Energy-saving technology of obtaining composite binders using technogenic wastes

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Abstract. The article considers energy-saving equipment for production of composite binder. The use of equipment makes it possible to reduce the power consumption of the grinding process up to 50%. Improving the energy efficiency of the line is achieved through the operation of the press roll grinder and rotor-vortex mills of the new design.

1. Introduction.

Annually around 30 billion tons of rock are extracted, about 4.5 billion tons of various minerals deposits are processed, of which only 2 to 10 percent becomes a useful product, and a significant part of it goes to the category of industrial waste and its rational areas of use, as a rule, are not defined [1-3]. Mining work is accompanied by the accumulation of billions of cubic meters of waste rock that occupy hundreds of thousands of hectares of land.

By the beginning of the 21st century, mankind has accumulated so much technogenic waste that it can be conditionally called as new deposits. Therefore, for today it is necessary to solve the task of using them with minimal expenses for processing.

For example, only stocks of waste in the form of slags of electric steelmaking furnaces of the Oskol electrometallurgical works are more than 4 million tons, with an annual replenishment of about 500 thousand tons.

2. Results and discussion.

A rational solution of the problem of industrial waste depends on a number of factors, but the most effective solution is the introduction of wasteless technology. Rational comprehensive use of mineral resources, involvement in the production of technogenic waste and secondary products of various industries for the production of building materials will significantly reduce the burden on the environment and lead to the saving of resources and energy. The maximum use of waste as raw materials should be the basis for accelerating the development of the construction materials industry in the Russian Federation.

Today, the problem of waste reduction is closely linked to the issues of stable economic development: in the context of an a constantly growing demand for raw materials, while reducing available reserves and limited natural resources [4].

In our country, according to the capacity of cement enterprises, there is an acute shortage of binders. According to the forecasts of the Ministry of Regional Development, which developed a strategy for the development of the building materials industry until 2020, the demand for the construction industry in
cement will almost double in ten years (up to 98 million tons). One way to increase the volume of its production is to obtain composite binders (CB). The use of CB with the use of industrial wastes will not only lead to a reduction in the consumption of the clinker component in the binders, but also to the production of highly efficient building materials based on them.

There is a technology for obtaining mineral binders using slag waste from blast furnaces in metallurgical industries, one of the main components of which is the fine grinding of its components, including slags [5-6].

However, the initial product, slag, is a fairly hard material with a grain strength limit of $P = 300 – 320$ kg / cm$^2$, abrasive properties and has larger dimensions than the final product requires, which requires crushing and grinding to obtain the desired product.

Currently, there is a wide variety of grinding mills and systems used for grinding materials and technogenic wastes, which have different strength characteristics.

The carried out analysis of technical and economic efficiency of using existing and developed grinding systems [7-9] made it possible to identify the most effective systems. The principle of stage-by-stage grinding of materials combines with the removal of the coarse grinding stage into a separate aggregate - press roll grinder (PRG). It provides for the economical way to break down the charge (bulk-shear deformation) than, for example, impact and abrasion.

Energy-saving technology and equipment for obtaining finely dispersed materials can be used for the paint and varnish, chemical industry, building mixtures, etc.

This technology (Figure 1) makes it possible to direct the shredded material into the press roller grinder (I) and effective force action in the direction of the least strength in a ball mill equipped with energy-exchange devices (EED) (II).

The press roll grinder used in the preliminary grinding stage has the following technical characteristics given in Table 1.

| № p | Technical characteristics | Parameter value |
|-----|--------------------------|-----------------|
| 1   | Geometrical dimensions of rolls, $L \times H$ | 0.5 x 0.3 m |
| 2   | Taper size of rolls, $K$ | 0.3 m |
| 3   | Clearance between rollers | (3-8) x 10^{-3} m |
| 4   | Circular speed of rotation of rolls | 0.8 m/s |
| 5   | Installed power of the roll drive | 2 x 7.5 kW |
| 6   | Maximum back pressure force | 90 x 10^4 N |
| 7   | Unit capacity, t/h | 5-8 t/h |

Figure 1. Energy-saving grinding complex (PRG-BM with LEED): I - press roll grinder with conical rollers and device for supplying anisotropic materials; II - ball mill, equipped with LEED.
The use of PRG in the technological line for the production of mineral binders provides, depending on the properties, grindable materials, a reduction in the specific electricity consumption by 25-40% and an increase in the productivity of the aggregate used at the grinding stage by 30-40%.

This is achieved by using tapered rolls in which the bulk-shear deformation of the particles of the material to be crushed, as well as the self-reduction effect realized in the material layer at a high level of pressure between the rolls. Compression of the mineral particles between the two working bodies results in the grinding of only the particle itself, whereas the compression of the particle between the others results in the grinding of all the particles in contact, and in order to achieve the required product size, less than half of the energy consumed by the ball mills is required.

![Figure 2. Press roll grinder (PRG): general view](image)

In addition, the material after the pressure treatment has a commodity form of compressed plates and a micro-defect structure (Figure 3), which makes it possible to mill it in subsequent stages with less energy. The ability to create a wide range of shear deformations, due to the shape of the rolls and the large range of pressures created in PRG, determines its use for processing materials with different physical and mechanical characteristics.

![Figure 3. Slag crushed in PRG: a – product form, b – microdefect structure (×80)](image)

Preliminarily grindable in PRG material is expediently subjected to a short-term impact in the first chamber of the mill for the deagglomeration of the pressed tape and the crushing-abrading action of the grinding charge in the second chamber for final grinding. Such conditions for grinding materials can be obtained in a ball mill (BM) equipped with lobed energy exchange devices (LEED): a double-acting blade (DAB) and a blade ellipse segment (BES).
Depending on the angle of rotation of the mill drum, the level of loading in the first chamber varies periodically. In the zone of active influence of the LEED there is a "scooping" of a part of grinding bodies along with the material to be crushed, raising them to a height and giving them a longitudinally transverse movement. At the same time on the extra work consumes engine power. However, the lack of a scientifically grounded methodology for calculating the engine power of windmills equipped with LEED inhibits their introduction into industry. In addition, the power consumed by the mill is associated with an additional displacement of the center of mass of the grinding charge along the axis of the mill's drum.

Power \( N \) over a certain period of time \( T \) is calculated by the formula

\[
N = \frac{A}{T},
\]

(1)

Where \( A \) is the work done in the same period of time \( T \).

A period of time \( T \) - the time of one revolution of the mill's drum. If the mill makes revolutions \( N \) per minute, then one revolution occurs in time:

\[
T = \frac{1}{n} \text{ min}
\]

(2)

or

\[
T = \frac{60}{n} \text{ sec.}
\]

(3)

Because

\[
n = \psi n_{cr},
\]

(4)

where \( \psi \) - relative speed, \( n_{cr} \) - critical speed.

As

\[
g = 9.81 \text{ m/s}^2 - \text{acceleration of gravity}, \quad R - \text{radius of the mill drum},
\]

then formula (3) can be written in the following form

\[
T = \frac{2\pi\sqrt{R}}{\psi \sqrt{g}} \text{ sec.}
\]

(6)

For one revolution of the mill's drum, the center of mass of the grinding charge in each chamber will move from one extreme position to the other and vice versa. For the first chamber, the movement of the center of mass of the load in one revolution of the mill's drum is determined by the formula:

\[
S_i = 2|y_i - y_i'|,
\]

(7)

According \[4\] \( y \) or \( y' \) are calculated, respectively, by formulas:
\[ \vec{V}_1 = -\frac{\lambda_1^2}{2} \left( \chi_1 \sqrt{1 - \chi_1^2} + \arcsin \chi_1 - \frac{\pi}{2} \right) - \frac{2\lambda_1 \cot \alpha}{3} \left( 1 - \chi_1^2 \right)^{3/2} + \]

\[ + \frac{\cot^2 \alpha}{8} \left( \chi_1 (1 - 2\chi_1^2) \sqrt{1 - \chi_1^2} - \arcsin \chi_1 + \frac{\pi}{2} \right). \]

\[ \vec{V}^*_{1r} = -\frac{\lambda_1^2}{2} \left( \chi_1' \sqrt{1 - \chi_1'^2} + \arcsin \chi_1' - \frac{\pi}{2} \right) + \frac{2\lambda_1 \cot \alpha}{3} \left( 1 - \chi_1'^2 \right)^{3/2} + \]

\[ + \frac{\cot^2 \alpha}{8} \left( \chi_1' (1 - 2\chi_1'^2) \sqrt{1 - \chi_1'^2} - \arcsin \chi_1' + \frac{\pi}{2} \right). \]

(8)

Moving the center of mass of the load for one revolution of the mill drum in the second chamber is determined by the formula:

\[ S_2 = 2|y_{s2} - y^*_{s2}|. \]  

(9)

Calculating \( y^*_{s2} \) or \( y^*_{s2} \), according (4) it makes possible to calculate:

\[ \vec{V}^*_{s2} = \frac{\cot^2 \alpha}{8} \left( 2\chi_2^2 - 1 \right) \left( 2\chi_2 - 1 \right) \sqrt{1 - \chi_2^2} + \arcsin \chi_2 - \frac{\pi}{2} \right) - \frac{2\lambda_2^2}{2} \left( 1 - \chi_2^2 + \arcsin \chi_2 - \frac{\pi}{2} \right) \].

(10)

\[ \vec{V}^*_{s2} = \frac{\lambda_2^2}{2} \left( \pi - \arcsin \chi_2' - \chi_2' \sqrt{1 - \chi_2'^2} \right) + \frac{2\lambda_1 \cot \alpha}{3} \left( 1 - \chi_2'^2 \right)^{3/2}. \]

(11)

Since the work is done by the friction force, then:

\[ A = |F_1 S_1| = F_{ir1} S_{1r} + F_{ir2} S_2. \]

(12)

In its turn,

\[ F_{ir1} = f \ G_1 = f \ M_1 g = f \ g \ \gamma \ V_{1load} = f \ g \ \varphi_1 V_1, \]

(13)

where \( f \) – coefficient of sliding friction of grinding load on the drum body; \( G_1 \) – the weight of the grinding charge in the first chamber; \( M_1 \) – mass of the grinding charge in the first chamber; \( \gamma \) – bulk weight of the grinding loading; \( V_{1load} \) – the volume of grinding loading in the first chamber; \( \varphi_1 \) – the loading factor of the grinding bodies of the first chamber; \( V_1 \) – volume of the first chamber.

A similar formula holds for the second chamber:

\[ F_{ir2} = f \ G_2 = f \ M_2 g = f \ g \ \gamma \ V_{2load} = f \ g \ \varphi_2 V_2. \]

(14)

Having carried out comparative results obtained experimentally and calculations for the following values of the input parameters: the mill's drum radius \( R=0.5 \) m, length of the first chamber \( l_1 = 0.65 \) m, load factor of the first chamber \( \varphi_1 = 0.18 \), length of the second chamber \( l_2 = 1.3 \) m, the load factor of the second chamber \( \varphi_2 = 0.3 \), coefficient of sliding friction \( f = 0.4 \), the bulk density of the grinding load \( \gamma = 4 \) 550 kg/m3, the angle of inclination of the DAB and BES to the axis of the mill drum \( \alpha = 60^\circ \); relative rotational speed of the mill drum \( \psi = 0.76 \). It is established that the difference between the experimentally obtained and calculated data does not exceed 10%. With the indicated values of the input parameters, the additional power consumption is calculated: for the first camera - 62.2 W; for the second chamber - 441.0 W; in general for the mill - 503.2 W, experimentally obtained - 545 W.
3. Conclusion.

Analysis of the dependences obtained makes it possible to study the effect on the additional power consumption of the first chamber length, the angle of inclination of the LEED and the coefficients of loading the chambers with grinding bodies.

The installation of energy exchangers in the mill drum makes it possible to intensify the operation of the grinding load, as indicated by the value of the additional power consumed by the drive. The change in the angle of inclination of the lobed energy exchange devices to the axis of the mill drum from 40 to 80 leads to a decrease in the range of the device's action on the grinding load. This results in a reduction in the additional power consumption. The equations obtained analytically reflect the real process with sufficient accuracy.

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