Study of process of materials grinding in energy-saving complex

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Abstract. The article presents the results of the analysis of the kinetics of the grinding process in a ball mill. The operating modes of grinding loading at various schemes of energy exchange devices installation, in a drum of a ball mill are defined. It is established that the nature of the dynamic action of grinding media in the mill drum is significantly influenced by the mutual location of the energy exchange devices both in the longitudinal and in the cross section of the mill body. The results of experimental studies on the process of grinding the material in an energy-saving complex include: a press roller grinder and a ball mill equipped with energy exchange devices. The influence of load factors of grinding bodies of the first and second chambers of the ball mill, their lengths, angles of inclination and mutual arrangement of energy exchange devices on the output parameters of the grinding process is studied. Their rational values are obtained.

1. Introduction

In the production of binding materials, various building mixtures and products, one of the most energy-intensive processes are the processes of crushing and grinding which consume about 10% of the world's electricity. At the same time, the power consumption significantly increases with the dispersion of the obtained product.

Despite the development of a number of grinders in recent years, ball mills (BM) due to their relative simplicity in operation, reliability in operation, high device capacity are unlikely to be replaced in the coming decade by more promising grinding devices. Therefore, the search for technological solutions aimed at reducing energy costs and intensifying the process of grinding materials in these devices is an urgent task.

The analysis of the graphical dependence of the material grinding process in a ball mill $R_{008}=f(L)$ using the linear approximation method (Figure 1) made it possible to establish that in order to achieve high grinding efficiency, this process must include at least three or four different stages of force action on the material. This mode of operation is problematic enough to achieve in one grinding device.
Scientists and practitioners both in our country and abroad are engaged in the development of the efficiency of the existing process of materials grinding. It has an energy-saving grinding technology consisting of two aggregates, a press roller grinder and a ball mill (PRG-BM) [3-4].

The scientists and practitioners, both in our country and abroad, have been engaged in increasing the effectiveness of existing grinding equipment. They developed energy-saving grinding technology consisting of two aggregates – a press roller grinder and a ball mill (PRG-BM) [3-4].

The implementation of the stepwise method of grinding allows one to increase productivity and reduce the specific energy consumption by 20-40% [5-6]. However, the material after the pressure treatment between the rolls of PRG has a shape and texture different from the feedstock and requires special conditions for its grinding in a ball mill.

2. Main part
The analysis of the material crushed in PRG made it possible to establish that it has the shape of compressed plates and an anisotropic texture with maximum strength in the direction of application of the grinding force, and the constituent particles are a microdefect structure that requires special conditions for its deagglomeration and grinding.

The experimental research on the effect of pressure grinding materials in PRG on the value of force of deagglomeration of pressed plates (Figure 2) revealed that with increasing compaction pressure, not only the fineness of the material, but also the strength of the pressed plates increase.

For example, when the materials are crushed with a pressure equal to 240 MPa, the forces necessary for the deagglomeration of the pressed plates, depending on the direction of application, are different: in the pressing direction of the material, $P_{\text{deag.leng}} = 10$ MPa, and in the perpendicular direction $P_{\text{deag.cross}} = 3$ MPa, which is substantially below. This indicates that for effective destruction of crushed and pressed materials in the plates in the PRG, it is advisable to exert efforts in the direction perpendicular to the force action in the PRG.

However, the results of the conducted studies showed that the crushed material in PRG after pressure treatment between conical rolls comes out as a compressed tape, and its particles have a microdefective structure. This requires special conditions for their re-grinding in BM.

As research has shown, it is advisable to subject the pre-grinded material to a short-term impact in the first chamber of the mill to deagglomerate the compressed tape and crush it – the abrading action of the grinding charge in the second chamber for final grinding.

![Figure 1. Kinetic of grinding of materials in BM](image-url)
Such conditions for the grinding of materials can be obtained in a BM equipped with energy-exchange devices (EED): an elliptical inclined partition (EIP) and an ellipse segment (ES). In this connection, it is necessary to study a rational scheme for the installation of LEU.

In order to determine the modes of operation of the grinding loading for various schemes of the EED installation, the studies were carried out on a model of a ball mill with a transparent body of $\varnothing 0.1 \times 0.5$ m in size (Figure 3). As a result of the research it was established that the character of the dynamic impact of the grinding media in the mill drum is significantly influenced by the mutual arrangement of the EED both in the longitudinal and in the cross section of the mill body.

Thus, as a result of the use of the EED, when the ellipse segment is installed at the unloading end of the drum, inclined towards the bottom and its major axis coincides with the larger axis of the elliptical inclined partition (Figure 3a), they simultaneously act with an interval of $360^\circ$ at grinding loading. This leads to the concentration of milling bodies in the middle of the second chamber, which will negatively affect the efficiency of the grinding process.

When the ellipse segment rotates relative to the EIP by an angle of $180^\circ$, it leads to alternate impact of the EED to the grinding medium, which facilitates a greater longitudinal displacement of the grinding bodies (Fig. 3b). This scheme of the installation of the EED should contribute to the intensity of the grinding process of the pre-crushed materials in the second chamber of the mill. However, the installation of the ellipse segment inclined to the discharge bottom leads to grasping of the grinding bodies and raising them to a high altitude, which contributes to the creation of a waterfall mode of operation and reduces the efficiency of the mill operation. The change in the angle of inclination of the ES to the opposite one, established it under the cladding from the unloading bottom (Figure 3, c), leads to the disappearance of the “waterfall effect” in the second chamber of the mill. This arrangement of the ellipse segment does not raise the grinding media, but only strengthens its impact on it in the longitudinal direction. This positively affects the grinding of the material.

When the angle of rotation of the ES with respect to the elliptical inclined partition is varied by an angle different from $180^\circ$ (for example, by $90^\circ$ or $270^\circ$) (Figure 3d), the grinding bodies in the center of the chamber are partially concentrated. This is a result of the mutual superposition of pulses from the EIP and the segment. All this will also negatively affect the efficiency of the grinding process of materials.

The installation of an elliptical inclined partition will ensure the impact-abrasive action of the grinding bodies on the grinding material in the first chamber of the mill. Thus, our studies of the nature of the movement of grinding bodies in BM equipped with energy-exchange devices have shown that the operating mode of the grinding bodies depends on a large extent on the installation scheme and the relative location of the EIP and ES. The rational scheme of the installation of the EED in the drum mill with the grinding of materials pre-crushed in PRG is the scheme in Figure 3 c.
During grinding in a ball mill, it is advisable to subject pre-shredded materials to short-term shock-shear action of grinding bodies in the first chamber for deagglomeration of the pressed plates and crushing-abrading in the second chamber for final grinding.

However, depending on the installation scheme in the drum of energy exchangers, the mode of dynamic action of the grinding media on the material to be grind varies, as well as the efficiency of the grinding process of the materials depends on the mill load factors, lengths and etc.

Therefore, in order to determine their rational values, we conducted experimental studies on a laboratory installation of a ball mill of dimensions D x L = 0.5 x 1.95 meters equipped with energy-exchange devices in Figure 4.

Using the method of mathematical design of the experiment, the dependence Q, N, q = f(K1; K2; L1; α; ξ) was studied. The investigated parameters were taken: the loading factors of the grinding bodies of the first K1 and the second K2 of the mill chambers, the length of the first chamber L1, the angle of inclination of the ES α and the angle of its displacement ξ with relative to the EIP.

To assess the efficiency of the process of deagglomeration and grinding of clinker in BM with ES, the following parameters were taken as output parameters: the productivity Q, reduced to a total residue on the ΣR008 sieve of 10%, the power consumption of the drive N and the specific power consumption q.

In this connection, studies have been carried out to study the effect of the mutual arrangement of the EED and the magnitude of the grinding bodies on the output of the ball mill with the deagglomeration...
and grinding of the pre-crushed materials

As a result of the conducted studies, it was established that the grinding process in BM of pre-crushed materials in PRG is most effectively performed when the mill of the elliptic segment is installed in the drum, inclined from the unloading bottom at an angle $\alpha = 30^\circ$ to its vertical axis. However, the mutual arrangement of energy exchange devices, the length of the chambers and the amount of their loading with grinding bodies have a significant effect on the output. Analysis of graphical dependencies presented in Figures 5-6 allowed one to establish the rational performance of BM.

From the graphical dependence $Q, N, q = f(\xi, K_2)$ (Figure 5), it is established that the relative position of the inclined partition and the ellipse segment in the mill drum has a significant influence on the grinding process of the materials in the ball mill.

![Figure 5. The influence of the angle of displacement relative to each other EED on the specific electricity consumption ($K_1 = 0m18; \alpha = -30^\circ; l_1 = 0.65m$)](image)

The best parameters of its operation ($Q = 170$ kg/h, $q = 22.7$ W h/kg at $K_2, K_1, \alpha; l_1 =$ const) are achieved when the inclined partition and ES in the mill drum are parallel, when their working surfaces are parallel between themselves. From this it follows that the rational length of the first chamber when grinding the material preliminarly crushed in the PRG is $l_1 = 0.6$ m, which corresponds to $l_1 = 0.3$ L, where L is the length of the mill's drum. With an increase in the loading factor of the grinding bodies of the first mill chamber in the range from $K_1 = 0.16$ to $K_1 = 0.20$, the power consumption increases proportionally with $N = 4.15 \cdot 10^3$ W to $N = 4.55 \cdot 10^3$ W, by 8.5%.

The increase in productivity is carried out with $Q = 164.1$ kg/h to $Q = 165.7$ kg/h, i.e. by 2-3%, which entails an increase in the specific energy consumption from $q = 22.7$ to $q = 23.5$ Wh/kg. Thus the grinding process is carried out effectively when $K_1 = 0.16$, which is significantly lower than during the grinding of clinker in a traditional way.

![Figure 6. The effect of the length of the first camera on performance ($\xi = 0^\circ; K_2 = 0.3; K_1; \alpha = -30^\circ$).](image)

Analysis of the graphical dependence $Q, N, q = f(K_1, l_1)$ (Figure 6) made it possible to establish that when the length of the first chamber varies from $l_1 = 0.4$ m to $l_1 = 0.9$ m, the performance has an extremum.

From the analysis of graphical dependencies 5-6, it is established that the process of grinding the materials pre-crushed in PRG is carried out at the coefficients of loading of its mill chambers $K_1 = 0.16$,
$K_2 = 0.3$, the length of the first chamber $L$ equal to 0.65 meters, which is 1/3 of the total length of the drum, the following output values of the ball mill were obtained: $Q_{pr} = 177$ kg/h, $N_{pot} = 4.07 \times 10^3$ W, $q = 22.9$ Wh/kg.

Comparative tests of cement samples obtained in energy-saving aggregates (PRG + BM with EED) made it possible to establish that their beam strength for compression and bending is higher by 15-20% than in the traditional way. This is due to the fact that the activated sample (Figure 7a) has a denser homogeneous structure with good adhesion of the cement stone to the aggregate compared to the reference one (Figure 7b).

![Figure 7. A structure of cement stone samples: a - from cement obtained in energy-saving aggregates (PRG + BM with EED), b - in a ball mill](image)

3. Conclusion
As a result of the conducted studies, it was established that the rational grinding regime of the pre-crushed clinker in a ball mill is ensured when the elliptical segment is tilted from the unloading bottom at an angle of $30^\circ$ from the vertical axis of the mill drum, parallel to the elliptic inclined wall, the load factors of its chambers – $K_1 = 0.18$, $K_2 = 0.3$, the length of the first chamber $L$ equal to 0.65 meters, which is 1/3 of the total length of the drum.

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