To the question of the cement production materials destruction

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Abstract. The article deals with the problem of determining the energy for the cement production materials destruction. It is shown that the destruction of various materials consumes a significant amount of energy. One of the most energy-intensive building materials is cement. The method of energy calculation for the cement production materials grinding on the cement clinker example is proposed. The grinding cement clinker process and additives is described on the basis of the thermodynamic method. The assumptions are made under which the destruction of the cement clinker occurs under the influence of external forces. The change in the volume of the crushed material due to the increase in energy in the original volume is shown. The expression for the elementary work on the cement clinker particles destruction is proposed. The expression for determining the total work on grinding the particle of cement clinker depending on its size, generalized thermodynamic force and elastic modulus of the crushed material is obtained.

Introduction
The production of various building materials requires considerable energy for the raw materials destruction [1-3]. Many materials are crushed to the sizes less than a millimeter dozens of times. This further increases the energy intensity of the grinding process, which can reach 100 kWh / t or more [1, 4-6]. Cement is one of the most popular building materials [1, 10-13]. At the same time, 30 ... 40 kWh / t and more are used for the cement clinker grinding. To ensure the maximum efficiency of the cement clinker and additives grinding, the value of the circulating load of ball mills of a closed cycle is of great importance [1, 6, 14, 15]. The negative effects occur (less, but still noticeable) to the open-cycle mills overgrinding, and as a result, sticking of chalking solids and lining, as well as aggregation of grinding products at the low values of circulation loads in ball mills. At the same time, the high circulation loads require a large capacity ball mills, classifiers and significant capital costs for the material large amounts transporting [16, 17].

The solution of the material crushing problem determining the energy, in particular the cement clinker, was discussed in the works [18-21]. The correct determination of the energy for the particles crushing in the mill will allow to choose the right composition of the chalking solids, mill lining of various chambers, etc. All this will improve the mill’s productivity, reduce the energy intensity of the process and the cement production total efficiency.

A number of formulas, determining the relationship between the circulating load, design elements of the mill and its performance are presented below. The conclusion is made on the basis of the
thermodynamic method of describing the grinding process of cement clinker and additives in the production of high-quality cements.

At the first stage, we determine the necessary amount of work to destroy the cement clinker in a ball mill.

In this method development, the destruction of cement clinker under the influence of external forces is assumed to occur under the following conditions:

– the cement clinker external impact occurs taking into account the volume of the substance particles;
– at the clinker particle’s transferring the energy value above the threshold, under the action of which the site begins to collapse, generating tensile stresses, then the equilibrium sizes of cracks (defects) start being increased under these stresses’ influence (at considerable stresses);
– on the other hand, the tensile stresses in the selected volume of the cement clinker generate a response that prevents this expansion.

**Theoretical**

If we determine the expansion work done by stretching the area of cement clinker, it is possible to calculate the value of the newly formed surface.

Supposing that the area volume $V_0$ was formed as a result of the external action in the cement clinker and concentrated the energy of $\delta Q$. Due to the increase in the volume of $V_0$ by the value of $dV$, the tensile stresses arise contributing to the formation and increase in the size of the crack, which reaches the free surface of the crushed clinker as a result of germination and thereby leads to its crushing.

When expanding the volume of $V_0$ by the value of $dV$ the elementary work is done:

$$\delta A = +fdV,$$

where $f$ is the generalized thermodynamic force, Pa; $V$ is the generalized coordinate equal in this case to the volume, m$^3$.

In the ratio (1), the change in the volume of the ground body occurs due to the increase in energy in the initial volume $V_0$ by $\delta Q$. At the same time, the force $f$ in the surrounding volume $V_0$ is generated, which prevents the latter from increasing. By virtue of the above-mentioned, we assume that $V = V(Q, f)$ then the full differential $dV$, included in the expression (1), can be represented as follows:

$$dV = \frac{dV}{dQ} \delta Q + \frac{dV}{df} df,$$

We introduce the following notations:

$$\alpha = \frac{dV}{dQ} \frac{1}{V_0},$$

where $\alpha$ is the coefficient of energy expansion of the substance.

$$E_0 = -\left( \frac{df}{dV} \right) V_0,$$

where $E_0$ is the bulk modulus of elasticity, which is associated with the modulus of elasticity by the following ratio, Pa:

$$E_0 = \frac{E}{3(1-2\mu)}.$$

Here $\mu$ is the Poisson's ratio; $E$ is the crushed material elasticity modulus (Young's modulus), Pa.

The ratio (2) given in the expressions (3) and (4) can be represented as:

$$dV = \alpha V_0 \delta Q - \frac{V_0}{E_0} df.$$
Substituting equation (6) into equation (1) leads to the following expression for elementary work on the destruction of a cement clinker particle:

\[ \delta A = f \alpha V_0 \delta Q - \frac{f V_0}{E_0} \, df. \]  

(7)

If we assume that the values of \( f, \alpha, V_0 \) do not depend on \( Q \), and \( V_0 \) and \( E_0 \) do not depend on \( f \), then the integration of the ratio (7) within certain limits leads to the result:

\[ A = f \alpha V_0 Q - \frac{f^2 V_0}{2E_0}. \]  

(8)

The first term in the expression (8) is the work of the compaction zone, which is spent on “crack germination” in the volume \( V_0 \), the second term in the same expression is the energy of elastic deformation, stored volume \( V_0 \) under the generalized thermodynamic force \( f \).

From the relation (8) we can assume that if \( Q \) and \( f \) are zero, then \( A = 0 \). That is, in the absence of energy supply to the milled clinker, there is no generalized thermodynamic force \( f \) and the work is not performed. In addition, there is a threshold value of the generalized thermodynamic force \( f^* \) and when the condition \( f \geq f^* \) \( a = 0 \). To obtain the expression defining \( f^* \), put \( f = f^* \) and \( A = 0 \) in equation (8). So we have

\[ f = 2\alpha E_0 Q. \]  

(9)

Calculating the first derivative of the work on \( f \), we get:

\[ \frac{dA}{df} = \alpha V_0 Q - \frac{f V_0}{E_0}. \]  

(10)

From the condition of equality to zero ratio (10) we find the value:

\[ f_e = \alpha E_0 Q. \]  

(11)

The expression of the second derivative of the expression (10) by \( f \) leads to the following relation:

\[ \frac{d^2 A}{df^2} = -\frac{V_0}{E_0} < 0. \]  

(12)

Because of the positivity of \( V_0 \) and \( E_0 \), the value of the expression (12) is negative for any values of \( V_0 \) and \( E_0 \). Therefore, the expression (8) takes the maximum value at \( f = f_e \), which is specified by the following expression:

\[ A_{\text{max}} = \frac{\alpha^2 Q E_0 V_0}{2}. \]  

(13)

Determine the efficiency \( \eta \) by converting the energy \( Q \), introduced into the volume \( V_0 \) of the crushed clinker, to work on its destruction (crack germination) and the formation of a new surface according to the following formula:

\[ \eta = \alpha V_0 - \frac{f^2 V_0}{2E_0 Q}. \]  

(14)

The increase of the value \( Q \) the efficiency also increases and reaches its maximum value at \( A = A_{\text{max}} \) follows from the relation (14), therefore the substitution of the relation (13) in (14) leads to the result:

\[ \eta_{\text{max}} = \frac{\alpha^2}{2} Q E_0 V_0. \]  

(15)

The equation (7) can also be converted to form:

\[ \frac{dA}{df} = f V_0 \left( \alpha \frac{dQ}{df} - \frac{1}{E_0} \right). \]  

(16)
Summary
The obtained ratio (16) shows that the change in the work depends on the change in the value of the generalized thermodynamic force depending on the change in the amount of the energy accumulated by the volume $V_0$.

In the future, taking the dimensions of the material to be ground and the chalking solids, it is possible to determine the number of particles obtained by a single particle grinding. By accepting the number of these particles and their sizes, the number of the chalking solids and their sizes, the number of collisions and the grinding time, and ultimately, with the given finished material’s specific surface through the average size of the finished material it is possible to determine both the productivity of the crusher and the time amount spent for the finished energy product.

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