Investigation of Layer-by-layer Destruction of Rocks in High-frequency Cone Crusher

V V Gabov, V S Romanova

St. Petersburg Mining University, 2, 21 Line of Vasilyevsky Island, St. Petersburg, 199106, The Russian Federation

E-mail: vica_00281@mail.ru

Abstract. The article addresses the features of rock disintegration based on the principles of selective and preferential destruction in high-frequency cone vibratory crushers with a free-turning inner cone. Based on the common method for determining the ultimate strength of rocks, a method for investigating the process of ore destruction under repeated and versatile influences has been proposed.

1. Introduction

The processes of crushing, grinding and screening have long been widely used in human production activities. It has been estimated that one-twentieth part of the electricity produced in the world is currently spent on crushing and grinding of solid materials.

The technological purpose of crushing and grinding operations is to open minerals at the largest possible size, with minimal re-grinding, i.e. to implement the “avoid crushing anything unnecessary” principle. Therefore, disintegration of rocks based on the principles of selective and preferential destruction is one of the expedient areas for further development of ore preparation and its efficiency increase [1].

The common principles of intensification of selective destruction suggest the following conditions [2, 3]:
- providing cyclic combined loading that suggests accumulation of microdamage in a significant part of the piece area including on the grain boundaries;
- achieving necessary level of a diversified energy impact on the material leading to accumulation of irreversible damage on the grain boundaries of the mineral;
- providing relative mobility and reorientation of ore pieces in the intervals between loading cycles, which leads to diversified impact and withdrawal of small fractions to the lower levels,
- reduction of energy consumption for plastic deformation (high frequency and speed of loading).

These principles can be implemented in a high-frequency cone crusher with a free-turning internal cone (HC with FTC) (Fig. 1). The features of construction of HC with FTC, the process of crushing rocks in them, the possibilities and prospects of their development are reviewed in papers [4, 5].
Bases on the results of experimental studies, the authors of papers [4, 5] note the unbalance of forces acting on the fractured pieces from the outer and inner cones that result in:
- multiplicity of force influence on crushed pieces in the zone of active interaction of the crushing chamber;
- versatility of force influence on the material;
- reactive motion of the internal cone;
- stable movement of pieces of crushed material in the working chamber, mainly in the circumferential direction;
- withdrawal of fractional factors.

2. Analysis of the Rock Crushing Process in the Crusher Chamber.

To detail the process of interaction between the piece and the bearing surfaces, the horizontal section of the crusher chamber shall be divided into four zones (Fig. 2): active force impact (zone A), load reduction (zone B), free material displacement (zone D) and cone convergence (zone C) with limited movement of the crushed material.

The division is conditional, since the adjacent zones partially overlap each other in different degrees along the height of the operating chamber [6].

Active force impact on the crushed material occurs in zone A where a piece d ≥ a in diameter (see Fig. 2) undergoes a complex stress state. When the angle of action of the vector of inertial forces Fi of the imbalances (from point K1 to K2) changes, the relative value of the normal voltage component in the crushed piece varies from the maximum value at point K1 to zero at point K2, and the value of the tangential voltage component first increases to the maximum value at α = 45° and then drops to zero. Compression strain (σв) is realized in sector A', and shear stresses (στ) in sector A". The eccentricity of the cone positions, due to the deformation of the crushed material, leads to the unbalanced forces acting on the crushed pieces [7].
Figure 2. Distribution of the process of interaction of the surfaces of cones of (HC with FTC).

In the stress relaxation zone B', the material does not undergo active force action, in sector B'' the material is stratified and displaced by the friction forces along the generatrix of the cone (lateral drift) and in the vertical direction under the influence of its own weight.

Figure 3. Computer simulation of the process of destruction of a piece and a graph of the distribution of the constituent forces.
In zone D – zone of free material descent, distribution (classification) of pieces depending on their size along the height of the chamber takes place. In zone C – zone of approximation of the surfaces of the inner and outer cones, selection of the largest pieces and their pinching takes place.

The process of material disintegration in the crusher is complex, multi-stage with a probabilistic result at each interaction stage. Therefore, the establishment and formalization of parametric interstructural links is required [8-10].

Assisted by the specialists of CADFEM CIS, CJSC, local models of individual stages are simultaneously practiced using software for technological process modeling in the mining industry - ROCKY [11]. Figure 3 shows the implementation of the rock crushing process using ROCKY software in the operating chamber of the crusher, which consists of a receiving chamber - 1, inner cone - 2 and outer cone - 3. On the left, there is a scale of the particle distribution by size. The right side shows changes in the normal and tangential components with time. The graph shows that the tangential component of the force is much smaller than the normal component, so it can be neglected during experimental studies.

3. Materials and Study Method

Investigation of the nature of a single piece destruction process in the grinding chamber and determination of the dependence of the cycles of loading caused by destructive force is extremely difficult because of the complexity to produce the testing technique. Therefore, experimental studies will be conducted on real rock samples while preserving the physical nature of the compression collapse process.

The essence of the method suggests testing of cylindrical samples. Testing of each sample (Fig. 4) consists in measuring the value of the destructive force applied through steel plates or wedges of the loading device to the generatrices of the sample at its diametrical cross-section oriented in a specified way with respect to the composition (bedding) of the rock.

The following conditions are met during the experiment:
- the value of the force impact on the sample is below the critical level;
- force loading is carried out with a predetermined pitch \( n_i \), so that when the sample is rotated in full, the pitch is shifted by 0.5 \( n_i \).

![Figure 4](image)

*Figure 4. Cylindrical segment hinge; 1 - lower plate (lower wedge); 2 - the sample; 3 - upper plate (upper wedge); 4 - segment*

The samples are made of lump ore or test cores that make up the sample, by drilling or cutting out. Before sawing a cylindrical sample, marking A-A' is applied on its entire length, and then the end plane of each sample is marked into sectors \( n_1 \) ... \( n_8 \) (Fig. 5a, b).
Figure 5. Samples for testing: a - marking the sample before cutting, b - finished sample.

The proposed method is implemented as follows. A piece of rock (a cylindrical sample) is placed between the indenters and evenly loaded up to global destruction, the maximum (breaking) force $P$ is recorded at the splitting time. In the subsequent tests, the force $P$ is reduced for each sample, and the number of cycles is increased by rotating the sample by a sector.

Based on the experiment results, the yield of the destroyed product is determined depending on the loading and the frequency of force impacts, the granulometric composition of the product at a constant interaction area.

**Conclusions**

For further investigation of the process of rock crushing in high-frequency cone crushers with free-turning inner cones, it is necessary to perform: testing of local models, experimental studies taking into account the shift, establishing of the possibility of a layer-by-layer destruction of rock pieces from the surface and values of the force action parameters, ensuring the stability of such process; identification of conditions that increase the probability of selective crushing of rocks in cone high-frequency crushers with free-turning inner cones.

**References**

[1] Hopunov Je A 2013 The selective destruction of mineral and technogenic raw materials (Ekaterinburg, UIPC) p 429
[2] Revnivev V I, Gaponov G V, Zagoratskij L P 1988 The selective destruction of mineral (Moscow, Nedra) p 430
[3] Gabov V V, Zadkov D A 2016 Energy-saving modular units for selective coal cutting. *IOP Conference Series: Materials Science and Engineering* 1(25)
[4] Golovanov A V 2015 Increasing the degree of crushing rocks in vibrating cone crusher with a free-turning inner cone (SPb, National mineral resources University «University of Mines») p 124
[5] Golovanov A V, Sapozhnikov A I 2012 *Ruda i metally* 6 39-37
[6] Kremer E B, Blehman I I, Titova L G 1998 *Ore processing* 1 3-9
[7] Evertsson C M 2000 *Cone Crusher Performance. Dept. of Machine and Vehicle Design. PhD Thesis*, (Göteborg, Chalmers University of Technology)
[8] Ivanov N A 2012 The inertial Cone Crusher. The theory, design, calculation, operation (SPb, Publishing house «Ore and Metals») p 128
[9] Pashkov E N, Martyushev N V, Ponomarev A V 2014 An investigation into autobalancing devices with multireservoir system *IOP Conference Series: Materials Science and Engineering* 66 (1) 012014
[10] Pashkov E N, Martyushev N V, Masson I A 2014 Vessel ellipticity and eccentricity effect on automatic balancing accuracy *IOP Conference Series: Materials Science and Engineering* 66(1), 012011
[11] Simulation of particle dynamics by DEM [electronic resource], "CADFEM"