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Diagnosis of the rock crushing modes to increase the efficiency of one-roll crusher operation

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Diagnosis of the rock crushing modes to increase the efficiency of one-roll crusher operation

A G Nikitin, S A Laktionov and K S Medvedeva

Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia

Abstract. In the paper the hypotheses of destruction of brittle materials are given, as well as the analysis of energy costs for crushing. The methods of crushing are considered and a comparative analysis of their energy capacity and quality of the product is carried out. The parameters of the crushing process are determined from the point of view of their productivity and, accordingly, their energy efficiency. It is shown that the process of crushing in the one-roll crushers is due to the frictional forces acting between the surfaces of the roll and a piece of the crushed material, and also between the piece and the immovable jaw. The comparison of initial sizes of the crushed pieces in the crushes with the vertical and inclined surfaces of immovable jaw, which shows that with the increase in the bend angle of the immovable jaw the degree of crushing increases. Based on the analysis of forces acting on the crushed material in the one-roll crusher with the inclined surface of the jaw, the calculation of maximal possible value of the bend angle of the immovable jaw is performed.

1. Introduction

Many industrial plants process and use in large amounts the bulk solid materials of various coarseness grades. In most cases the required size is achieved by grinding lumps on crushers, including one-roll crusher. The need for processing a large volume of materials results in the need for fundamentally new approaches, first of all, to the problem of destructive effect of the machine on the material and to the realization of a new method, which is achieved by solving design problems.

The process of fracture of brittle rocks by impact and the process of destruction by compression differ from each other and require different energy inputs necessary for the destruction of the material (compression failure requires 1.5 times more energy compared to impact destruction [1]). However, impact crushers have a serious drawback associated with the quality of the finished product; only 25-30% of the finished product is obtained with a required range of fineness after processing in the impact crushers [2].

2. Methods of research

Under a brittle piece we shall understand the material that is crushed without noticeable plastic deformations. The complete cycle of crushing of individual pieces to the required size consists of successive independent acts of crushing the pieces of smaller size. Determination of the necessary work of a single act of destruction allows energy costs for the entire crushing process to the required size to be established [3].

The amount of energy needed to crush the material to a certain size depends on many factors: size, shape, relative position of the pieces, hardness, brittleness, homogeneity of the initial material, its humidity, type and condition of the working surfaces of the machine, etc. Therefore, it is possible to establish an analytical relationship between the energy consumption for crushing, physico-mechanical properties of the material to be crushed and the features of the process only in the most general form [4].

In 1867 Prof. P.V. Rittinger for the first time hypothesized that the work for crushing or grinding the initial material is directly proportional to the newly formed surface. Subsequently this hypothesis was called the first law of fragmentation. On the basis of experimental work on grinding it was concluded that Rittinger's hypothesis is valid in a certain interval of values of the specific surface area of the crushing products from 250 to 1000 mm^2/mm^3. However, when the values of the specific surface of the products do not correspond to this interval the proportionality of the increase in the specific surface and the energy consumption for grinding are disturbed [5].

In work [6] the process of destruction is divided into two stages: deformation and destruction. The results of the destruction of glass balls with sizes from 3 to 15 mm made it possible to state that the total energy required for destruction can be determined by the useful work of destruction multiplied by the proportionality coefficient. This hypothesis is called the second law of grinding or "volumetric".

F.H. Tartaron [7] believes that the "volumetric" hypothesis characterizes the work that should be spent on overcoming the connection between atoms and ions of the crystal lattice, and destruction should occur up to particles with micron sizes. In turn, R.T. Hookey [8] believes that the "volumetric" hypothesis is better to apply for coarse grinding, and other hypotheses can be applied for a narrow range of sizes of the crushed pieces. Statements of F.H. Tartaron and R.T. Hooks were not experimentally confirmed.

I. Brach [9] made an attempt in practical calculations to take into account the work of crushing depending on the sizes of the crushed rock by introducing the notion of specific work, and recognized that it is impossible to correctly determine the work of crushing taking only elastic deformation into account. Having proposed a calculated dependence I. Brach did not formulate the physical essence of the hypothesis.

Majima Hirosi and Oka Ikkitosi [10] on the basis of the theory of elasticity and the results of experiments showed that the destruction of an individual piece under the action of compressive loads occurs when the maximum permissible tensile stresses are exceeded. They found that the work of deformation of some ideally rigid body in the process of grinding is directly proportional to the particle size in a variable degree.

Since plastic deformations are practically absent in brittle rocks, their destruction at the point of contact occurs immediately after the elastic deformation and the compressive stresses reach the limiting values. The hypotheses proposed to date do not give accurate results in the theoretical determination of energy consumed by crushing. Numerous amendments and additions to the main hypotheses of crushing, as well as new hypotheses did not make the methods of calculating energy for crushing more reliable. This, in many respects, is due to the peculiarities of the initial material, most often anisotropic, the physico-mechanical characteristic of which varies considerably even within a single deposit, and also due to the very process of crushing which depends on many random circumstances.

The main indicators of the process of crushing are the degree and efficiency of crushing [5]. The degree of crushing is estimated by the ratio of the size of the crushed piece to the size of the gap between the roll and the fixed jaw, which depends on the value of the angle of nip, and the greater the angle of capture, the greater the degree of crushing. The efficiency of crushing is determined by the mass of the crushed material obtained by consuming a unit of electricity and depends mainly on the hardness of the crushed material.

With all the variety of crushing processes and types of loads used for crushing materials (crushing, splitting, breaking, etc.), normal stresses arise in the crushing body, the ultimate strength of which is almost twice as high as the tensile strength under the action of tangential stresses. Consequently, it becomes necessary to develop such a process of crushing in which tangential stresses arise in the material to be crushed, so that fracture occurs due to the shift.

In a two-roll crusher compressive forces act on the crushing material and, accordingly, normal stresses arise. In order to reduce the energy consumption for material crushing in a two-roll crusher it is necessary to create such conditions when not only normal stresses but also tangential stresses act on the crushed material. This crushing process can provide a one-roll crusher. In the one-roll crushers the crushing process is provided by the presence of frictional forces acting between the roll surfaces and a piece of a material, as well as between the piece and the immovable jaw. If we carry out a force analysis of the crushed material in a single-roll crusher it will be seen that not only compression forces on the crushed piece occur during the operation of the one-roll crusher but also the internal torque which results in shearing stresses [11]. The disadvantage of one-roll crushers is consists in their low degree of crushing.

3. Results and discussion

In order to increase the degree of crushing of brittle materials in a one-roll crusher the design of a one-roll crusher [12] has been developed at Siberian State Industrial University, in which the fixed jaw has a bend (figure 1).

As it can be seen from figure 1 when using the fixed jaw with a bend, the size of the nipped piece is larger than when using the vertical fixed cheek with the unchanged nipping conditions, which are determined by the nip angle, the coefficient of friction between the roll and the crushed piece and the friction coefficient between the fixed cheek and the crushed piece, due to which the degree of crushing increases.

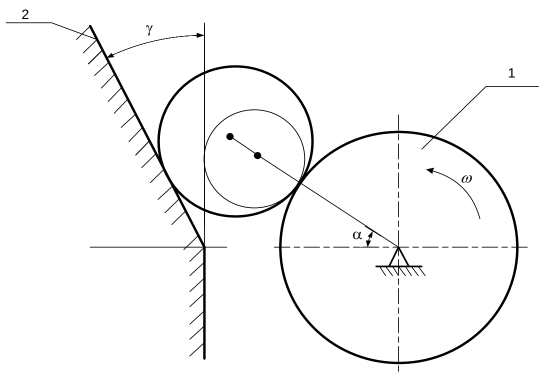

Figure 1. Comparison of the crushed pieces radii. 1 – driven roll, 2 – fixed jaw.

To ensure the maximum degree of crushing it is necessary to determine the maximum permissible bend angle of the fixed jaw.

The crushed piece is in contact with the roll and the fixed jaw at some points A and B (figure 2). The force of gravity determines the forces of interaction $\vec{N}_1$ and $\vec{N}_2$ between the contacting surfaces. These forces are directed perpendicular to the tangent to the roll circumference and perpendicular to the jaw surface. The angle between the horizontal line and the force line $\vec{N}_1$ is the nip angle α. The bend angle of the surface of the fixed jaw γ.

When the roll rotates between it and the crushed piece, a frictional force $\vec{F}_1 = f_1\vec{N}_1$ arises directed along the tangent in the opposite direction of rotation of the roll preventing its rotation. Then the reactive frictional force, equal in magnitude to the force of friction $\vec{F}_1$ and directed at point A perpendicular to the line of action of the normal force in the direction of roll rotation, will act on the fractional piece. The projection of the resultant two forces $\vec{R} = \vec{N}_1 + \vec{F}_1$ determines at point A the compression force acting on the crushed piece. Also the reaction of this resultant force creates at the point of contact B of the crushed piece with a fixed jaw having a bend, the force of normal pressure $\vec{N}_2$ (figure 2).

When the roller begins to rotate, it pulls the crushed piece into the crushing gap, while the normal pressure forces increase manyfold due to the compression force and thereby increase the frictional force that drags the piece into the crushing zone. As a result the forces of normal pressure, that arise when the engine is running, exceed manyfold the forces of normal pressure that arise under the action of gravity, that is why gravity is not taken into account because of its insignificance in comparison with the forces arising in the process of crushing the material.

The condition for nipping the crushed piece into the gap will be satisfied if the vertical component of the resultant of all forces participating in the crushing process is directed downward. These forces are determined by the nip angle α, the bend angle γ of the fixed jaw with a bend and the friction coefficients f_1 and f_2 between the crushed piece and the roll, the crushed piece and the jaw, respectively.

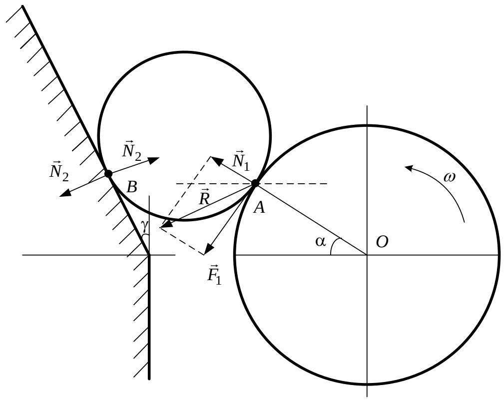

Figure 2. Distribution of forces in a one-roll crusher with a jaw having a bend.

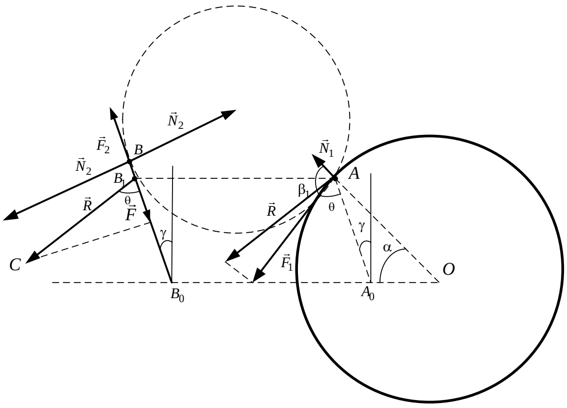

Figure 3. Scheme of the forces acting on a crushed piece in the crusher with a jaw having a bend.

The condition for nipping the crushed piece into the gap will be satisfied if the vertical component of the resultant of all forces participating in the crushing process is directed downward. These forces are determined by the nip angle α, the bend angle γ of the fixed jaw with a bend and the friction coefficients f_1 and f_2 between the crushed piece and the roll, the crushed piece and the jaw, respectively.

The equal force $\vec{R}$ at the point of contact A of the crushed piece and roll relative to the horizontal makes the angle $\beta_1 - \alpha$, where α is the nip angle, and β_1 is the friction angle $(tg\beta_1 = f_1)$ between the roll and the crushed piece. It is obvious that to capture the piece, it is necessary for this angle to be positive, so that the vertical component of the resultant R to be directed downward, i.e. the condition $\alpha < \beta_1$ must be satisfied. This condition is the determining factor for the crusher with an inclined jaw surface, while the component $\vec{F}$ of the resultant force R will be directed downward along the section of the jaw at the contact point B, therefore, the angle θ must be sharp (figure 3).

In the parallelogram $B_0B_1AA_0$, the angle $B_1B_0A_0$ equals to angle B_1AA_0, from which it follows that $\gamma + \frac{\pi}{2} = \theta + \beta_1 - \alpha$, and, consequently, $\theta = \gamma + \frac{\pi}{2} - \beta_1 + \alpha$. On the plane of the inclined section the resultant $\vec{R}$ determines the force $\vec{F}$ acting on the crushed piece and directed downward along the plane of the jaw. The magnitude of this force is determined by equality $F_2 = R\cos\theta$.

In this plane it is counteracted by the frictional force $F_2 = f_2 N_2 = f_2 R \sin\theta$, where f_2 is the coefficient of friction between the piece and the stationary jaw. As long as the force F is greater than the friction force F_2, the crushed piece will be drawn into the crushing gap. To carry out the crushing process in the one-roll crusher, in which the fixed jaw has a bend, it is necessary that $F > F_2$ or $R\cos\theta > f_2 R \sin\theta$. Thus, $tg\theta < \frac{1}{f_2}$.

Then solving $tg\left(\gamma + \frac{\pi}{2} - \beta_1 + \alpha\right) < \frac{1}{f_2} \Rightarrow \gamma + \frac{\pi}{2} - \beta_1 + \alpha < arctg\frac{1}{f_2}$ we find out that the value of the inflection angle of the jaw equals $\gamma_{\max} = arctg\frac{1}{f_2} + arctgf_1 - \frac{\pi}{2} - \alpha$.

From the analysis of the equation obtained, it is seen that the inflection angle depends on the values of friction coefficients between the roll and the crushed piece and also between the fixed jaw and the crushed piece. And the greater the coefficient of friction between the roll and the crushed piece is, the smaller the friction coefficient between the fixed jaw and the crushed piece is, the greater the angle of inflection can be set.

4. Conclusions

Based on the analysis of the forces acting on the crushed piece in a one-roll crusher with an inclined jaw surface, the maximum possible bend angle of the fixed jaw is calculated, which ensures the maximum degree of crushing and increases the efficiency of the crusher.

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