_f = 2.1–5.0$ and $D = 1.4$. For centrifugal crusher $K_f = 1.5–1.8$ and $D = 1.17$. These parameters testify to the energy feasibility of using centrifugal crushers. The high value of the multiple correlation coefficients R^2 and Fisher criterion *F*, whose value at a significance level of 0.05 is higher than the critical one, indicates a sufficient convergence between the experimental and theoretical results and the accuracy of the obtained analytical dependences.

Practical value. The generalized models for determining the Roller Crusher performance, obtained for each rock type, based on significant factors, greatly facilitate the choice of parameters for crushing and grinding processes, and also allow choosing a rational mode of crusher operation.

Keywords: *basalt, puff-stone, crusher, energy efficiency, screening, rock mass, destruction*

Introduction. Intensive quarrying of basalt deposits is conducted in Ukraine. It is mainly concentrated in the western area of the country and most widely – in Rivne region [1]. The basalt mined in this process is used in construction. At the end of the last century, geologists of the Rivne expedition revealed a high content of valuable metals in the basalt compositions, as well as the accompanying puff-stones and lava breccia in the deposit [2]. However, basalt is currently used only for construction purposes, while puff-stone and lava breccia are dumped. At the same time, these components of the deposit are ore-bearing and can be involved in processing, since, despite the differences in structures and physical-mechanical properties, they contain native copper, iron and titanium in quantities suitable for commercial production [3].

The heterogeneous structure of the deposits, the variety of forms of mineralization and the mineral composition of the rock, even with the current level of knowledge, necessitate an integrated approach to the development of deposits. Moreover, this applies both to the technology of mining and processing [4], and to the use of final products [5, 6].

Let us study the possible reasons for the formation of reticular (or other) planes in the studied basalt. There are two main, well-known reasons for changing the structure, composition and properties of rocks: temperature and pressure [7]. The temperature of the basaltic lava, according to available data, is in the range of 900–1200 °C. The multi-meter trap formation will naturally cool for some time to the temperature existing in the earth's crust upper layers (about 20 °C). In the process of cooling, partial crystallization occurs according to a well-known scheme: from refractory to fusible minerals (in basalts, there are microliths and crystallites, crystal nuclei). In addition, the cooling process is characterized by a decrease in the volume of the matter [8].

The columnar structure formation of basalts as a result of convection processes during the cooling of molten basalts was explained by the French scientists Rayleigh and Benard. The basalt joint is called columnar, because the length of the formed pillars significantly exceeds the horizontal size of hexagons or pentagons. A detailed study on basalt pillars shows that they are divided by subhorizontal fracturing into relatively comparable blocks with a height approximately equal to their horizontal dimensions [9].

Basalt is currently mined for crushed stone. The technological mining scheme includes overburden operations (thickness of the sandy-chalky overburden layer is 2–5 m), drilling of wells according to the certificate of drilling-blasting operations, blasting of the face with subsequent excavator loading into vehicles for delivery to the crushing and screening site. Crushed stone as a commercial product is obtained in three grain size classes (–10; 10–20; 20–40 mm) using gear, cone, centrifugal crushers and vibrating screens.

Literature review. According to empirical studies, the most effective rock mass destruction into joints occurs in centrifugal crushers and mills [10]. For example, centrifugal crushers are used to produce cube-shaped crushed stone with relatively low energy consumption. The destruction of the ore body rock containing the metal nuggets occurs without crushing metal inclusions [11]. Destruction in this case obviously occurs along the so-called reticular planes, characterized by the number of nodes (atoms, ions) of a flat lattice per unit of its plane (in accordance with the Bravais hypothesis). Obviously, this rule extends not only to crystals, but also to rocks in general [12]. The results obtained require additional applied and theoretical research. A brief review of the theoretical aspects and analysis of existing ideas about the rock joints indicates the relevance and prospects of such research. The studies of recent years testify to the effectiveness of taking into account the structure of deposits when substantiating the parameters of their mining and processing [13, 14].

Unsolved aspects of the problem. Taking into account the above technological peculiarities, M. S. Polyakov Institute of Geotechnical Mechanics NAS of Ukraine has developed an intra-roller cone mill, which allows limiting the fineness of grinding finely disseminated ore [15]. This mill prepares it, and the task of this process is to provide the initial fineness for grinding in a specially designed centrifugal mill. In this mill, the metal inclusions of native copper are not crushed, but only exposed to deformation, while the rocks containing them are crushed to the micron level, releasing finely disseminated copper inclusions [16]. The centrifugal mill is unloaded onto a vibrating screen of fine classification with the purpose of separating nuggets (oversize product) from waste rock (undersize product). A normal vibration mode stability in conservation non-linear system is discussed in the paper [17]. The subsequent process operation is in separating nuggets from intergrown pieces by electrical separation or metallurgical redistribution. Crushed basalt after screening on a screen is a valuable chemical raw material (basalt casting, thermal-insulation wool, etc.).

The previously studied aspects of the problem of natural rock fracturing and the impact of various natural and technogenic factors on this process [18, 19], as well as the determined patterns of fracturing of quarry benches throughout the height with the formation of rock joints [20, 21] indicate the theoretical and practical possibility of using the natural rock properties to reduce the energy consumption for their destruction, improving the opening of ores and the recovery of minerals.

Results. In the research process, the fact of the influence of lumpiness on the energy intensity and performance of crushing and grinding is determined. The physical difficulty is in the fact that in the transition from coarse grinding to fine grinding, the total surface area of the crushed rock mass (ore) increases several times and even orders of magnitude. As a result, energy consumption for the process of ore preparation and ore body opening increases. It is known, for example, that the electricity consumption for grinding is 94.2 % of its total consumption for all stages of ore preparation. The remaining 5.8 % are the costs for drilling the wells (0.4 %), blasting destruction (4.9 %), crushing (0.5 %) of the total electricity consumption. Therefore, when planning the ore preparation process, the consideration of the large-scale (by the size of pieces) effect of strength, as well as using the idea of preliminary weakening of the lumpy rock mass through increased fracturing, contribute to the organization of large, medium, fine crushing and grinding operations on new principles. At present, cone inertial and shock-roller centrifugal impact crushers have already been created, in which the lumpy mass is not crushed, but deformed, which contributes to the development of a network of fractures and its weakening. These factors, however, are not sufficiently taken into account in the rock destruction methodologies.

Based on the above considerations, experimental studies on crushing the Rivne basalts by various crushers and the analysis of the results obtained have been performed, designed to show the possibility of using the patterns of formation of quasi-crystals to solve an important practical problem – the destruction of matter into joints of such sizes that are inherent in nature itself, that is, with less energy consumed.

Experimental studies are carried out on the example of basalts from the Rafalivskyi quarry in the Rivne region. The quarry has an overburden from 2 to 7 m, represented by light gray calcareous marl loams. The height of the basalt bench face is from 16 to 20 m. The rock is greenish-gray in color, highly-fractured, with well-defined columnar joint and mineralization of iron hydroxides, zeolites, siliceous and other minerals along fractures, as well as locally concentrated point, vein inclusions of native copper. The subvertical hexahedral (or pentahedral) columnar joint characteristic of basalts is complicated by numerous secondary joint, mainly prismatic, less often pyramidal in shape.

The basalt destruction in centrifugal and cone crushers makes it possible to obtain crushed stone with various shapes.

This schematic thesis can be explained in more detail as follows. The centrifugal crusher principle is based on rotating the rotor and giving a piece of rock a certain velocity, at which the specified piece hits the wall (one contact side), while breaking down into smaller fragments. It is this part of the process that needs to be studied in more detail, since these small fragments, for the most part, have regular geometric shapes. For a cone (jaw, roller, etc.) crusher, the destruction process during compression is characteristic, that is, two contact sides are involved. A detailed analysis is presented below.

In the processes described, the history of the given piece formation, its textural and structural peculiarities are realized as much as possible. Currently, the literature describes reticular planes that have been formed in the process of evolutionary structuring, according to Bravais law. It should be noted that, according to this law, the faces with the densest planar networks predominate on the crystal surface. The statement refers to the crystalline form of the matter, and basalt, as is known, does not apply to those. Nevertheless, the scientific direction studying the problems of the matter destruction is based on a well-known fact: where it is thin, it breaks there. In other words, the rock piece destruction occurs along weakened zones, which obviously exist in the studied rock. Such zones may include such a textural feature as stratification, which, in turn, is represented by a different mineralogical composition, different structure or a complex of these factors. However, in our case, this factor is absent; basalts have a relatively homogeneous, massive texture.

In the course of the research, the sizes of basalt pieces are analyzed after two types of crushers: cone medium crushing and centrifugal, which are set at the same crushing and screening site. The parameters measured are: length – a, width – b, thickness – c. These sizes, as well as their ratios are presented in Table 1. The calculated values are the shape factor K_f of the pieces and their fractal dimension D. The shape factors are the aspect ratio, and the fractal dimension is determined in accordance with the Freder E. methodology using the logarithmic method. The essence of the fractal dimension calculation method is as follows. For example, crushed pieces are selected after a centrifugal crusher from five pieces with their sizes:

1) $a = 46.4$ mm; $b = 16.8$ mm; $c = 15.9$ mm;
2) $a = 27.0$ mm; $b = 23.5$ mm; $c = 13.0$ mm;
3) $a = 33.8$ mm; $b = 15.9$ mm; $c = 14.7$ mm;
4) $a = 20.3$ mm; $b = 15.5$ mm; $c = 10.0$ mm;

5) $b = 29.7$ mm; $b = 21.1$ mm; $c = 17.1$ mm.

The volumes are calculated ($v = a \cdot b \cdot c$) of each piece (crystal): $v_1 = 1{,}234.4$ mm^3; $v_2 = 8{,}245.5$ mm^3; $v_3 = 7{,}900.1$ mm^3; $v_4 = 31{,}467.5$ mm^3; $v_5 = 10{,}716.1$ mm^3.

The max and min values of crystal volumes are chosen: $v_{max} = 12{,}394.4$ mm^3; $v_{min} = 3{,}146.5$ mm^3.

The natural logarithm of max and min values is found: $\ln v_{max} = \ln 12{,}394.4 = 9.425$; $\ln v_{min} = \ln 3{,}146.5 = 8.054$.

The fractal dimension is calculated

$$D = \frac{\ln \nu_{max}}{\ln \nu_{min}} = \frac{9.425}{8.054} = 1.17.$$

The average statistical calculated coefficients of shape and fractal dimensions of basalt pieces after centrifugal and cone crushers are presented in Table. Using the methods for determining the matter fractal dimensions (Academician Sadovsky M.A. distribution method), the hierarchy methods, it is possible with a sufficiently high degree of accuracy to predict the crushed matter sizes in order to obtain the maximum opening of ores, the optimal yield of middling product with fractions (the level of mineral opening). This is a method for studying jointing (fracturing) that is, structural heterogeneity.

By analyzing the data given in Table, a significant increase in the shape factor of basalt pieces obtained in a cone crusher can be observed. The fractal dimension value is also higher for the destruction products of a cone crusher compared to a centrifugal crusher and indicates a complication of the obtained shape structure. The basalt pieces after the centrifugal crusher have shape factors from 1.5 to 1.8. Thus, the shape tends to be isometric, which significantly affects the industrial product yield towards its increase (on average by 20 % for a size of 20 mm).

The basalt pieces after the cone crusher have shape factors from 2.1 to 5.0. Thus, the shape tends to be anisometric, acute-angled. The fractal dimension is also significant (1.40).

Thus, a centrifugal crusher gives the pieces a simpler shape (closer to the cube), which is energetically favorable and inherent in nature. The fractal dimension is, accordingly, minimal. A cone crusher gives the pieces a more complex shape (technological factors are superimposed on natural factors). The fractal dimension is, accordingly, higher.

The fractal dimension analysis of basalt pieces taken from the quarry after blasting destruction revealed the following distinguishing features. Three fractions of joints with average sizes are statistically selected: $a_1 = 350$ mm; $a_2 = 90$ mm; $a_3 = 17–20$ mm. The fractal dimensions of each of the samples are determined using the logarithmic method. The fractal dimensions of these fractions are, respectively

$$D_1 = 1.16; \quad D_2 = 1.56; \quad D_3 = 1.85.$$

According to the ideas presented in the works, with a decrease in the average size of quasi-crystals, the structure becomes more complex and tends to a bulk form, but a dimension value of less than 2.0 indicates the clastic nature of the obtained pieces (a system of weakly bound particles).

The fractal dimension of fractions after crushing plants is: after the centrifugal one – $D = 1.17$; after the cone one – $D = 1.4$. Thus, fractality reflects the degree of structure (shape) complication of basalt pieces obtained by different methods of destruction. This fact is logical, since natural patterns are formed with a minimum amount of energy consumed. This nature "rationality" was formulated by the French scientist Le Chatelier. The Le Chatelier–Braun principle of braking resistance states that any equilibrium system tries to maintain its equilibrium state and responds to changes in one of the three equilibrium factors – temperature (T), pressure (P), heat capacity (C) – by the occurrence of such a process within the system that seeks to cancel the impact of this factor.

Table

Results of calculating the shape and fractality coefficients of basalt pieces obtained by different crushing methods

Crusher type	Shape factors			Fractal dimension, D
	a/b	a/c	b/c	
Centrifugal	1.5	1.8	1.5	1.17
Cone	2.1	5.0	2.5	1.40

From here the result obtained is as follows: during the destruction by the impact method (one contact side), the simplest and energy-efficient shape is formed in the process of destruction or laid down by nature itself during the cooling process. In the process of destruction by the compression method (two contact sides), the structure and shape of rock pieces become more complicated, which is fixed by the fractal dimension. The blasting affects with an additional energy factor on the size and shape. The smaller the particle, the more impacted the rock, the greater the fractal dimension.

Roller crushers are widely used in ore preparation technological schemes of rock mass for beneficiation. Depending on the mode, they provide both crushing and grinding of the rock. As a rule, this equipment has a low performance, but it is quite sufficient for the conditions of the experimental site planned for processing of raw materials from basalt quarries.

When analyzing the energy efficiency of ore preparation of basalt raw material from quarrying, which contains basalt, lava breccia and zeolite-smectite puff-stone, it becomes necessary to determine the degree of influence of various factors on the roller crusher performance. This is important for the subsequent modeling of the process and predicting its rational parameters both at the design stage and during further operation.

The research purpose is to experimentally determine the main design, operational parameters and the influence of rock mass properties on the roller crusher performance when processing basalt rock mass.

In the experiments, the following parameters are variable:

1 – roll diameter (D, mm);

2 – size of a piece loaded into the crusher (ρ, mm);

3 – roll length (L, mm);

4 – slot size between rolls ($\Delta\rho$, mm);

5 – crushed material density (γ, g/cm^3): for puff-stone $\gamma = 1.4$, for lava breccia $\gamma = 2.2$, for basalt $\gamma = 2.4–2.6$, for titanomagnetite inclusions $\gamma = 4.0$ (t/m^3);

6 – roll rotation frequency (ω, rpm).

The research is conducted on an experimental roller crusher with replaceable rolls, adjustable drive speed and discharge slot within the limits of fine crushing and grinding.

One of the important factors influencing the crusher performance is the roll rotation frequency. For crushers of mass production at various plants and firms, it is determined within the range of 100–300 rpm.

In the studied case, the rational frequency is determined experimentally. The nature of $Q = f(\omega)$ dependence is shown in Fig. 1 for all four types of basalt rock mass.

As it can be seen from Fig. 1, the function extremum is within $\omega = 120$ rpm. It is this drive frequency that is adopted in further studies on the choice of influencing factors. The research is performed with the following crusher parameters: $L = 400$ mm; $D = 600$ mm; $\omega = 120$ rpm – var; $\Delta_k = 30$ mm $= \rho$; $\Delta\rho = 3$ mm.

It is known that from the point of view of choosing the angle of capture of pieces by rolls during crushing and the friction coefficient of rolls with rock mass, the diameter of the rolls should be approximately 20 times larger than the crushed piece size. In the studied ore preparation scheme of raw material, the rock mass is supplied to the roller crusher after the jaw crusher, with a particle size of not more than 30 mm. However, the rock mass characteristics are different, so it is important to determine the nature of the dependence of performance on the crusher roll diameter.

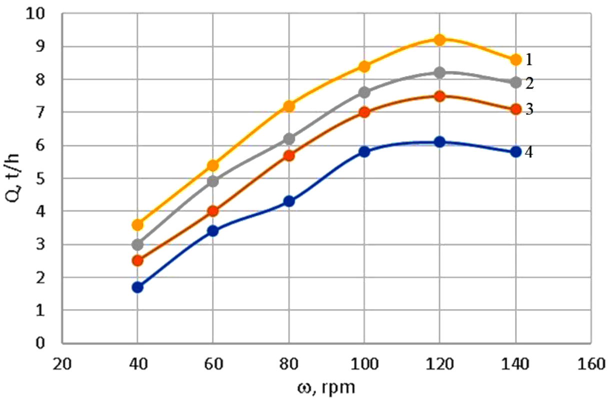

Fig. 1. Dependences of the crusher performance on the roll rotation frequency:

1 – for puff-stone; 2 – for lava breccia; 3 – for basalt; 4 – for rocks with titanomagnetite inclusions

The research is performed with the following crusher parameters: $L = 400$ mm; D – var; $\omega = 120$ rpm; $\Delta\rho = 30$ mm $= \rho$; $\Delta\rho = 3$ mm. The research results of this dependence are shown in Fig. 2.

The dependence is non-linear and indicates the expediency of using the roll diameter $D = 600$ mm for further research.

The size of the crusher's discharge slot, determined by the spacing between the rolls, has a significant impact on the performance of the control size class. Experimentally, this characteristic is determined on a crusher with a roll length $L = 400$ mm with a variation of $\Delta\rho = 3.0–12.0$ mm. It has been found that the dependence of performance on the discharge slot size is almost linear for rocks of low density, up to $2.4 \cdot 10^3$ kg/m^3. With an increase in density $(2.4–4.0) \cdot 10^3$ kg/m^3, the dependence acquires a slightly parabolic character (Fig. 3). The research is performed with the following crusher parameters: $L = 400$ mm; $D = 600$ mm; $\omega = 120$ rpm; $\Delta_k = 30$ mm $= \rho$; $\Delta\rho = 3–12$ mm – var.

Technologically, performance significantly depends on the length of the rolls L. Therefore, further, the dependence of the performance on the length of the rolls $Q = f(L)$ is determined experimentally (Fig. 4).

According to the data shown in Fig. 4, this dependence is linear within the variation range of $L = 100–600$ mm at a constant diameter of the rolls and their rotation.

Further research is related to studying the nature of dependence of the crusher performance on the loaded rock mass size at a constant discharge slot width $L = 3.0$ mm, constant length of the rolls $L = 400$ mm and their diameters $D = 600$ mm.

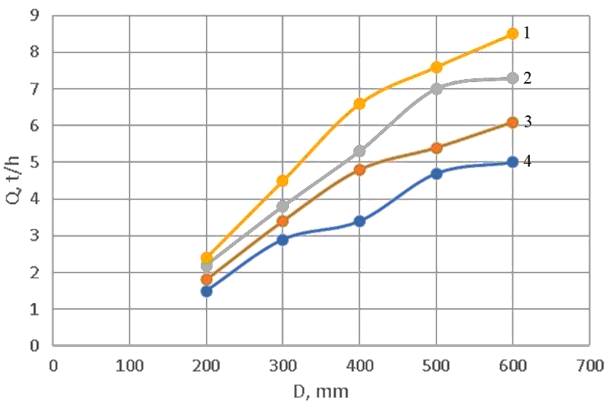

Fig. 2. Dependences of the crusher performance on the roll diameter:

1 – for puff-stone; 2 – for lava breccia; 3 – for basalt; 4 – for rocks with titanomagnetite inclusions

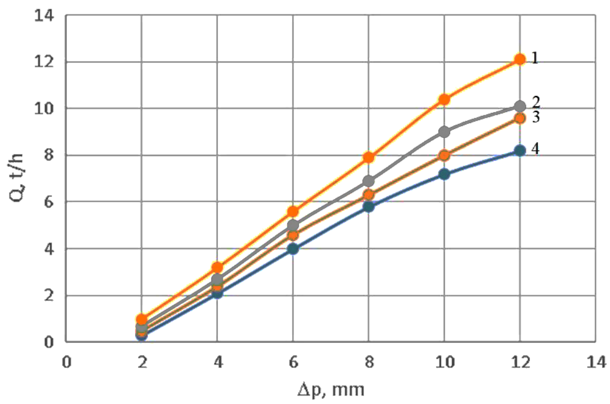

Fig. 3. Dependences of the crusher performance on the size of the slot between the rolls:

1 – for puff-stone; 2 – for lava breccia; 3 – for basalt; 4 – for rocks with titanomagnetite inclusions

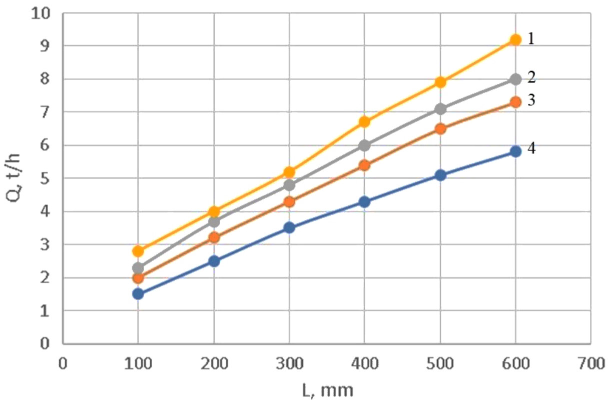

Fig. 4. Dependences of the crusher performance on the length of the rolls:

1 – for puff-stone; 2 – for lava breccia; 3 – for basalt; 4 – for rocks with titanomagnetite inclusions

The nature of the experimental dependence obtained is shown in Fig. 5. It can be seen that it has a weak non-linear form for all four types of the studied rock mass and shows that an increase in the rock mass density by 2–3 times reduces the crusher performance by 25–30 %.

When the crusher is switched from a fine crushing mode to a grinding mode by reducing the discharge slot width between the rolls to $\Delta\rho = 0.5$ mm, its performance decreases according

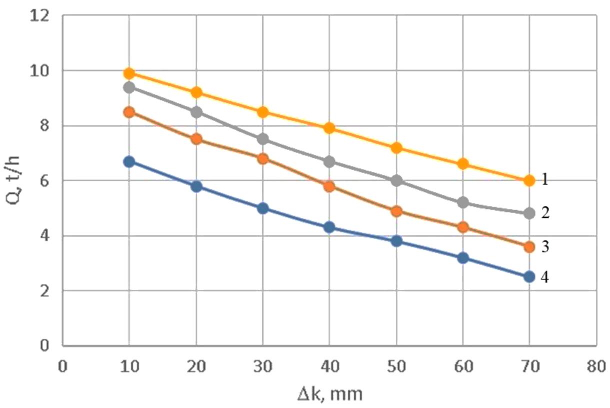

Fig. 5. Dependences of the crusher performance on the crushed rock mass size:

1 – for puff-stone; 2 – for lava breccia; 3 – for basalt; 4 – for rocks with titanomagnetite inclusions to a weak non-linear law for all grain sizes of the loaded material. The results of this research are presented in Fig. 6.

Thus, the experimental dependences of the roller crusher performance in crushing and grinding modes on six main parameters have been obtained (Figs. 1–6). It has been determined that all the selected factors of these dependences are significant, and each of them can be selected as a regulatory element for managing the ore preparation process for setting the optimal parameters for the crushing or grinding process, with known optimization criteria.

The dependences obtained as a result of the performed research served as the basis for the development of generalized process models, namely, they made it possible to develop generalized models for each rock mass for the performance of the type

$$Q = f(L, D, w, \rho, \Delta_{\rho}, \gamma). \quad (1)$$

The following generalized roller crusher performance models have been developed:

- for puff-stone

$$Q_{tuff} = 2.167 - 0.00086 \cdot \omega^2 - 0.00089 \cdot \rho^2 - 0.000024D^2 + $$
$$+ 0.000062LD + 0.0263\omega\Delta + 0.0007 \cdot \omega\Delta; \quad (2)$$
$$R^2 = 0.981; \quad F = 183.2;$$

- for lava breccia

$$Q_{l/breccia.} = 1.741 - 0.00078 \cdot \omega^2 - 0.00083 \cdot \rho^2 - 0.024\Delta^2 -$$
$$- 0.000057LD + 0.0032 \cdot \omega\Delta + 0.00052 \cdot \omega\Delta; \quad (3)$$
$$R^2 = 0.979; \quad F = 134.5;$$

- for basalt

$$Q_{bas.} = 3.27 - 0.085 \cdot \rho^2 - 0.0007 \cdot \omega^2 - 0.000022D^2 +$$
$$+ 0.00005LD + 0.021 \cdot \omega\Delta + 0.00057 \cdot \omega\Delta; \quad (4)$$
$$R^2 = 0.971; \quad F = 146.1;$$

- for titanomagnetite agglomerations

$$Q_{tit/magn.} = 1.62 - 0.066 \cdot \rho^2 - 0.0066 \cdot \omega^2 - 0.026 \cdot D^2 -$$
$$- 0.000013D^2 + 0.00004LD + 0.029 \cdot \omega\Delta + 0.0004 \cdot \omega\Delta; \quad (5)$$
$$R^2 = 0.982; \quad F = 188.4.$$

The high value of the multiple correlation coefficients R^2 and Fisher criterion F, whose value at a significance level of 0.05 is higher than the critical one, indicates a sufficient convergence between the experimental and theoretical results and the accuracy of the obtained analytical dependences (2–5).

The generalized models obtained for each of the rock types for determining the roller crusher performance from significant factors greatly facilitate the choice of crushing and grinding process parameters and allow choosing a rational crusher operation mode.

Conclusions. The analysis of the result of crushing by different methods is, in fact, a confirmation that the second method (cone crusher) is based on the irrational consumption of impact energy during destruction. In addition, the yield of an industrial product is significantly reduced (about 40 % after the centrifugal one, about 26 % after the cone one), which, in combination with a significant metal consumption (several times) of crushing equipment for destruction by compression method, indicates the inexpediency of using this method and equipment for industrial purposes. The efficiency of screening and the quality of rock mass crushed in a centrifugal crusher are higher due to the absence of flaky (elongated) material. The obtained results on crushers make it possible to use centrifugal crushers as the basis for an energy-efficient basalt ore processing complex at the Rafalivskyi quarry in the Rivne region (Ukraine).

The main type of basalt mining is open-pit mining in quarries for the production of construction crushed stone and facing tiles. However, the presence of a stratified rock structure with various mineralogical composition in the thickness of basalts, in which, in addition to native copper of various dissemination, there are valuable metals of industrial interest, and the host rocks are valuable chemical raw materials, the studied deposits require comprehensive development both in terms of the mining method and use of mined raw material.

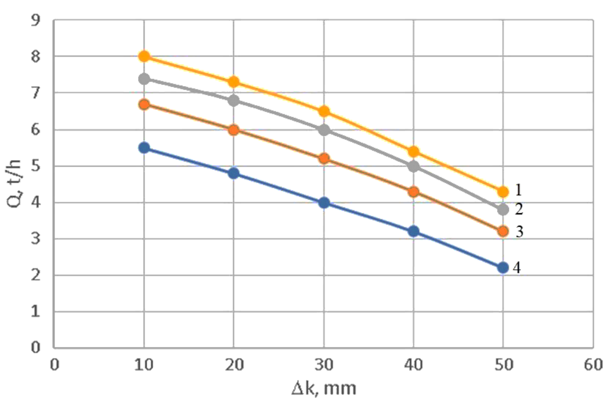

Fig. 6. The nature of the change in the crusher performance when switching to the grinding mode (Δρ = 0.5 mm) with titanomagnetite inclusions

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Обґрунтування результатів досліджень енергоефективності подрібнення базальту

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Мета. Експериментальне визначення основних конструктивних і режимних параметрів впливу властивостей гірської маси на продуктивність валкової дробарки при переробці базальтової гірської маси.

Методика. Дослідження із подрібнення базальтів проводилися з використанням методів математичної статистики для ідентифікації отриманих результатів і встановлення залежності технологічних параметрів від впливу механічних факторів. Експериментальні дослідження виконані на прикладі базальтів Рафалівського кар'єру Рівненської області.

Результати. Встановлено, що елементний склад породи уступів базальтових кар'єрів має різний мінеральний склад. Експериментальні дослідження результатів дроблення породи визначили ефективність використання грохочення для дроблення базальтів. Отримані експериментальні залежності продуктивності валкової дробарки в режимі дроблення й подрібнення від властивостей гірської маси.

Наукова новизна. Встановлена величина фрактальних окремостей подрібненої породи на конусній і відцентровій дробарках характеризується коефіцієнтом форми та фрактальною розмірністю *D*. Для конусної дробарки $K_f = 2{,}1–5{,}0$ і $D = 1{,}4$. Для відцентрової дробарки $K_f = 1{,}5–1{,}8$ і $D = 1{,}17$. Ці параметри свідчать про енергетичну доцільність використання відцентрових дробарок. Високе значення коефіцієнта множинної кореляції R^2 та критерію Фішера *F*, величина якого при рівні значущості 0,05 вище критичної, свідчать про достатній збіг експериментальних і теоретичних результатів і про достовірність отриманих аналітичних залежностей.

Практична значимість. Отримані для кожної із порід узагальнені моделі для визначення продуктивності валкової дробарки за значущими факторами значно полегшують вибір параметрів процесу дроблення та дозволяють вибрати раціональний режим роботи дробарки.

Ключові слова: *базальт, туф, дробарка, енергоефективність, грохочення, гірська маса, руйнування*

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