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Determination of rational parameters for process of grinding materials pre-crushed by pressure in ball mill

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Abstract: The article presents the results of experimental studies on the grinding process of a clinker preliminarily ground in press roller mills in a ball mill equipped with energy exchange devices. The authors studied the influence of the coefficients of loading for grinding bodies of the first and second mill chambers, their lengths, angles of inclination, and the mutual location of energy exchange devices (the ellipse segment and the double-acting blade) on the output parameters of the grinding process (productivity, drive power consumption and specific energy consumption). It is clarified that the best results of the disaggregation and grinding process, judging by the minimum specific energy consumption in the grinding of clinker with an anisotropic texture after force deformation between the rolls of a press roller shredder, are achieved at a certain angle of ellipse segment inclination; the length of the first chamber and the coefficients of loading the chambers with grinding bodies.

1. Introduction

In the production of binders, one of the energy-intensive processes is the fine clinker and additives grinding, realized mainly in ball mills. However, despite seeming simplicity of design and operation, ball mills realize an inefficient method of grinding materials, in which most of the supplied mechanical energy is spent on heating grinding bodies and grinding materials, on the noise effect, etc. It increases significantly energy consumption for grinding. So, for example, on average about 35-40 kWh of electricity is used to grind one ton of cement in ball mills [1-2]. In addition, the implementation of several grinding regimes in ball mills presents certain difficulties and reduces the efficiency of grinding.

One of the promising directions both in Russia and abroad is the development of energy-saving systems for grinding materials with the removal of the coarse grinding stage into a press roller grinder (PRG) [3-4]. Implementation of a stepwise grinding method in cement manufacture using the ball mill (BM) together with the press roller unit makes it possible to increase productivity and reduce specific energy consumption by 20-40% [5-6].

2. Main part

Literature data analysis and conducted experimental studies have shown that a significant part of the grinding process of the material is carried out in the press grinding mill [6-7]. However, operation of the PVI in the open grinding cycle requires the final grinding of the material in a separate unit, particularly in a ball mill. Material crushed in PVI has specific properties; it has an anisotropic texture



and shape such as compressed plates with maximum strength in the direction of force action, and the particles - a microdefect structure. It is advisable to expose milling bodies with shock-shearing action in the first chamber and crushing-shearing - in the second one for its effective disaggregation and fine grinding by the ball mill. The installation of an energy exchange device (EED) in the mill drum: a double action blade (DAB) and an elliptical segment (ES) (Figure 1), leads to such impact of a grinding load on the crushed material. [8-10].

However, the process of grinding materials in BM is influenced significantly by the mutual position of the energy exchange devices in the drum, the load factors of the mill chambers and their length. Experimental researches were conducted to study their mutual influence on the performance of a ball mill. For the studied parameters, the following is adopted: the loading factors of the grinding bodies of the first φ_1 and second φ_2 mill chambers, the length of the first chamber - l_1 , the angle of ES slope - α , and the angle of ES and DAB displacement relative to each other - ξ .

To evaluate the efficiency of the clinker grinding process, output parameters are taken as follows: productivity Q , reduced to a total residue on the ΣR_{008} equal to 10%; the power consumption of drive N and specific electricity consumption q . The meaning of the variable parameters and rational variation levels are presented in Table 1.

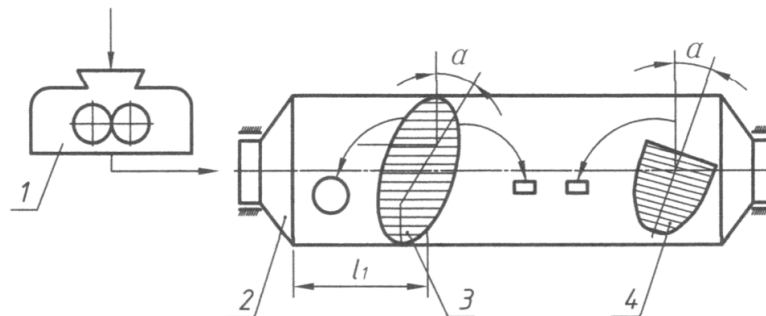


Figure 1. The grinding complex: 1-press roller grinder; 2-ball mill; 3- double-acting blade; 4- Ellipse segment

Table 1. Levels variation of factors

Factors	Coded notation	Step value	The value of the variable parameters				
			-1.547	-1	0	1	1.547
φ_1	X_1	0.02	0.149	0.16	0.18	0.2	0.211
φ_2	X_2	0.02	0.269	0.28	0.3	0.32	0.331
l_1, m	X_3	0.15	0.42	0.5	0.65	0.8	0.88
α, degree	X_4	30	-48.2	-30	0	30	48.2
ξ, degree	X_5	90	-139.2	-90	0	90	139.2

Regression equations were obtained after processing the results of the research. Regression equations $Q, N, q = f(\varphi_1, \varphi_2, l_1, \alpha, \xi)$ are presented in Figures 2 – 5 below.

The analysis of graphic dependences $Q, N, q = f(\varphi_1, l_1)$ (Figure 2) allows one to find out that with increasing the load factor of the grinding bodies of the first chamber mill in the range from $\varphi_1 = 0.149$ to $\varphi_1 = 0.211$, power consumption increases in proportion from $N = 4.15 \cdot 10^3 \text{ W}$ to $N = 4.55 \cdot 10^3 \text{ W}$, that is about 8,5%.

Mentioned productivity (Q) also increases from $Q = 164.1 \text{ kg/h}$ to $Q = 165.7 \text{ kg/h}$ in proportion to the growth of the mass of grinding bodies in the first chamber from 0.149 to 0.16.

However, with further increasing φ_1 to $\varphi_1 = 0.211$, there is a decrease in increment Q from $Q = 165.7$ kg / h to $Q = 166.4$ kg / h (less than 1%) and an increase in the specific electric power consumption from $q = 22.7$ to $q = 23.5$ W.h/kg.

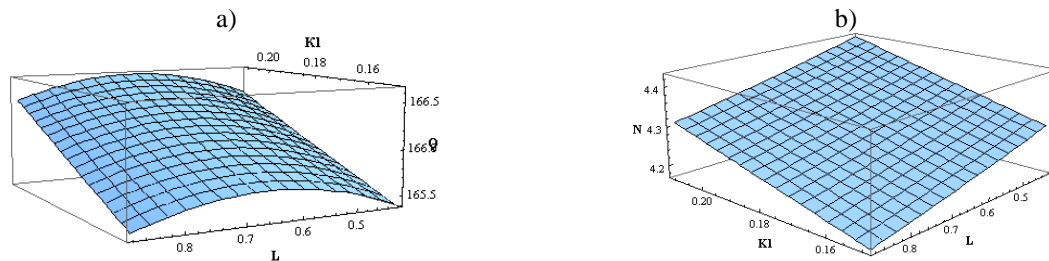


Figure 2. The effect of value of loading grinding bodies first chamber at Q, N, q , at different length, ($\varphi_2 = 0.3$; $\xi = 0$; $\alpha = -30^\circ$)

From the above, the following conclusion follows that the most efficient grinding process according with an amount of energy consumption is carried out at $\varphi_1 = 0.16$, which is much lower than during grinding of the clinker in the traditional way in a ball mill equal to $\varphi_1 = 0.3$.

When the length of the first chamber is changed (Figure 2a) in the range from $l_1 = 0.42$ m to $l_1 = 0.88$ m, the indicated capacity varies in dependence with extremum at $l_1 = 0.6$ m. The change of the length of the first mill chamber in one direction or another leads to a decrease of productivity. Thus, as the length of the first chamber decreases from $l_1 = 0.6$ m to $l_1 = 0.42$ m (Figure 1), the specific power consumption increases from $q = 22.7$ W h / kg to $q = 23.7$ W h / kg, i.e. by 4.5%. The increase in the length of the first chamber to $l_1 = 0.88$ m leads to a growth of q to $q = 24.9$ W h / kg, i.e. by 9.7%. From the foregoing information, it follows that the rational length of the first chamber during grinding of the clinker pre-milled in the PVG is $l_1 = 0.6$ m, that corresponds to $l_1 = 0.3 L$, where L is the length of the mill's drum.

Analysis of the graphical dependence (Figure 3) $Q, N, q = f(\varphi_2, \alpha)$ shows that changing the angle of inclination of the ellipse segment from the vertical axis of the mill ($\alpha = 0^\circ$) by an angle $\alpha = -30^\circ$ (0.53 radians) from the bottom of the mill leads to growth of performance from $Q = 158$ kg / h to $Q = 159.5$ kg / h - by 3.9%, while the specific energy consumption is reduced to the extremum $q = 23.0$ W h/kg. A further increase of the angle of inclination of ES to $\alpha = -48.2^\circ$ leads to an increase in the specific energy consumption from $q = 23.0$ W h/kg to $q = 23.7$ W h/kg (by 3%) and a more significant increase of N by 5%. This is because the ellipse segment inclines towards the unloading of the bottom of the mill by an angle of $\alpha = 48^\circ$, so there is accomplished a mixed mode of grinding bodies in the second mill chamber. Segment grabs a part of them and rises to a high altitude, thereby creating a waterfall grinding regime, instead of the required cascade. In this case, despite the fact that much grinding loading takes place, this does not lead to a significant increase in the reduced productivity Q (from $Q = 159.5$ kg/h to $Q = 160.2$ kg/h). Specific energy inputs increase more significantly from $q = 23.0$ W h/kg to $q = 25.5$ W h/kg, i.e. by 10.8%, which are due to a more significant increase in N . An increase in the angle of inclination of the ES towards the unloading bottom of the mill to $\alpha = 48.2^\circ$ leads to an increase of N by 4.8% ($N = 4.2 \cdot 10^3$ W to $N = 4.4 \cdot 10^3$ W), with an insignificant growth Q (from $Q = 159.5$ kg/h to $Q = 160.2$ kg/h), which affects the growth of q from $q = 23.7$ W h/kg to $q = 25.5$ W h/kg (by 6.7%).

From the foregoing information, it follows that in the grinding of pre-crushed in PRG materials with anisotropic texture, the most rational angle of the ellipse segment equals to 30° (0.53 radians) and it should be inclined from the unloading bottom of the mill. This is due to the fact that this location of the ES contributes to the intense crushing-abrasive action of the milling bodies on the material to be crushed, without disturbing the cascade operation. The increase in the loading factor of the grinding bodies of the second chamber from $\varphi_2 = 0.269$ to $\varphi_2 = 0.331$ leads to an insignificant proportional increase in the reduced productivity and the power consumption of the drive. This indicates that the

enhancement of the crushing-shear deformation positively affects the grinding process of materials with an anisotropic texture.



Figure 3. Influence of the angle of inclination of the ES on Q, N, q for different values of the loading of the grinding bodies of the second chamber, ($\varphi_1 = 0.16$; $\xi = 0^\circ$; $l_1 = 0.6$)

From the analysis of the graphical dependence $Q, N, q = f(\xi, \varphi_2)$ (Figure 4), it is clear that the mutual location of the double-action blade and the ellipse segment in the mill drum has a significant influence on the grinding process of the materials. Thus, the location of the DAB and ES in the mill drum, while their working surfaces are parallel to each other, allows obtaining the best results of the output parameters ($Q = 170$ kg/h, $q = 22.7$ W h/kg for ($\varphi_2, \varphi_1, \alpha$; $l_1 = \text{const}$). This location of energy exchange devices in the drum of the mill contributes to the creation of intense crushing-abrasive action of the milling bodies on the grinding material.

When the ellipse segment is displaced in one direction or another, the output parameters of the grinding process deteriorate. This is due to the creation in the second chamber of the mill conditions under which a part of grinding bodies operates in the waterfall mode. Such motion of the grinding bodies is ensured by the formation of a spatial trapezoidal figure between the energy exchangers, which helps to raise them to a bigger height. The symmetric nature of the change in the indices at the same angle of rotation of the ES along and against the direction of rotation of the drum is due to their different spatial positions relative to each other.

With an increase in the grinding factor of the mill (Figure 4) from $\varphi_2 = 0.269$ to $\varphi_2 = 0.3$ (at $\xi = 0^\circ$), there is observed a slight decrease in the specific electric power consumption from $q = 23.8$ W h/kg to $q = 22.7$ W h/kg, i.e. on 4.6%. This is due to a faster increase in productivity than the power consumption of the drive. A further increase in φ_2 to $\varphi_2 = 0.331$ does not lead to a significant improvement in the output. This indicates the need to maintain the loading factor of grinding bodies of the second mill chamber, equal to $\varphi_2 = 0.3$.

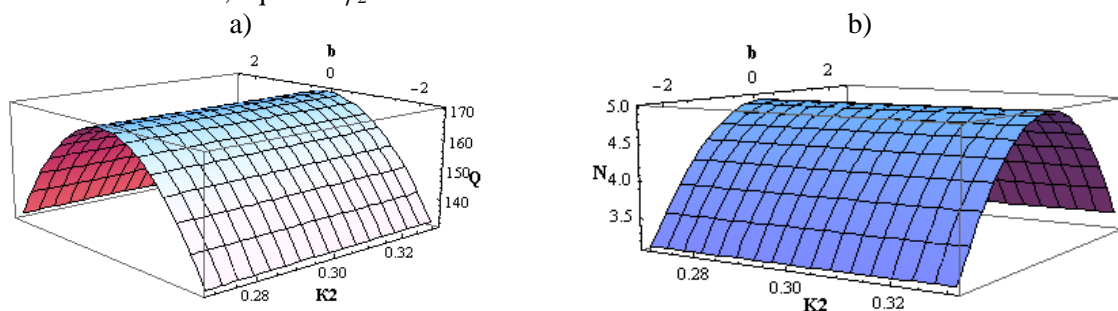


Figure 4. Influence of the displacement angle of the ES with relative to the LDE on Q, N, q at different loading values of the grinding bodies of the second chamber, ($\varphi_1 = 0.16$; $\alpha = -30^\circ$; $l_1 = 0.6$ m)

Analysis of the graphical dependence $Q, N, q = f(l, \alpha)$ (Figure 5) makes it possible to determine the influence of the length of the chambers on the output parameters of the ball mill at different slope angles of the ellipse segment.

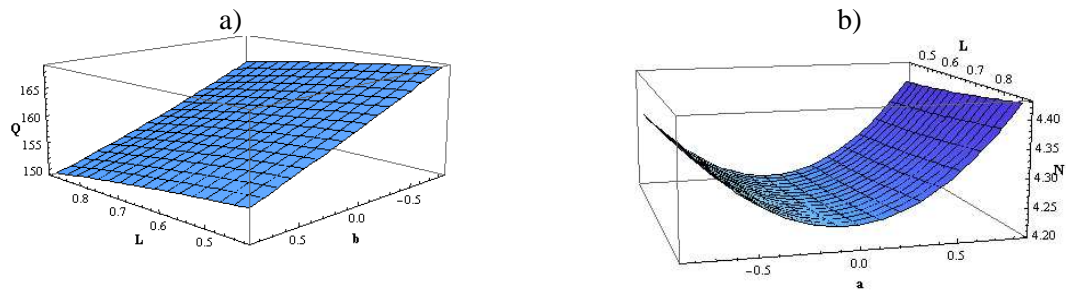


Figure 5. Influence of the length of the first chamber on Q , N , q for different angles of inclination of the ellipse segment ($\varphi_1 = 0.16$; $\xi = 0^\circ$; $\varphi_2 = 0.3$)

Extremes of functions that describe the change in Q productivity and specific energy consumption q for different angle of inclination of the blade ellipse segment correspond to the position of the length of the first chamber on the graphs equal to $l_1 = 0.6$ m.

The change in the angle of inclination of vane ellipse segment α from the vertical position in either direction to $\alpha = -48.2^\circ$ and $\alpha = 48.2^\circ$ (Figure 5) entails a change in the nature of the action of the ellipse segment on grinding bodies, which adversely affects the aggregate productivity.

The change in the length of the first chamber from position $l_1 = 0.6$ m leads to a decrease in the mill's productivity because of a decrease in its length the coarser product enters the chamber of fine grinding. And as its length increases the second mill chamber decreases, which does not provide the required grinding quality.

The best results of the process of disaggregation and grinding, judging by the minimum specific energy consumption in the grinding of clinker with anisotropic texture obtained after force deformation between the rolls of a press roller grinder equal to $q_{min} = 22.7$ W h/kg ($Q = 170$ kg/h), are achieved with: the angle of inclination of the ellipse segment equal to $\alpha = -30^\circ$, the length of the first chamber - $l_1 = 0.6$ m, the loading coefficients of the chambers - grinding bodies $\varphi_1 = 0.16$, $\varphi_2 = 0.3$, and the displacement angle of the double-action blade relative to the segment - $\xi = 0^\circ$.

3. Conclusion

Thus, the conducted experimental studies on the process of de-agglomeration and grinding in a ball mill, equipped with an ES of the pre-crushed in PVI clinker with an anisotropic texture, testify to the advisability of realizing the shock-shearing effect of grinding bodies in the first mill chamber and the crushing-shearing effect of it in the second. The rational operating mode of the ball mill is ensured when the ellipse segment is tilted from the unloading bottom at an angle of 30° from the vertical axis of the mill drum when its working surface is parallel to the double-action blade, at $\varphi_1 = 0.16$, $\varphi_2 = 0.3$, $l_1 = 0.6$ m and $\xi = 0^\circ$. The following results are achieved: $q_{min} = 22.7$ W h/kg, $N = 3.86 \times 10^3$ W, $Q = 170$ kg / h.

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