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Prospects for Energy-Saving Methods of Crushing Brittle Materials

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Abstract—Crushing machines are part of the charge departments of blast-furnace and steel-making shops of metallurgical enterprises. One of the main indicator of the crushing process is its energy efficiency. It is determined by the mass of crushed material when consuming a unit of electricity. The article considers various methods of crushing brittle materials and the design of crushing machines for their implementation. The analysis of the crushers has shown that impact crushers are the most energy-efficient. However, due to a significant drawback (the yield of a suitable product is very small), they are practically not used in the metallurgical industry, in which high requirements are imposed on the finished product fractional composition. In the metallurgical industry, compression crushers are widely used with approximately the same specific energy intensity, that is, with the same energy consumption for the destruction of a unit volume of material of equal strength. Compression fracture is the most energy-intensive crushing method known. In single-roll crushers, a piece of material is fed into the gap between a roll and a solid, stationary plate. During the operation, a complex stress state is generated in the destructed material. Compressive forces act on a piece of crushed material, causing normal compressive stresses in it, as well as an internal torque causing shear stresses. This is achieved by the reduction in energy on crushing by 20–30% in comparison with crushers operating in compression (all other things are equal). The authors describe the design of a crusher, in which the destruction of the processed material occurs due to the forces acting on the crushed piece in one plane towards each other. In this case, only shear stresses arise in the processed piece. The use of crushers, in which the destruction of the processed material occurs due to generation of only tangential stresses in a piece, can reduce the energy consumption per unit of finished product by almost a half. The design of such crushers is a promising direction in the development of machines intended for crushing.

Keywords: metallurgical equipment, crusher, energy efficiency, compression, deformation

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INTRODUCTION

The world demand for various types of crushed material is growing by 3—8% per year [1, 2]. Crushing machines are part of the charge departments of blast-furnace and steel-making shops of metallurgical enterprises [3]. When preparing ore and non-metallic materials (ores, fluxes, fuel, sinter) for introduction into the metallurgical process (smelting iron and steel), the appropriate fractional composition must be observed. In most cases, the required size is achieved by crushing larger pieces on crushers. In the production of ferroalloys, crushing is the final operation to obtain a finished marketable product.

One of the main indicators of the process is energy efficiency of crushing [3], which is determined by the mass of the crushed material, when consuming a unit of electricity.

STATE OF THE ISSUE

In industry, crushers are used to destroy brittle materials by compression (roll, jaw, cone) and impact (gear, hammer). Therefore, the properties of crushing at the level of quantitative estimates and characteristics have been studied for these two types of destructive action [4].

Compression crushers, widely used in the metallurgical industry, are divided into the following types: jaw crushers, in which destruction occurs due to the counter working movement of plates [5, 6]; roll, destroying a piece, when it is pulled into the gap between rotating towards each other [7, 8]; conical, in which crushing is carried out by compression of the material between the cones, located with eccentricity one inside the other [9, 10]. These crushers, working for the compression of the destroyed material, have

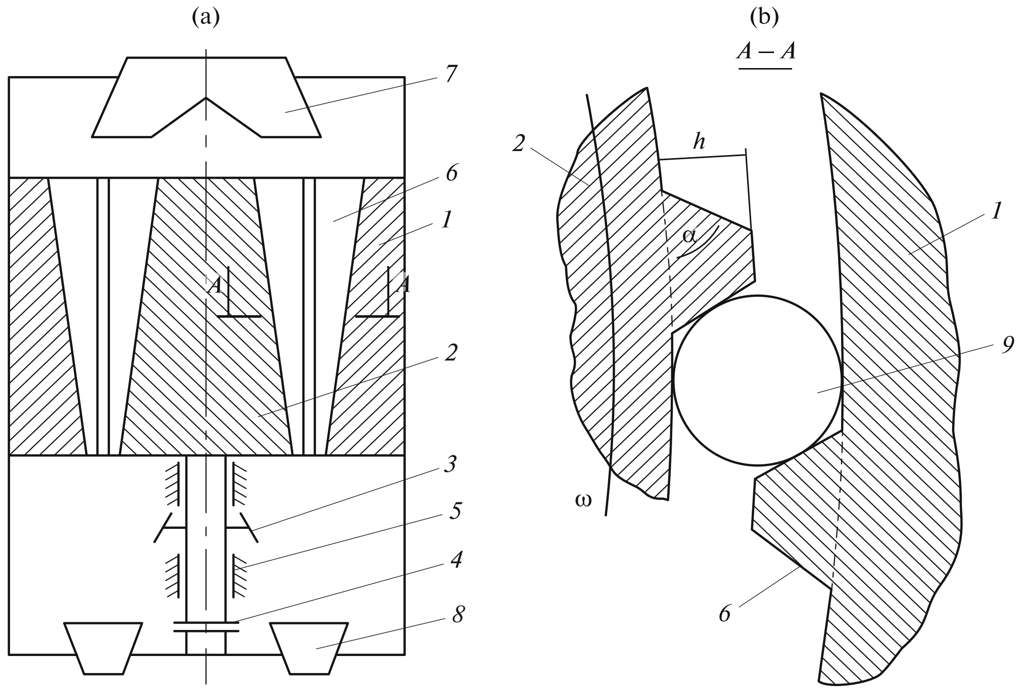

Fig. 1. Scheme of a rotary cone crusher: (a) sectional view of the crusher; (b) cross-section *A–A*.

approximately the same specific energy consumption, that is, the same energy consumption for the destruction of a unit volume of material of equal strength [11]. Compression fracture is the most energy-intensive of the known crushing methods [12].

Impact (rotary and hammer) crushers are designed for impact crushing of various fragile materials using beats, rigidly fixed to a rotor rotating around a horizontal axis [13, 14], while destruction occurs due to splitting.

The destruction of brittle rocks by impact and compression requires different energy inputs, required for the destruction of the material, while destruction by compression requires almost one and a half times energy consumption compared to destruction by impact [15]. However, impact crushers have a significant drawback: 25–30% of the finished product is obtained in a given fractional range [16].

The designs of single-roll crushers are known, in which a piece is fed into the gap between the roll and a solid stationary plate. In the process of work, a complex stress state is generated in the destructible material, in which both compressive forces act on a piece of crushed material, causing normal compressive stresses in the piece, and an internal torque, causing shear stresses [17]. Under the action of a complex stress state in a material, the strength is estimated through the equivalent stress, the ultimate strength of which is less than under the action of only normal stresses [18]. This achieves reduction in energy consumption for crushing, all other things being equal, by 20–30% in comparison with crushers, operating in compression.

OBJECT OF STUDY

In order to increase the energy efficiency of the destruction process of brittle materials, the design of a rotor-cone crusher has been developed at the Siberian State Industrial University [19]. Crushing occurs due to the generation of only tangential stresses in the piece, under the action of which shear (shear) deformation occurs. At this type of deformation, the ultimate strength for the material under consideration takes on the minimum possible value, equal to about 0.5 of the value of the ultimate strength in compression [20]. Hence, it follows that this crushing method is the most energy efficient in comparison with all others, while obtaining a finished product of a given size.

During the operation of the crusher under consideration, destruction of the processed material occurs due to the forces acting on the crushed piece in one plane towards each other, that is, the condition for generation of only tangential stresses in the piece is provided.

The crusher consists of a body *1*, made in one piece with a fixed cone, and a rotating inner cone *2* located coaxially with it with a drive *3* (Fig. 1). The rotating inner cone is installed in radial bearings *5* and rests on a thrust bearing *4*. On the working surfaces of the cones along their generatrices, the ribs *6* are located. In the upper part of the housing *1*, there is a chute *7* for feeding the material, and there are discharge windows *8* in the lower part.

Crushing occurs as follows. A piece of the crushed material *9* through chute *7* is fed into the crushing zone formed by the working surfaces of the cones *1* and *2*. When the inner cone *2* rotates, the ribs *6* located on the working surfaces of the cones are periodically located opposite each other and form channels in which, under the action of gravitational forces, piece *9* falls to a depth, at which its transverse size is equal to the size of the gap between the surfaces of the fixed outer and rotating inner cones *1* and *2*. With further rotation of the inner cone *2*, piece *9* is clamped between the lateral surfaces of the ribs *6* and due to the occurrence of tangential stresses in it shear deformation develops, the piece is destroyed.

The dimensions of the rib are characterized by the following parameters: the height of the rib h and the angle of the inclination α of the side surface of the rib to the base. Their meanings are defined as follows. The height of the rib h should not be more than 0.5 of the size of the gap between the surfaces of the stationary and rotating inner cones in order to ensure the possibility of rotation of the inner cone, and not less than 0.1. In this case, a piece can be rolled over the rib without destruction due to its elastic deformation (5–7% for brittle materials). At $\alpha = 90°$, the destruction of the crushed piece occurs under the action of only shear stresses. Therefore, energy consumption will decrease by 50% compared to compression crushers. The resulting finished product corresponds to the required fractional composition.

The design of crushers, in which destruction of the processed material occurs due to the generation of only tangential stresses in the piece (which makes it possible to reduce the energy consumption per unit of finished product by almost half), is a promising direction in the development of machines intended for crushing.

CONCLUSIONS

The analysis of the crushers showed that impact crushers are most energy efficient. Due to a significant drawback (the yield of the suitable product is very small), they are practically not used in the metallurgical industry, in which high requirements are imposed on the granulometric composition of the finished product. Compression fracture is the most energy-intensive known method for crushing brittle material.

A description of the design of the crusher is given, in which destruction of the processed material occurs due to the forces acting on the crushed piece in the same plane towards each other, while only tangential stresses arise in the processed piece. The design of crushers, in which destruction of the processed material occurs due to generation of only tangential stresses in a piece (it allows reducing energy consumption per unit of finished product by almost two times) is obviously a promising direction in the development of machines intended for crushing.

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