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Specifics of Studying Crushability of Construction Rocks

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Abstract

Objectives: The existing techniques of studying crushability of rocks are based on the determination of power consumption and aggregate size of the resulting products. Given that during disintegration of the construction rocks it is required to retain rock strength in the crushed stone grains, to improve methodology for crushability assessing is an urgent task. **Method:** When choosing a method to study crushability of rocks it should be considered that the processes of disintegration in various crushing machines have different mechanisms of action, the most accurate forecast figures are provided by the technique using the destruction mechanism similar to an industrial crusher. A deformation field is created in the entire volume of the body under the load, which leads to a change in the structure and strength of the products formed. In this regard, the strength of crushed stone grains being a final product of disintegration is introduced as an additional indicator that characterizes crushability of rocks. **Findings:** The article presents the results of studying crushability of construction rocks by different methods. It was found that porosity, particle size, grain shape and loading effort application rate are the factors affecting the strength of crushed stone grains. Mechanical stresses undergone by the rocks during blasting and disintegration result in increased porosity and, consequently, reduce strength. Theoretical dependence of increased strength while reducing the fraction size appears for gabbro-diabases being homogeneous in texture. For granites that are non-uniform in composition and texture there is no unique relationship between the strength and the fraction size. Increased grain cubicity of crushed stone enhances its strength. The study of the crushing kinetics revealed that with decreased loading rate the strength of granite crushed stone having high porosity is reduced, while the strength of the low-porous crushed stone made of gabbro-diabase remains practically unchanged. When choosing a crushing method, either shock or static one, it is necessary to take into account, first, the size of the crushed objects and, second, mineral composition and texture-structural features of the rocks. **Improvements:** The results obtained are of practical value in selecting rational processing technology and relevant equipment, as well as in the crushing process management to reduce energy costs and improve product quality.

Keywords: Crushability, Crushed Stone, Disintegration, Rocks, Strength

1. Introduction:

To assess energy consumption and determine the result of splitting – aggregate size of the obtained product is the main objective of studying crushability of rocks. In this case crushing hypotheses establishing a relationship of work used for crushing and fineness of the obtained products are scientific basis for assessing the disintegration effectiveness[1].

At the same time it should be highlighted that disintegration of rocks during construction crushed stone manufacture is characterized by the need to obtain fractions with preset fineness and the required quality in terms of grain shape and strength, which largely depends on the crushing method and conditions, as well as on the physical and mechanical properties of the feedstock. In other words, if while crushing and grinding ore materials effective for further enrichment it is necessary to uncover

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the mineral aggregates as much as possible, it is important to retain their strength during production of crushed stone.

Analysis of the current state of the problem rocks disintegration shows that research to improve the process efficiency is underway in the following areas: 1. Development of the theory of destruction of rocks as polycrystalline materials; 2. Creation of a new crushing equipment providing high quality crushed stone at minimal energy costs; 3. Scientific substantiation and development of crushing process flowsheets[2–10].

It should be noted that all crushing hypotheses anyway assume that the energy consumed for crushing depends on the properties of the crushed material. Further study of the crushing process laws shows that due to the presence and formation of micro cracks in the volume of crushed piece, as well as the heterogeneity of rocks, the actual fracture energy is significantly different from the calculated theoretical values[11–14]. In this context, the problem of improving techniques for studying crushability of rocks is an actual scientific and practical task.

There are numerous experimental procedures for testing crushability of rocks, enabling to assess energy costs and granulometric characteristics of the obtained products. In a survey[15] based on the analysis of such methods as Drop-Weight Tear Testing (DWT), The Determination of Short-Term Impact Loads (SILS), Tests on a Rotary Breakage Tester (RBT), uniaxial compressive strength testing of individual samples of regularly shaped rocks and the particulate layer[16-19], an important conclusion was made that the obtained results – consumed energy and granulometric composition of the breakage products – depend not only on the properties of the rock, but on the applied method as well. In other words, it is required not just to record the obtained result, but to study the response of the rocks for a particular load. This conclusion seems very important in solving the practical problems associated with disintegration of rocks, where it is necessary not only to minimize energy consumption and get the required volumes of crushed stone fractions, but to preserve rock strength in the grains of the crushed stone.

2. Concept Headings:

The research was performed to identify and compare the crushability assessment of certain genetic types of construction rocks – gabbro-diabases, granites and gneiss granites.

The research is based on the hypothesis proceeding from the fact that the action of the load creates the deformation field throughout the body volume, which leads to a change in the structure and strength characteristics of products formed during crushing. In this respect, strength of crushed stone grains as finished disintegration products has been introduced as an additional indicator that characterizes crushability of rocks.

In this connection, an important task of research is comparative assessment of methods used for studying strength characteristics of rocks and their behavior in the process of breakage, and the factors affecting the strength of the obtained mineral aggregates.

3. Results and Discussion:

3.1 Studying Strength and Crushability of Rocks

The studies are conducted using basic types of ingenious rocks as an example – gabbro, gabbro-diabases, plagio granites, microcline-plagioclase granites, gneiss granites – from the Karelian deposits (commercially developed and prepared for commercial development). The number of studies samples made 100 (gabbro, gabbro-diabases), 45 (plagiogranites), 135 (microcline-plagioclase gran-

Table 1. Comparative Characteristics of Physical and Mechanical Properties of Rocks (Karelian Deposits, Averaged Testing Results)

Rock (number of determinations)	Density, g/cm³		Water absorption, %	Porosity, %	Ultimate compr. strength, MPa
	Mineral	Volumetric			
Gabbro-diabases (100)	3.05	3.01	0.44	0.036	234
Plagiogranites (45)	2.96	2.95	0.63	0.04	210
Microcline-plagioclase granites (135)	2.68	2.63	1.71	0.16	120
Gneisso-granites (20)	2.66	2.62	1.38	0.11	124

ites), 20 (gneiss granites). Main physical and mechanical properties were determined for each sample, such as mineral and volumetric density, water absorption, porosity, compressive strength (**Table 1**).

The basic rock forming minerals of pyrogenic (magmatic) rocks of the main composition – gabbro-diabases are plagioclase and amphibole (actinolite). Content of quartz in these rocks does not exceed 1-5 %, ore minerals making 1-6 % and micas (biotite) – 0.5-10 %. Showing relatively stable values of mineral density (2.96-3.17 g/cm^3), volumetric density (2.93-3.1 g/cm^3), and porosity (0.01-1.0 %), the rocks manifest differences in strength (152-490 MPa).

The basic rock forming minerals of plagiogranites are plagioclase (55-65 %), quartz (25-35 %), micas (biotite amounting to 3-10 %). Some samples contain epidote (1-15 %). Composition of microcline-plagioclase granites includes plagioclase (25-45 %), microcline (up to 37%), and quartz (25-37 %). Content of micas (biotite) ranges from 1-2 % to 20%, epidote makes up to 2%. Plagiogranites are characterized by higher values of mineral and volumetric density and lower porosity as compared to microcline-plagioclase varieties. Compressive strength of plagioclase granites is 165 MPa, that of microcline-plagioclase being 117 MPa.

In the domestic practice, compressive strength is the main criterion for evaluation of rocks when choosing crushing equipment. Depending on the value of this parameter the performance and the required motor rating of industrial crushers are determined.

According to the existing procedure, compressive strength of rocks (σ_{compr}) is determined using samples of proper form by crushing in a hydraulic press.

Determination of σ_{compr} of rocks indicates significant differences in the values obtained. Testing of the samples belonging to one production sample (**Table 2**) shows that the satisfactory convergence of the values obtained is achieved only with samples of rocks having homogeneous structure (coefficient of variation of gabbro-diabase makes 2.2%). Considerable differences in the values obtained for granite (coefficient of variation being 19.0%) are associated with the variability of the spatial distribution of minerals within the volume of individual samples, as well as with the possible presence of hidden defects. Rocks of foliaceous structure (gneisso-granite) characterized by the anisotropy of the properties have different values of the compressive strength in the directions along and across the stratification, moreover, in the direction perpendicular to the lamination, the difference of the results is much less (coefficient of variation is 5.0).

Compressive strength depends on mineral composition, texture and structure of rock, and the number, size and orientation of the defects present in it[1,11]. Thus, the variability of mineral composition, textural and structural features and the degree of structure imperfection are the cause of significant differences in strength of rocks both within the same genetic type, and within the same field.

Rocks differing in structure and texture can have similar values of ultimate compressive strength. Figure 1, shows the fineness characteristics of crushed products, differing in texture and structure, but having similar values of ultimate compressive strength: plagiogneiss granite (σ = 121 MPa for 15 samples); medium-grained plagiogranite (120 MPa for 25 samples); coarse-grained microcline-plagioclase granite (125 MPa for 20 samples). There is no analysis of the results of reciprocal correspondence between the strength of rocks and character of their destruction. The granulometric characteristic of disintegration products is largely dependent on the grain size of the minerals and the peculiarities of their spatial distribution in the amount of rock.

Thus, the selection of process equipment depending on the ultimate compressive strength results, in some cases, in a mismatch between the selected crusher capac-

Table 2. Results of Determining Ultimate Compressive Strength of Rocks

Rock	Compressive strength for samples, MPa						Statistical parameters		
	1	2	3	4	5	average	σ2	σ	V, %
Gabbro-diabase	302	299	301	307	287	299	44.2	6.6	2.2
Granite	84	115	113	153	125	118	501	22.4	19.0
Gneisso-granite									
- along stratification	64	77	92	46	56	67	259	16.1	24.0
- across stratification	119	104	111	107	105	109	29.8	5.5	5.0

Note: σ^2 – dispersion; σ – root mean square deviation; V – coefficient of variation ity and rock properties, and as a consequence, leads to exorbitant energy costs and increased yield of sand-sifting.

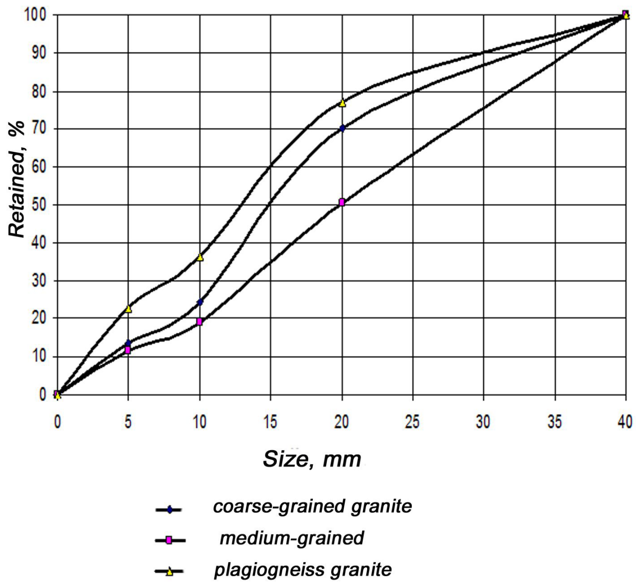

Figure 1. Fineness characteristics of crushed products (DShch 60 × 100 jaw crusher)

The Bond Work Index (Wi) is a criterion for assessing crushability of rocks linking the granulometric composition of the source and the crushed product and the energy costs of the disintegration process. This index characterizes the material resistivity to crushing and is a constant for a given type of rock[20]. The numerical value of the Bond work index depends on the source rock properties and is determined experimentally in the impact crushers (standardized DWT method or its simplified analogues[20-23]).

At the same time, testing of rocks in the impact plants does not take into account the whole complex of phenomena that occur during the mass disintegration of rocks in the jaw and cone crushers, operating on the principle of compression.

In our opinion, the most accurate and reliable results can be obtained when studying the energy intensity of rock disintegration process directly in the crushing apparatuses.

The studies were performed on a BB200 laboratory jaw crusher manufactured by Retsch (Germany) with a nominal capacity of 1500 watts operating on AC power. To register the electricity consumed, ROBITON PM-2 (electric power meter) was connected to the crusher; the device is equipped with a liquid crystal display (Figure 2) with the displayed parameters: current time; mains voltage (V); current consumed by the connected crusher (A); active power consumption (W); electricity consumed by the crusher (kWh.); total operating time (sec).

Figure 2. ROBITON PM-2 power meter display

The studies were performed on averaged samples of gabbro-diabase, granite and gneisso-granite with fineness of -40 + 5 mm and -20 + 5 mm, sampled at industrial crushing and screening plants.

The experiment was carried out as follows: after switching on the crusher and its idling operation (60 seconds) a sample was loaded through the charging hopper, the volume of which corresponded to the complete crushing chamber filling. With the electric power meter connected to the crusher power consumption was recorded automatically at the intervals of 1 sec. When testing PM-2 readings were taken with a video camera and then the record was transferred to the computer. The obtained values were treated with standard EXEL software.

In the experiments, the width of the discharge gap corresponded to 5mm, crusher idle capacity – 649 W, electric line voltage – 224 V.

In absolute terms, energy intensity of the disintegration process is defined as the ratio of power consumed *N, kW* to the crushed material weight per unit time (*Q,t/h* – crusher performance), but without consideration of waste energy. Therefore, the calculations took into account only the effective power $N\text{-}N_x$, where N_x is idle crusher capacity:

$$q_{abc} = \frac{N - N_x}{Q}, \text{kW×h/t}$$

Since the specific energy intensity increases with increasing the degree of reduction, all other conditions being equal, relative energy intensity was calculated assuming that the energy intensity of the crushing process complies with the Bond law and is proportional to the crushing degree unit less *i-1*:

$$q_{rel} = \frac{N - N_x}{Q(i-1)}, \text{ kW×h/t}$$

The results of experiments are given in **Table 3**.

Analysis of the results shows that regardless of the fineness of the source material specific energy consumption at crushing decreases during the transition from gabbro-diabase to granite and gneisso-granite, which is consistent with the results of determining ultimate compressive strength.

Specific energy intensity in absolute terms (without taking into account the reduction ratio) decreases with decreased feedstock fineness. Theoretically, with decreasing particle size their strength shall increase and, accordingly, the breakage energy shall increase, as well. If the specific energy consumption is calculated as the ratio of effective power consumed during crushing and crusher performance, the decline of this indicator at disintegration of finer product is explained by the decrease in the duration of its stay in the crushing chamber to achieve the desired fineness. Accordingly, with reduced fineness of the initial feedstock the crusher performance increases and consumed power reduces.

Relative energy intensity of crushing that takes into account the reduction ratio, increases with reduced feedstock fineness, which is consistent with Bond's provision (specific energy intensity is inversely proportional to the square root of the average fineness of crushed material).

Analysis of diagrams describing the variation of power consumption over time points to significant fluctuations in this parameter (**Figure 3**), which is due to the fact that in the crushable material narrow classes of fineness have different strength of the particles

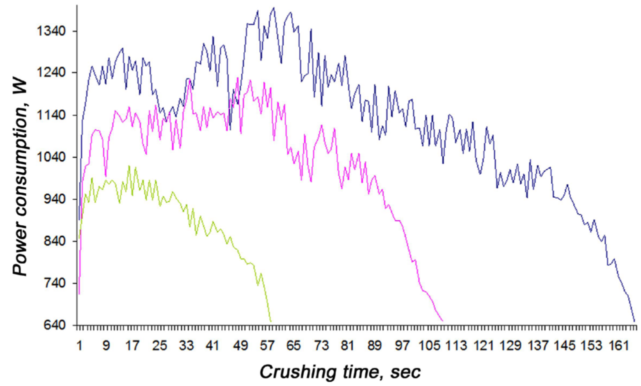

Figure 3. Consumed power fluctuations when crushing gabbro-diabase, granite and gneisso-granite

An attempt was made to determine the numerical value of the work index W_i by testing rock directly in the crusher according to the technique developed by the Mekhanobr Institute[24].

Under this technique, crushing work index W_i is determined on the basis of functional dependence between the energy used for crushing and the results of rock fineness reduction:

$$\frac{N - Nxx}{Q} = 10W_i\left(\frac{1}{\sqrt{d_{80}}} - \frac{1}{\sqrt{D_{80}}}\right)$$

Table 3. Experimental Results of Crushing Process Energy Cost Determination

Source product fineness, mm	**Average product fineness, mm**		**Capacity Q, t/h**	**Power consumed *N*, kW**	**Crushing degree, *i***	**Energy intensity kWh/t**	
	D_{av}	D_{av}				$q_{abc} = \frac{N - N_x}{Q}$	$q_{rel} = \frac{N - N_x}{Q(i-1)}$
Gabbro-diabase							
-40+5	13.4	2.8	0.118	1.254	4.8	5.1	1.3
-20+5	7.1	2.3	0.158	1.117	3.1	2.9	1.5
Granite							
-40+5	12.1	2.4	0.139	1.029	5.0	2.7	0.68
-20+5	6.4	2.1	0.171	0.995	3.0	1.8	1.0
Gneisso-granite							
-40+5	12.3	2.1	0.147	0.977	5.9	2.2	0.45
-20+5	5.2	1.8	0.209	0.926	2.9	1.3	0.70

Table 4. Results of Work Index Determination for Gabbro-Diabase (Testing in the Crusher with Simultaneous Recording of the Consumed Power According to the Technique[5])

Mesh size screening 80% of product, mm		Power, kW		Capacity, t/h	Energy intensity kWh/t	Work index W_i, kW/h
source product	crushed product	consumed	effective			
38.5	3.8	1.411	0.741	0.23	2.6	32.4

where N – power consumed during on-load operation, kW; N_{xx}– crusher idle capacity, kW; Q –crusher performance, t/h; 10 – dimension factor; W_i – work index, kW×h/t; D_{80} and d_{80} – mesh size of square sieves screening 80% of the crusher feedstock and discharge, mcm.

In the experiment source material (gabbro-diabase core sample) fineness was -40+5 mm, sample weight – 15.6 kg, crusher setting made 7.5 mm. Crushing was carried out with fully charged crushing chamber. Consumed power was recorded automatically by means of the electric power meter connected to BB200 crusher (Retsch). During calculation of the effective power only values corresponding to the full charge of the crushing chamber were considered. The results of experiment are given in **Table 4**.

At the same time, rock strength is not a constant value, since it changes in the processes of extraction and processing. Mechanical loads undergone by the rocks during drilling and blasting operations and disintegration lead to increased porosity and, as a consequence, to decreased strength and crushing work index. This conclusion is confirmed by the results of gabbro-diabase testing sampled at the crushing and screening plant and corresponding to the different sections of the process flowsheet (**Figure 4**).

3.2 Studying Factors Affecting the Strength of Disintegration Products

In the course of disintegration process the rocks are subject to compressive and impact loads. The result of crushing – granulometric composition of the breakage products and strength of individual grains – is determined by the duration of the load action.

According to the kinetic theory of strength, developed by S. N. Zhurkov, the destruction is rather a continuous process of damage accumulation which starts from the time of load application than a critical phenomenon. With the deformation of rocks the rock strength decreases. The process is studied in detail using individual samples of rocks. With regard to the disintegration process it is not a process of micro damage accumulation as such in individual samples being of interest, but the change in strength characteristics of crushed stone as an aggregate of grains of different fineness and shape.

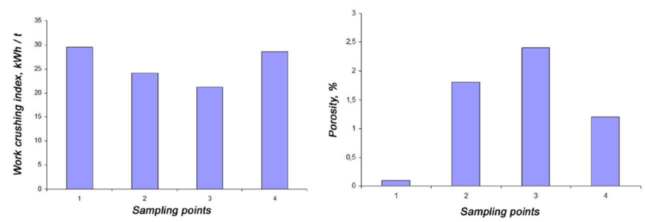

Figure 4. Variation of work crushing index and porosity with rock (gabbro-diabase) passing through the process equipment: 1 – source rock (core sample); 2- broken material (I stage crusher feed); 3 – II stage crusher feed; 4 - III stage crusher feed

Breakage kinetics of crushed stone was studied by compression in the cylinder using hydraulic press at different charging rate. Maximum load made 200 kN. The degree of destruction of the grains was evaluated at fixed intervals when compressed by the press. Destruction of grains was estimated by weight loss during sieving through a sieve with a mesh size of 5 mm. Crushed stone fractions sized 20-40 mm of rocks having different strength were used for testing.

Comparative test series were conducted: 1. With different types of rocks (gabbro-diabase with ultimate compressive strength of 185 MPa and plagiomicrocline granite with ultimate compressive strength of 102 MPa); 2. With different charging rate: 0.5 kN/sec (maximum loading of 200 kN was achieved after 400 sec of crushing), (2 kN/sec (maximum loading was achieved during 100 sec of crushing) and 5 kN/sec (40 sec of crushing until the maximum loading is achieved).

The analysis of breakage kinetics shows that granite starts breaking practically at once: already in 20 sec of compressive load action the weight loss makes 5.9%, achieving 18.2% after 100 sec of crushing. More coherent rock – gabbro-diabase with ultimate compressive strength of 185 MPa – starts breaking only after the load achieves 100-150 kN, which occurs in 50-75 sec at the charging rate of 2 kN /sec (**Figure 5**).

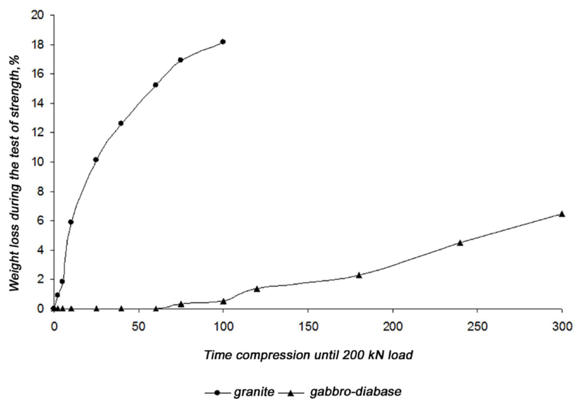

Figure 5. Breakage kinetics of crushed stone; charging rate 2 kN/sec

In this case granite porosity increases from 2.1% in the initial sample up to 4.5% in the sample loaded to 200 kN. Porosity of gabbro-diabase increases from 1.6 % up to 1.8%.

A series of experiments with different loading rate – from 0.5kN/sec up to 5.0 kN/sec was performed. The maximum compressive force of 200 kN was achieved: at the charging rate of 0.5 kN / sec – after 400 sec; at 2.0 kN – after 100 sec; at 5.0 kN / sec – after 40sec. Analysis of the results shows that with decrease in the charging rate the strength of granite crushed stone reduces: at the charging rate of 0.5 kN/sec weight loss during strength testing makes 26.7%; at high charging rate of 5 kN/sec – 14.3% (**Figure 6**). During fast loading (5 kN/sec) porosity increases up to 3.4%, at the charging rate of 0.5 kN/sec porosity increases up to 7.3%.

Table 5. Weight Loss When Testing Crushed Stone Strength by Size Distribution (Results of Laboratory Experiments)

Rock (number of determinations)	**Weight loss when testing strength for sizes, %**		
	5-10 mm	**10-20 mm**	**20-40mm**
Granites (84)	17.7	13.6	15.2
Gabbro-diabases (53)	8.2	10.1	12.2

Experiments with single samples of rocks proved that the dynamic strength of rocks is by 5-13 times greater than the static one. When applied to the crushed rock this ratio decreases, as confirmed by the compressive strength test results of crushed stone fraction sized 20-40 mm (crushing in the cylinder using a hydraulic press) and by falling-weight test results. The experiments were performed according to standard procedures. The average weight loss during compressive strength testing makes 12.5% for the 34 samples tested, when testing impact strength it equals to 5.9%. This dependence is described by the polynomial equation and has a common view for all the studied rocks (**Figure 7**).

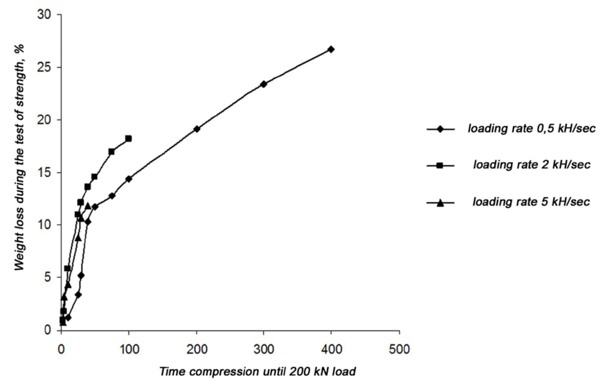

Figure 6. Breakage kinetics of crushed granite stone at different charging rates

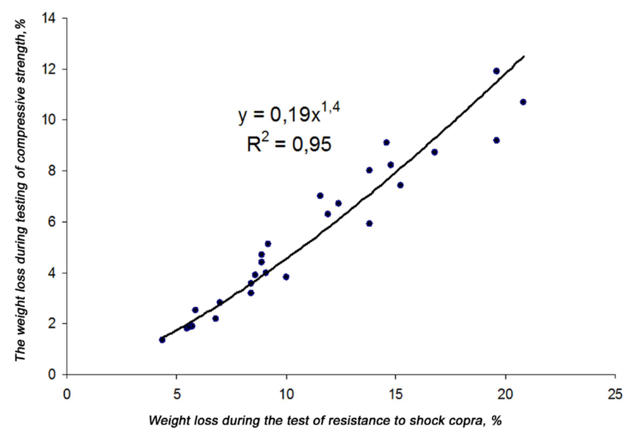

Figure 7. Interrelation between compressive strength (crushability) impact resistance of crushed stone sized 20-40 mm

In any case, when choosing a breakage method, either shock or static one, it is necessary to take into account, first, the size of broken objects, and secondly, mineral composition and textural-structural features of the rocks.

3.1.1 Fineness (Fraction Size)

It was found that weight loss has different meanings when testing crushability of crushed stone according to fineness fractions (**Table 5**).

Theoretically strength of crushed stone should be reduced with increased fraction size. Influence of the scale factor on the compressive strength is described by the empirical formula proposed by L. I. Baron[25]

$$\sigma_{compr2} = \sigma_{compr1} \sqrt[3]{\frac{d_1}{d_2}}$$

Where σ_{compr2} is compressive strength of a sample having regular form with diameter d_2, σ_{compr1} – compressive strength of the same rock sample with diameter d_1.

Strength of crushed stone is characterized by its crushability estimated by the degree of grain destruction (weight loss) in the cylinder using a hydraulic press. Baron's formula is written as:

$$\Delta \grave{I}_{2} = \Delta \grave{I}_{1} \sqrt[3]{\frac{d_2}{d_1}}$$

Where ΔM_2 – weight loss when testing strength of crushed stone fraction with average grain size d_2; ΔM_1 – weight loss when testing strength of crushed stone fraction with average grain size d_2.

Average grain size in the crushed stone fraction is calculated by formula:

$$d_{av} = \frac{2d_1 d_2}{d_1 + d_2}$$

Experimental studies carried out on crushed stone fractions sized 5-10 mm, 10-20 mm, 20-40 mm and 40-70 mm, obtained by the laboratory way, show that the theoretical dependence of the strength increase with decreasing fraction size is manifested for to gabbro-diabases (Figure 8). For granites the unique relationship between strength and fraction size is absent.

One reason for the absence of dependency between strength of crushed granite stone and fraction size is texture heterogeneity that is characteristic of some rock types. Gabbro-diabases are uniform in texture (Figure 9), therefore, strength of crushed stone grains of different sizes is determined only by porosity, having similar values for crushed stone fractions. Accordingly, crushed stone fractions have almost the same strength.

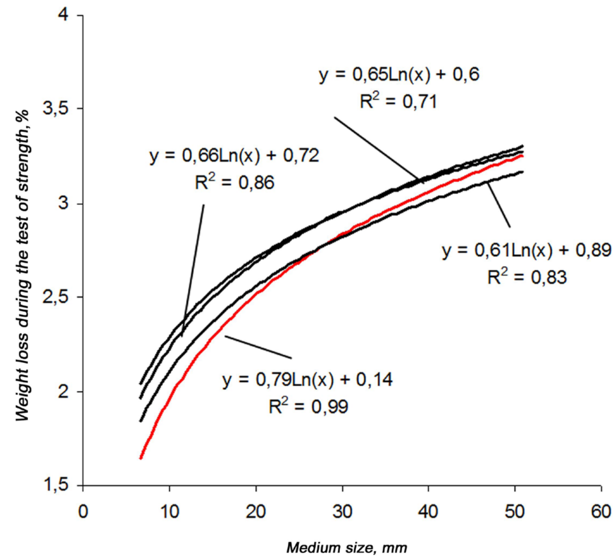

Figure 8. Weight Loss Curves when Testing of Crushed Gabbro-Diabase Strength vs. Average Grain Size, Red Line is obtained by Calculated Data.

Figure 9. Grains of Crushed Gabbro-Diabase Stone.

Granites with heterogeneous texture contain mineral aggregates differing in strength and size, and destruction occurs mainly along the boundaries of their intergrowth. As a result, grains are formed that are heterogeneous in composition and strength (Figure 10). Accordingly, there is no unique relationship between strength of crushed stone and the fraction size for these rocks.

3.1.2 Porosity

The rock strength is determined by its mineral composition, texture and structure, as well as by the number, dimensions and orientation of defects available in the rock. Porosity is an informative characteristic linking the rock strength with its structure imperfection. Dependence of ultimate compressive strength on average density has a general character and is traced for all the studied types of rocks (**Figure 11**).

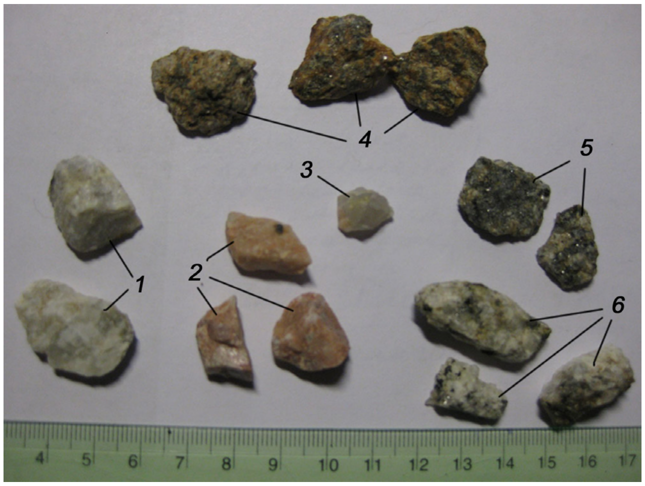

Figure 10. Grains of Crushed Granite Stone Sized 10-20 mm (One Sample Material): 1 – Plagioclase Grains; 2 – Microcline Grains; 3 – Quartz Grain; 4 – Grains with Sign of Weathering; 5 – Grains Containing Intergrown Plagioclase, Amphibole and Biotite; 6 – Grains, Containing Intergrown Plagioclase and Amphibole.

At the same time, significant correlative relationships between strength and density within a single genetic type of rocks are absent. Analysis shows that rocks with the same mineral composition and equal values of mineral density, but having different texture and structure, exhibit differences in strength properties. The test results of the rocks with basic composition, having similar values of density, but a different structure, demonstrate that strength decreases during transition from medium-grained to fine-grained and pelitic rocks. Rocks of crypto-crystalline structure are most coherent: average value of their ultimate compressive strength for 20 studied samples was 278 MPa. Rocks of granular structure are less coherent: their compressive strength equals to 133-178 MPa.

During disintegration a deformation field is created throughout the entire volume of rocks, leading to the development of micro failures and increased porosity. This conclusion is confirmed by numerous research results when studying basic physical and mechanical properties of rocks and obtained crushed stone: in all cases, regardless of the texture-structural type, porosity of crushed stone has higher values as compared to porosity of the source rock (**Figure 12**).

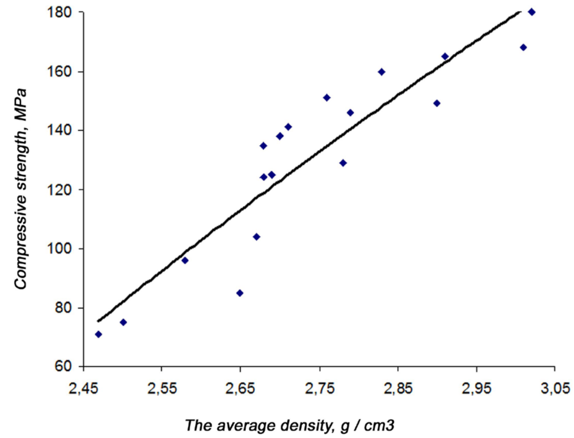

Figure 11. Average Density vs. Strength of Rocks.

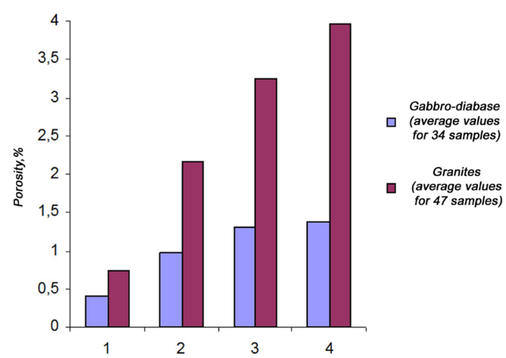

Figure 12. Porosity of Source Rock (1) and of Crushed Stone Sized 20-40 mm (2), 10-20 mm (3), 5-10 mm (4).

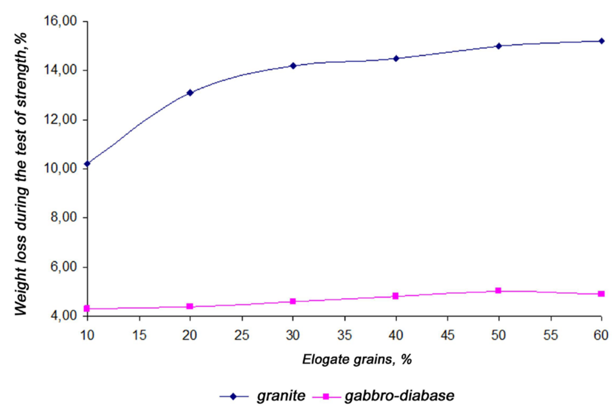

Figure 13. Dependence of Weight Loss on the Flakiness Index of Crushed Stone during Strength Testing (Particle Size 10-20 mm, Results of Laboratory Experiments).

Crushed stone made of gabbro-diabases, characterized by high density, is most coherent gradually decreasing during transition to the granites with higher porosity values.

3.1.3 The Grain Shape

Laboratory experiments on artificially generated fractions of crushed stone of various flakiness revealed that the dependence of the strength on the grain form is quite clearly manifested for granite and is less noticeable for gabbro-diabase (**Figure 13**).

4. Conclusion

Existing techniques for studying crushability of rocks are based on determination of energy consumption estimates and finding the result of crushing – aggregate size of the obtained product. Under the load a deformation field is created throughout the entire volume of the body, which changes the structure and strength characteristics formed during product crushing. This hypothesis is fundamental in the study of the disintegration process of construction rocks in production of crushed stone when the strength of breakage products should be retained.

In this regard, grain strength of crushed stone as a finished disintegration product should be introduced as an additional indicator that characterizes crushability of rocks.

It was found that porosity, fineness, grain form, as well as the rate of load application are the factors affecting the grain strength of crushed stone. Mechanical stresses undergone by the rocks during drilling and blasting operations and disintegration result in increased porosity and, as a consequence, in decreased strength. Theoretical dependence of increasing strength while reducing the fraction size appears for gabbro-diabases that are homogeneous in texture. For granites that are inhomogeneous in composition and texture unique relationship between the strength and the size fraction is absent. Increasing cubicity of crushed stone grains enhances their strength.

The study of the crushing kinetics found that with decreased loading rate the strength of granite crushed stone having high porosity is reduced, while the strength of the low-porous crushed stone made of gabbro-diabase remains practically unchanged. When choosing a crushing method, either shock or static one, it is necessary to take into account, first, the size of the crushed objects and, second, mineral composition and texture-structural features of the rocks.

When choosing a method to study crushability of rocks it should be considered that the processes of disintegration in various crushing machines have different mechanisms of action, and accordingly, the most accurate forecast parameters are provided by the technique using the destruction mechanism similar to an industrial crusher. Standard practice of testing the strength of samples having regular geometric form in the static conditions and crushability assessment by the drop-weight tear testing method fail to consider the entire complex of phenomena occurring during mass disintegration of rocks presented by pieces of various fineness and do not allow estimating energy costs, granulometric composition and strength of the obtained products. The most accurate and reliable results can be obtained when studying the energy intensity of rock disintegration process directly in the crushing apparatuses.

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