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EXPERIMENTAL RESEARCH OF EFFICIENCY OF THE CRUSHER WITH WAVE PROFILE OF ROLLS DURING DESTRUCTION OF LAMELLAR PIECES

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Abstract. The purpose of this work is to confirm experimentally the fact that crushers with a wave profile of rolls have improved efficiency to reduce the yield of lamellar pieces in lump materials compared to conventional equipment such as cone crushers and other types of crushers. In addition, it is necessary to identify the target size classes, for which, first of all, it is necessary to reduce the yield of lamellar pieces they are included. Here, the evaluation of efficiency of processing of the rock mass having increased yield of lamellar pieces was carried out based on the analysis of change in the amount of lamellar pieces yield in narrow fractions of feed material and crushing products. The latter was carried out by passing the pieces sequentially through round and slit sieves to obtain so-called subfractions. During the experiment, a two-roll crusher equipped with bands of the original wave profile design has been used. It allows effective use of schemes for pieces destruction under bending loads. These loads are the more effective, the larger a piece shape differs from the isometric one. The starting material has been 10-25 mm quartzite classified by subfractions having the yield of lamellar pieces from 0 to 91%. The obtained results confirmed, that the smallest yield of lamellar pieces has for the target fraction of products with a size of 1-2 width of the gap between the ledges of crusher rolls, almost independently on the lamellar yield and the size of feed material. The result of the work is also a proposed and tested in practice method for determining the yield of lamellar pieces for narrow fractions of material by sequential sieving on round and slit sieves. Note here, that piecemeal -linear nature of the dependence for the yield of lamellar pieces in narrow fractions of material on the ratio of the average size of slit sieve to the average size of round sieve for mentioned fractions is established. It has been shown, that the lamellar yield of crushing products is effectively reduced for all feed subfractions, with the exception of those containing practically only non-lamellar particles. Improved efficiency of the crusher with wave profile of rolls has been proved, in comparison with conventional equipment, when working with small degrees of crushing. Here, the destruction of mainly lamellar pieces and the minimal re-grinding of non-lamellar pieces is achieved.

Keywords: roll crusher, wave profile, bending load, lamellar piece, slit sieve.

Introduction. Recently, the most popular in construction is the so-called "cube-shaped" crushed stone, which, in general terms, has the shape of pieces close to isometric. According to standards, this means that the proportion of lamellar particles having a flattened shape classifies the material into a particular class in terms of lamellar pieces yield [1]. Cuboid crushed stone belongs to the first category, having a share of lamellar pieces of no more than 10%. Its use as aggregate for concretes allows, on the one hand, to provide better laying of the framework and, accordingly, to reduce the consumption of cement mortar [2]. On the other hand, it allows to reduce significantly the destruction of pieces of the framework under bending loads leading to the destruction of the concrete mass at significantly lower effective stresses [3].

Obtaining of cuboid crushed stone requires solving several problems.

Firstly, it is necessary to have equipment, that is able to provide such a force field, which contributes to their destruction into fragments of close to isometric shape.

Secondly, this is the control of the content of lamellar pieces in the initial rock mass and in crushing products.

Thirdly, this is the choice of rational crushing modes, taking into account the target granulometric fractions of the material, which should have a minimum of lamellar particles.

The recent trend is to replace traditional equipment, such as cone crushers, which produce a large proportion of lamellar pieces, with impact crushers [4]. The fact is that the destruction characteristic of them by the so-called "free" blow leads to the spontaneous development of cracks inside the piece after contact with the impact surface, i.e. the proportion of lamellar pieces depends on the material specific way to form the cracks. For materials, that do not have essential anisotropy of properties in different directions, it is minimal.

However, the main disadvantage of impact crushers is the high wear of the working surfaces, which, along with the need for balancing, high noise and vibration, makes their use fraught with certain difficulties.

An alternative option is to use crushers with wave profile of rolls [5]. First of all, they differ in reduced dynamics during operation being characteristic of all crushers of quasi-static action. This results in reduced wear of rolls during operation compared to impact machines. In addition, the presence of longitudinal ledges and hollows on staggered rolls results in bending loads, primarily for lamellar pieces. Thus, the probability of breaking the lamellar pieces is much higher than the isometric ones, i.e. the selective influence on the material is evident. The pieces that are larger than the gap between the rolls are forcibly processed to eliminate the lamellar pieces, and thus the shape quality of the product pieces is improved.

The problem of estimating the content of lamellar pieces in the material is also significant. The conventional method of taking samples and then determining the size ratio of the piece is quite laborious and not operational. Other options are the use of screening surfaces of special structures that separate lamellar pieces from non-lamellar ones, while also solving the problem of removing the latter from the crushing process. Despite its performance, this method requires a separate justification of its effectiveness.

In order to practically evaluate the efficiency of the crusher with wave profile of rolls considered in this work, it is necessary to perform experimental studies with the analysis of the composition of crushing products not only by size, but also by the shape of the pieces, which is associated with the need to process a sufficiently large number of samples. To do this, you need to develop an appropriate analysis method.

Methods. *The purpose of this work is* to confirm the increased efficiency of the crushers with wave profile of rolls to reduce the yield of lamellar pieces in lump materials compared to traditional equipment, as well as to identify so called target size classes of crushing products.

Here, the target size classes are mentioned as those ones, where the decrease in lamellar pieces yield is of the main interest.

The idea of the work is to evaluate the efficiency of the crushing process between wave-profiled rolls based on the analysis of the change in the amount of lamellar pieces in narrow fractions of the feed material and the product obtained using a combination of round and slit sieves.

Laboratory equipment and experimental research methods.

A laboratory twin-roll crusher with a wave profile of working surfaces was used, having an outer diameter of bands of 260 mm.

The material entered the crusher from the hopper, providing, in fact, consecutive crushing of the pieces, avoiding the effect of destruction in the thick layer with the interaction of the pieces with each other.

After crushing, sieve analysis of crushing products was carried out using sieves with round and slit holes, as well as by directly measuring the dimensions of the obtained pieces. The purpose of the analysis is to determine the yield of narrow fractions of crushing products, as well as the content of lamellar pieces in each fraction.

With manual measurements, each piece had its dimensions determined: *a* - minimum (thickness), *b* - average (width), *c* - maximum (length).

In further calculations, relative values [6] were used:

- relative width of the piece

$$k_{ba} = \frac{b}{a};$$

- relative length

$$k_{ca} = \frac{c}{a}.$$

As it was established in [6], statistical estimates of these two values are related by linear dependence:

$$k_{ca} = A + B(k_{ba} - 1), \quad (1)$$

where *A* and *B* are approximation coefficients.

According to definition given in [1], the lamellar pieces are those that have corresponding coefficient value $k_{ca} \geq 3$.

In fact, in the case of precise sieving on round sieves, an analysis is carried out by the average size of piece *b*, while in the case of sieving on slit sieves - by the minimum size *a*. Thus, by sequentially classifying the material into narrow fractions of round sieves, and then passing each of these fractions through slit sieves, we obtain subfractions with a known relative width of pieces k_{ba}.

To subsequently determine whether the piece is lamellar or not, it is necessary to turn from its relative width to the relative length k_{ca} using formula (1).

Here, it should be taken into consideration, that even for narrow fractions, the dimensions of the pieces fluctuate in certain ranges, and the average value of the relative length of the piece obtained by formula (1) has a dispersion of values. Therefore, it is more correct to talk about the average share of lamellar pieces for a particular subfraction of the material. The narrower a subfraction is, the smaller the dispersion of the lamellar pieces yield value, and in the limit we will strive for a piece with definitely given sizes, either lamellar or not. This applies to both the feed material and the crushing products.

Quartzite with a size of 10... 25 mm, obtained by crushing in traditional cone crushers, has been used as a material for experiments.

For crushing, initial subfractions have been prepared in advance using a combination of round and slit sieves, so as to provide different versions of the initial content of lamellar pieces.

The material has been passed once through the crusher and the products have been analyzed.

Here, the size of the gap between rolls has been of such value, that the degree of crushing, determined by the formula

$$i = \frac{b_0}{b},$$

has been in the range from 1.3 to 2.2, which corresponds to the mode of improving the shape of the material, with the destruction of lamellar pieces and the minimum re-grinding of non-lamellar ones. Here b_0 is the particle size before crushing, b is the particle size after crushing.

For granulometric analysis of the feed material and the crushing products, round screens in the range from 3 to 20 mm have been used, as well as slit sieves in the range from 2.5 to 14 mm.

Results and discussion. *Results of crushing and implementation of the method for determining the yield of lamellar pieces using slit sieves.*

The most reliable and accurate way of determination whether a particle is lamellar or not is to measure directly its three dimensions.

However, it is very labor intensive and requires sampling due to the inability to measure all the particles completely, so, finally, it has also an error.

In this regard, in order to establish the content of lamellar particles, it is proposed to increase the analysis rate by sieving each fraction obtained on round screens, additionally on subfraction using slit screens, excluding measurements of individual pieces. Obviously, the smaller the slit the pieces passing through, having severe limitations in their width, the greater the percentage of the lamellar material among them.

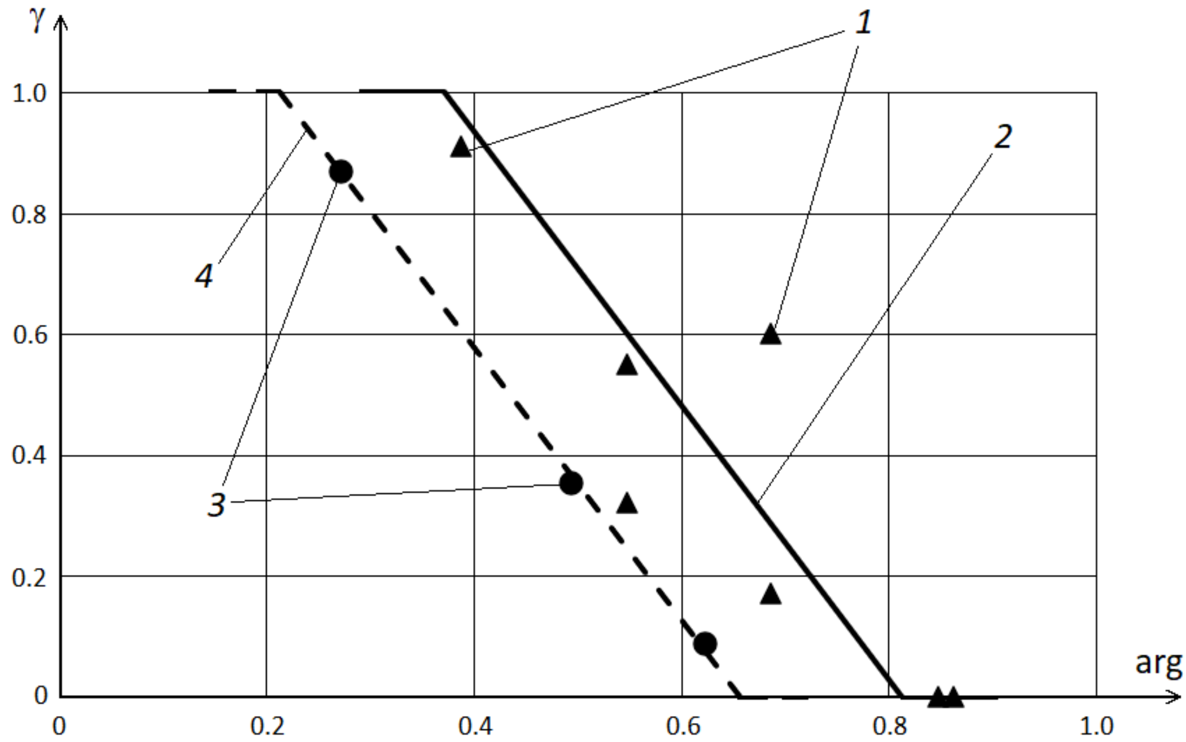
Based on the results of the experiment, subfractions have been analyzed, both feed materials for crushing and their products.

The results are shown in Figure 1. Here, the following relation is chosen as the argument:

$$arg = \frac{a_{av}}{b_{av}} = \frac{1}{k_{ba,av}},$$

where a_{av} is the average size of the subfraction on slit sieves; b_{av} is the average size of the subfraction on round sieves; $k_{ab,av}$ is the average relative width of the subfraction.

Figure 1 shows the experimental points of the lamellar particles yield for the feed material (item 1) and for the crushed products (item 3). Each set of points has been approximated by the regression equation of type (2), resulting in the corresponding regression lines (items 2 and 4).



1 - starting material; 2 is the regression line for the source material; 3 - crushing products; 4 - regression line for products

Figure 1 – Dependence of yield fraction of lamellar pieces on ratio of average dimensions of subfraction on slit and round sieves

It follows from the analysis of the Figure, that:

1) experimental data are satisfactorily approximated by linear dependence for yield of lamellar particles having the form:

$$arg = \left\{ \begin{array}{cc} 0, & arg > arg_2 \\ \dfrac{arg_2 - arg}{arg_2 - arg_1}, & arg_1 \le arg \le arg_2 \\ 1, & arg < arg_1 \end{array} \right\}, \tag{2}$$

where arg_1 is the characteristic value of the argument for 100% lamellar particles; arg_2 is the characteristic value of the argument for 0% lamellar particles;

2) the characteristics of the initial subfractions and their products are practically parallel;

3) the characteristics of the crushing products are shifted to the left in relation to

the characteristics of the initial subfractions.

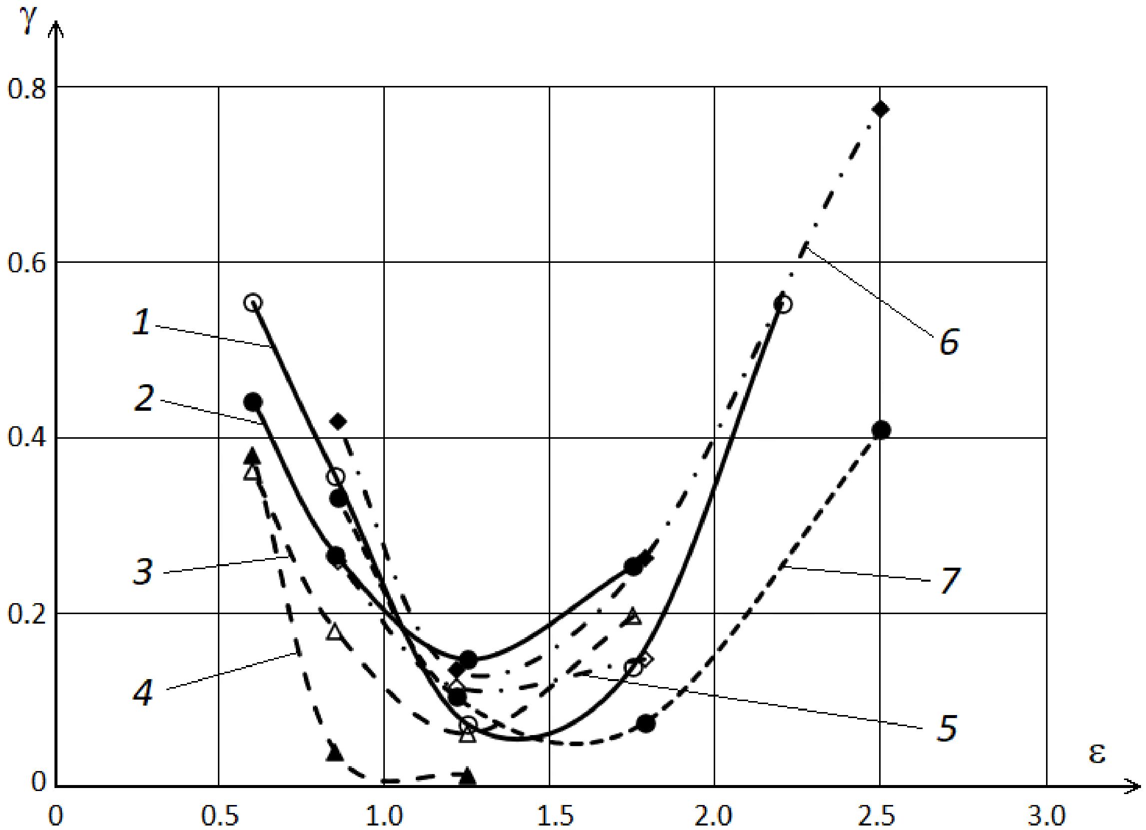
The latter fact indicates a decrease in the relative length of the pieces of crushing products in relation to the feed material, all other things being equal. However, in both cases, the difference of values $(arg_2 - arg_1)$ is constant and is 0.44.

Analysis of the gap value influence on the distribution of lamellar particles yield by fractions of crushing products.

The dependence of lamellar particles yield in crushing products on the ratio of the piece size to the gap value is of particular interest.

It was found during the experiment, that in the case where the average size of the crushing products fraction corresponds approximately to the size of gap between ledges of adjacent rolls, the yield of lamellar pieces tends to be minimal, and as it is shifted from this size in both directions, it increases.

Figure 2 shows the dependencies of distribution of the lamellar pieces shares in the fractions after crushing γ on the relative size of the fraction ε for different initial conditions, such as the lamellar pieces yield of the feed material subfraction γ_0 and the ratio of the feed size to the size of slit ε_0.



1 – γ_0=0,32 and ε_0=2,2; 2 – γ_0=0 and ε_0=1,75; 3 – γ_0=0,6 and ε_0=1,75; 4 – γ_0=0 and ε_0=1,25; 5 – γ_0=0,55 and ε_0=3,14; 6 – γ_0=0,91 and ε_0=3,14; 7 – γ_0=0,17 and ε_0=2,5

Figure 2 – Distribution of the lamellar pieces shares by product fractions for different samples of feed material

Here there are relations:

$$\varepsilon = \frac{b}{s};$$

$$\varepsilon_0 = \frac{b}{s},$$

where *s* is the width of the slot between the roll projections.

For example, the line *1* has been plotted for the crushing products obtained from material having initial yield of lamellar pieces being equal to 0.32, and it has been crushed with the gap size between rolls corresponding to the parameter $\varepsilon_0 = 2.2$.

The given results indicate that, almost independently of the initial data, the fraction of the size (1.0... 1.5) of the gap width has the minimum yield of lamellar particles and, as the percentage of lamellar particles increases from this range in both directions.

Summary data on quartzite crushing in the crusher having wave profile of rolls are given in Table.

Table – Quartzite crushing results

Ratio of the fraction size to the gap between rolls value	Fraction yield,% Range (average)	Lamellar content,% Range (average)
2…3	4…26 (15)	41…77 (59)
1,5…2	14…47 (31)	7…26 (18)
1…1,5	15…87 (43)	1…15 (9)
0,7…1	3…13 (6)	4…42 (26)
0,5…0,7	2…17 (5)	36…55 (43)

For example, in the first line it is stated, that the fraction of crushed products having a size from 2 to 3 units of the gap between the rolls value, obtained by screening on the sieves having round openings, has a yield from 4% to 26% (average 15%), and also contains from 41% to 77 % of lamellar pieces (average 59%), for all experimental tests.

Thus, after crushing, we have obtained about 75% of the material within the target fraction having a size from 1 to 2 units of the gap between the rolls, which has a share of lamellar pieces equal to 10... 15% and belongs by this parameter to the most popular the 1st and the 2nd groups of crushed stone [1].

The re-grinding of the material in this case is minimal, since only about 10% of the dropout is formed.

It should be noted, that the material taken for the experiment, in general, had a fairly high initial yield of lamellar pieces, also the parameters of the crushing process have not been optimized. However, despite this, the crusher has showed high efficiency in reducing the yield of lamellar particles in the target fraction.

It should also be noted, that the treatment of a material with a low yield of lamellar pieces can even lead to an increase in this yield and, therefore, to a deterioration in the material quality. Thus, it is recommended to guarantee taking the appropriate pieces before crushing, if possible.

Conclusions.

1. The high efficiency of reducing the lamellar pieces yield of lumpy material during processing with small degrees of crushing in a crusher with a wave profile of rolls has been experimentally confirmed.

2. The method of determining the yield of lamellar pieces for narrow fractions of material by sequential sieving on round and slit sieves is proposed and tested in practices. Note here, that granular-linear nature of dependence of the lamellar particles yield for narrow fractions of material on the ratio of the slit sieve average opening size to the round sieve average opening size for the mentioned fractions is established.

3. It has been found, that the yield of lamellar particles for products of crushers with a wave profile of rollers has a pronounced minimum of lamellar particles content for the target fraction with a size from 1 to 2 units of width of the gap between the opposite rolls ledges. This fact practically does not depend on the lamellar pieces yield and the size of feed material.

REFERENCES

1. State Committee on Construction, Architecture and Housing Policy of Ukraine (1999), *DSTU B V.2.7-71-98 (HOST 8269.0-97): Shchebin i hravii iz shchilnykh hirskykh porid i vidkhodiv promyslovoho vyrobnytstva dlia budivelnykh robit* [DSTU B V.2.7-71-98 (HOST 8269.0-97): Crushed stone and gravel from dense rocks and industrial production wastes for construction works], DP "UkrNDNTs", Kyiv, Ukraine.

2. Bozhyk, D.P., Sokur, M.I., Biletskii, V.S., Shevchuk, Yu.V. and Sokur, I.M. (2017), "Research of state and development of the construction materials production from natural construction stone", *Zbahachennia korysnykh kopalyn* [Mineral Dressing], no. 68 (109), pp. 3–12.

3. Tytov, O.O. (2019), "*Analysis of Mining Rocks Disintegration Conditions in Crushers Having the Wave Profile of Rolls*", Modernization and Engineering Development of Resource-Saving Technologies in Mineral Mining and Processing, Multi-authored monograph, UNIVERSITAS Publishing, Petrosani, Romania, pp. 366-380.

4. Sokur, M.I., Biletskii, V.S., Vedmid, I.A. and Robota, Ye.M. (2020), *Rudopidhotovka (droblennia, podribnennia, klasyfikatsiia): monohrafiia* [Ore preparation (crushing, grinding, classification): monography], Kremenchutskyi Natsionalnyi Universytet im. M. Ostrohradskoho, Akademiia Hyrnychykh Nauk Ukrainy: PP Shcherbatykh O.V., Kremenchuk, Ukraine.

5. Nadutiy, V.P. and Tytov, O.O, National Technical University «Dnipro Polytechnic» (2019), *Valkova drobarka* [Roll crusher], State Register of Patents of Ukraine, Kiev, UA, Pat. no. 122015.

6. Nadutyy, V.P., Titov, A.A. and Gorokhova, A.R. (2020), "Rational Parametrization of fine materials pieces shape during calculation of their destruction in disintegrators efficiency", *Heotekhnichna Mekhanika* [Geo-Technical Mechanics], no. 150, pp. 46-53. https://doi.org/10.15407/geotm2020.150.046

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ЕФЕКТИВНОСТІ ДРОБАРКИ З ХВИЛЬОВИМ ПРОФІЛЕМ ВАЛКІВ ПІД ЧАС РУЙНУВАННЯ ЛЕЩАДНИХ ШМАТКІВ

Титов О.О., Сухарєв В.В., Сущенко О.І.

Анотація. Метою даної роботи є експериментальне підтвердження того факту, що дробарки з хвильовим профілем валків мають підвищену ефективність процесу зниження лещадності шматкових матеріалів, в порівнянні з традиційним обладнанням, таким як конусні та інші типи дробарок. Крім цього, необхідно виявлення цільових класів крупності, для яких в першу чергу потрібне зниження лещадності шматків, що їх складають. Тут оцінка ефективності процесу переробки гірничої маси з підвищеною лещадністю виконувалася на основі аналізу зміни величини вмісту лещадних шматків у вузьких фракціях вихідного матеріалу та продуктів дроблення, який проводився шляхом послідовного пропуску шматків через круглі та щілинні сита з отриманням так званих субфракцій. В експерименті використовувалася двовалкова дробарка, яка була обладнана бандажами оригінальної конструкції, які мають хвильовий профіль, що дозволяє ефективно використовувати схеми руйнування шматків згинальними навантаженнями. Ці навантаження тим ефективніше, чим більше форма шматка відрізняється від ізометричної. Вихідним матеріалом був кварцит крупністю 10-25 мм, розсіяний на субфракції з лещадністю 0-91%. Отримані результати підтвердили, що найменшу лещадність має цільова фракція продуктів крупністю 1-2 ширини щілини між виступами валків дробарки, практично незалежно від лещадності і крупності вихідного матеріалу. Підсумком роботи є запропонований і випробуваний практично спосіб визначення виходу лещадних шматків для вузьких фракцій матеріалу шляхом послідовного просіювання на круглих і щілинних ситах. При цьому встановлено шматково-лінійний характер залежності виходу лещадних частинок вузьких фракцій матеріалу від відношення середнього розміру щілинного сита до середнього розміру круглого сита для цих фракцій. Показано, що лещадність продуктів дроблення ефективно знижується для всіх вихідних субфракцій, за винятком тих, що містять практично нелещадні частинки. Доведено підвищену ефективність роботи дробарки з хвильовим профілем валків, у порівнянні з традиційним обладнанням, при роботі з малими ступенями дроблення, коли досягається руйнування переважно лещадних частинок та мінімальне переподрібнення нелещадних.

Ключові слова: валкова дробарка, хвильовий профіль, навантаження вигину, лещадний шматок, щілинне сито.

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