Study of the material crush process with an anisotropic texture between rolls with displaced rotation centers

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Abstract. The article aims at obtaining the analytical dependences to determine the optimal material crush process with an anisotropic texture between rolls with displaced centers of rotation. The data analysis allowed establishing the grinding materials process implementation due to the sectional mode with the coarse grinding stage removal outside the ball mill in a separate unit, providing the best conditions for the material crush and is very promising. The material crush process is determined by the rocks’ destruction mechanism and its features, which include the rock-crushing action dual nature – crushing rock axial force, as well as some design features of the rolls. The features affecting the anisotropic rock crush process and the overturning moment appearance the shape and size of the rock-breaking inserts, the angle of their suspension, the parameters of the rock-breaking elements’ physical and mechanical properties.

Introduction
During analytical and exploratory experimental studies, it was found that anisotropic materials are advisable to grind by crushing-shear deformation between the rolls with a gravity displaced center. In order to determine the grinding pressure value, let us consider the material crush process with an anisotropic texture in the press-roll grinder by deformation between the rolls with a displaced center of gravity. [1]

Let us consider the scheme to determine the grinding pressure value (Figure 1), according to which the sum of forces arising in the elementary layer on the coordinate axis “x” and “y” is equal to:

\[
\sum F_x = 0,
\]

\[
R_{\alpha} \cdot q \cdot d \alpha \cdot \cos \alpha - R_{\alpha} \cdot q \cdot d \alpha \cdot f \cdot \sin \alpha - \delta_x \cdot dy = 0; \tag{1}
\]

\[
\sum F_y = 0,
\]

\[
\delta_y \cdot h_x - (\delta_y + d\delta_y) \cdot (h_x + dh_x) + R_{\alpha} \cdot q \cdot d \alpha \cdot \sin \alpha - f \cdot R_{\alpha} \cdot q \cdot d \alpha \cdot \cos \alpha = 0 \tag{2}
\]
where \( R_s \) - is the roll radius, m; \( q \) - is the specific pressure, N/m\(^2\); \( \alpha_{def} \) - defines the force application angle value; \( f \) - is the coefficient of friction; \( \delta_x \) - is the normal stress arising in the milled layer, N/m\(^2\). [2]

According to Figure 1 we get:

\[
\sin \alpha_{def} = \frac{dh_x}{R_s d\alpha_{def}}; \quad R_s \sin \alpha_{def} = \frac{dh_x}{d\alpha_{def}},
\]

\[
dy = R_s d\alpha_{def} \cos \alpha_{def}, \quad h_{x,def} = \delta + R_s (1 - \cos \alpha_{def}).
\]

**Figure 1.** The scheme for determining the pressure of grinding.

Substituting the equality data in (1) and (2), we obtain the following expressions:

\[
R_s q d\alpha_{def} \cos \alpha_{def} + R_s q d\alpha_{def} f \sin \alpha_{def} - \delta_x R_s q d\alpha_{def} \cos \alpha_{def} = 0 \quad (3)
\]

\[
d\delta_x h_x + \delta_x dh_x + R_s q f d\alpha_{def} \cos \alpha_{def} - R_s q d\alpha_{def} \sin \alpha_{def} = 0 \quad (4)
\]

Grinding of material particles with an anisotropic texture has the following form \( \nu = \frac{dy}{dx} \), then the equation takes the form:

\[
q \left( \cos \alpha_{def} + f \sin \alpha_{def} \right) - \nu \delta_x \cos \alpha_{def} = 0 \quad (5)
\]

After carrying out the corresponding transformations, we obtain the following expression:

\[
q = \frac{\nu \delta_x \cos \alpha_{def}}{f \sin \alpha_{def} + \cos \alpha_{def}} \quad (6)
\]

From figure 1. we obtain that \( q = P_{xy}, \; dh_x = R_s d\alpha_{def} \sin \alpha_{def} \)

then \( - R_s q d\alpha_{def} \sin \alpha_{def} = -Pdh_x \quad (7) \)

and, \( R_s q f d\alpha_{def} \cos \alpha_{def} = F_{b,xy} \frac{dh_x}{tg \alpha_{def}} \quad (8) \)

Substituting the values (7) and (8) into the equation (4) we obtain:
\[ d\delta_y h_x + \delta_x dh_x - Pdh_x + F_{\delta x y} \frac{dh_x}{\tan \alpha_{def}} = 0 \] (9)

The force required to overcome the fracture resistance of material particles layer with an anisotropic texture can be described by the equation:

\[ P_i = P_{max} \left(1 - \frac{h_x - \delta}{\Delta h}\right) \] (10)

where, \( P_{xy, max} \) is the maximum force value required for the material layer crush with an anisotropic texture, N/m²; \( \Delta h \) - is the value of the material layer deformation with anisotropic texture, m. [3]

According to figure 1 and the equation (10) takes the form:

\[ P_i - \delta_y = P_{max} \left(1 - \frac{h_x - \delta}{\Delta h}\right) \] (11)

Converting the equation (2.36) we obtain the following expression:

\[ d\delta_y = dP_i + \frac{P_{max}}{\Delta h} dh_x \] (12)

After making the appropriate substitutions, deciding together (11) and (12) we obtain the following expression:

\[ \frac{dP_i}{dh_x} + P_i \frac{f}{h_x \tan \alpha_{def}} = \frac{P_{max}}{\Delta h} \left(1 - \frac{2}{h_x} \right) \] (13)

where \( h_x \) - is the initial height of the material particles layer with anisotropic texture. By differentiating, the expression will take the form:

\[ P_{xy} = \frac{P_{max}}{\Delta h} \frac{h_{\alpha, def} - 2}{h_x} \exp \int \frac{f}{\tan \alpha_{def} h_x} dh_y dx + C \]

\[ \exp \frac{f}{\tan \alpha_{def} h_x} \] (14)

By making the necessary transformations, we have:

\[ P_i = \frac{P_{max}}{\Delta h} \frac{h_{\alpha, def} - 2}{h_x} \left( \frac{\tan \alpha_{def} \left(H_o \tan \alpha_{def} + f (H_o - 2h_x) \right)}{f \left(f + \tan \alpha_{def} \right)} \right) + C \frac{1}{h_x^f \tan \alpha_{def}} \] (15)

Let us define a constant value from the equation \( C \), at \( h_x = h_{\alpha, def} \); \( P_{xy} = 0 \); the expression will take the form:

\[ C = \frac{P_{max}}{\Delta h} \frac{H_o \tan \alpha_{def} - f_{\alpha} \tan \alpha_{def} h_x^f \tan \alpha_{def}}{f_{\alpha} f + \tan \alpha_{def}} \] (16)

After the joint solution of equations (15) and (16) we obtain the following expression:

\[ P_i = \frac{P_{max} H_o \tan \alpha_{def}}{\Delta h f \left(f + \tan \alpha_{def} \right)} \left[ 1 + \frac{f}{\tan \alpha_{def} \left(1 - \frac{2}{H_o} \right) - \left(\tan \alpha_{def} - f \frac{H_o}{h_x} \right) \tan \alpha_{def}}{h_x^f \tan \alpha_{def}} \right] \] (17)
Taking into account the equation (2.19), we determine the total value of the grinding pressure $F_{ud}$, which depends on their physical and mechanical characteristics of materials with anisotropic texture and design of the grinder working bodies and can be determined by the expression:

$$F_{ud} = 0.71fL\alpha e\sigma_{szh} (tg\gamma - f_T)/e^{S,cos\alpha}$$

The value of the total force $P_i = F_{ud}$ in the zone of maximum pressure of grinding materials with an anisotropic texture, equating $h_T = \delta$ expression (17) will take the form:

$$Dl \frac{0.71fL\alpha k\sigma_{szh}}{k_{an}} (tg\gamma - f_T)/e^{S,cos\alpha} \cdot \frac{H_0 \cdot tg\alpha_{def}}{\Delta h_{\delta}} (f_{\alpha} + tg\alpha_{def})$$

$$\left[1 + \frac{f_T}{tg\alpha_{def}} \left(1 - \frac{2(H_0 - \delta)}{H_0} \right) \cdot \frac{tg\alpha_{def} - f_T}{tg\alpha_{def}} \left(\frac{H_0}{h_x} f_{\alpha} + tg\alpha_{def} \right)\right]$$

(18)

**Main part**

We will calculate the required amount of effort to overcome resistance of material layer crush with an anisotropic texture $P_i$, based on the following design and technological parameters of the press-roll grinder between the rolls with a displaced center of rotation and physical and mechanical characteristics of organogenic limestone: bulk mass $- \rho_0 = 2320$ kg/m$^3$; compressive strength $- \sigma_{szh} = 95$ MPa and $\sigma_{szh} = 65$ MPa; radius of rolls $R = 0.5$ m; the gap between the rolls $- \delta = 15 \cdot 10^{-3}$ m; the displacement of the center of rotation of the rolls $e_1 = e_2 = 30 \cdot 10^{-3}$ m; respectively, the anisotropy and deformation coefficients are equal to $k_{an} = 1.46$ and $k_a = 3.2$. The average diameter of the pieces is $d_{av} = 4 \cdot 10^{-3}$ m. The average value of the angle of inclination of the contact area of the grains, to three axes of coordinates $tg\gamma = 1.2$; $\alpha = 4^\circ$, the friction coefficients of internal $f$ and external $f_T$ $- f = 0.35$; $f_{\alpha} = 0.42$; the value of the coefficient, depending on the lateral pressure $\xi = 0.24$; the force application angle value $a = 30^\circ$; deformation coefficient $K_{upl} = 2$; $\alpha_k = 1$; $tg \gamma \approx 45^\circ$ $= 1$; $k_a = 2$; $\xi = 0.24$; $H_0 = 30 \cdot 10^{-3}$ m; roll width $B = 0.3$ m; the rolls radius $R_{av} = 0.25$ m. [4]

The deformation angle value is determined by the expression:

$$\alpha_{defR} = arccos \left[1 - \frac{\delta(K_{upl} - 1)}{2R}\right],$$

$$\alpha_{defR} = arccos \left[1 - \frac{15 \cdot 10^{-3} (2 - 1)}{2 \cdot 0.5}\right] = arccos 0.985 \approx 10^\circ.$$  

The angle value of material deformation with an anisotropic texture for each roll is determined by the following equation:

$$\alpha_{defR1} = arctg \frac{R \sin \alpha_{defR}}{R \cos \alpha_{defR} + e} = arctg \frac{0.5 \cdot 0.1736}{0.5 \cdot 0.9848 + 3 \cdot 10^{-3}} \approx arctg 0.1752 \approx 9.9^\circ.$$
Taking the value of the material deformation angle with an anisotropic texture for each of the rolls, equal $\alpha_{defRe} = 10^\circ$.

Let us determine the grip width between the rolls:

$$H_o = 2R(1 - \cos\alpha_{def}) + \delta = 2 \cdot 0.5(1 - \cos10^\circ) + 15 \cdot 10^{-3} = 30 \cdot 10^{-3} \text{ m}.$$  

The value of the material deformation perimeter with an anisotropic texture is determined by the equation:

$$L = 2(B + \delta) = 2(0.3 + 0.015) = 0.63 \text{ m}.$$  

The grinding pressure value of the material in the rolls with a displaced center of rotation is determined by the equation:

$$P_i = \frac{0.71 \cdot 1.03 \cdot 0.35 \cdot 95}{1.46} \cdot (1.2 - 0.42) \cdot 2.7 \left( \frac{0.240 \cdot 0.350 \cdot 0.630 \cdot 0.015}{0.5^2 \cdot 3.141} \right) \cdot \frac{30 \cdot 10^{-3} \cdot 0.1763}{15 \cdot 0.42 \cdot 10^{-3} (0.42 + 0.1763)} \cdot \left[ 1 + \frac{0.42}{0.1763} \left( 1 - \frac{2 \cdot 15 \cdot 10^{-3}}{30 \cdot 10^{-3}} \right) \right] = 148.6 \text{ MPa}.$$  

By comparing experimentally obtained values equal to 141 MPa and calculated values equal to 148.6 MPa, it was found that the obtained expression reflects the real process with sufficient accuracy. The difference is less than 10%.

Results

The obtained graphic dependence analysis allowed us to establish that with the increase in the rolls’ diameter, the forces necessary for the material crush also increase. In order to reduce the efforts of grinding materials with an anisotropic texture, it is necessary to make efforts in the pieces’ lowest strength direction. This makes it necessary to develop a device that allows a directed supply of materials with an anisotropic texture to the working bodies of the shredder. [5-8]

Summary

1. In the article, the material crush analytical model of s with anisotropic texture between the rolls was constructed.

2. As a result of the analytical studies, an equation for determining the force required for grinding anisotropic materials by pressure was obtained.

3. The rolls radius influence and the strength of the materials with the required pressure was established, etc.

References

[1] Denisevich G A 2001 Mechanics of a granular medium (Problems of mechanics) 3 91-93.

[2] Verdiyan M A 1977 The Process of grinding solids, results of science and technology (Processes and devices of chemical technology) 5 5-90.

[3] Gridchin A M 2006 Improving the efficiency of road construction through the use of anisotropic raw materials (Moscow, Ed. Association of construction universities) 2 486-788.

[4] Mersman M 2005 Technology for the modernization of cement plants of the company KHD Humboldt Wedag GmbH (Cement and Its application) 3 40-43.
[5] Sucker M 2006 Installations for the production of roller presses cement company (Cement, lime, gypsum) 2 60-64.

[6] Romanovich A A, Romanovich M A, Belov A I, Chekhovskoy E I 2018 Energy-saving technology of obtaining composite binders using technogenic wastes (IOP Conference Series, Journal of Physics: Conf. Series) 1118 (012035).

[7] Romanovich A A, Kolesnikov R S, Romanovich M A 2018 Study of device for precompaction and uniform supply of materials to working bodies of aggregate (Materials Science and Engineering, Conf. Series) 042052.

[8] Romanovich A A, Chekhovskoy E I, Romanovich M A 2017 Apukhtina, Calculation of the power of the unit drive for obtaining cube-shaped rubble (Bulletin of I.V. BSTU named after V.G. Shukhov) 7 111-115.

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