Chapter 108
Study on the Crush Model of High-Pressure Grinding Rolls

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Abstract A high-pressure grinding roll is energy efficient crush equipment. On the basis of mass balance, energy conservation and overall balance, this paper puts forward the intersected idea due to the uneven stress in the roller surface. The grinding and comminution model of roller press is deeply investigated. It puts forward crush model using mathematic theory. The simulated specific energy consumptions and particle size distributions, compared with the experiment data, were considered good enough. The model was able to predict adequately throughput capacity, specific energy consumption and particle size distributions of the edge, center and total products.

Keywords HPGR · Bed compression · Modeling

108.1 Introduction

The first commercial application of high-pressure grinding roll (HPGR) was in 1985 and its success resulted in increasing numbers of applications since then. The classical theory is bed compression crush theory. It can be described: mineral particle is crushed under lots of bed compression condition. Every crush machine cannot reach the ideal bed compression condition because of different crush

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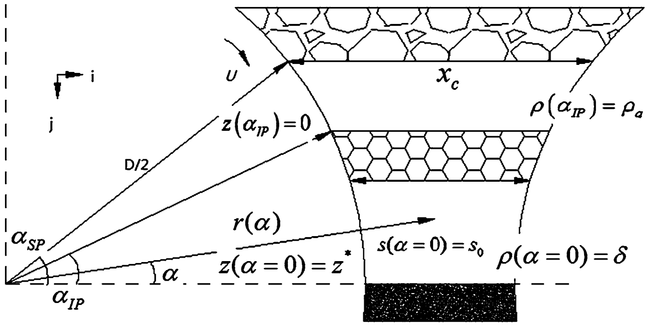

Fig. 108.1 Crush schematic diagram of HPGR

condition. Reference [1] studies the effect law which load—displacement curves, bed height and load characteristic direct crush on the basis of bed compression grinding theory. Reference [2] gets a new concept of the differential shear theory, which based on the study of process and result of the high-pressure double roller cracker for brittleness ore crush. Most of the researchers follow the crush of a single particle theory of crack propagation and energy balance principle and the experimental test data for various amendments; there is no good explanation for formation mechanism of the cake under the high-pressure crush.

108.2 Modeling

HPGR rely on pure compressive stress to squeeze broken. The breakage of ore occurred in a short time. Its energy consumption is mainly reflected by the amount of the pressure. This paper puts forward the crush model of HPGR on the basis of ore characteristics, equipment dimensions and operating conditions. The model structure is developed by Daniel and Morrell [3] on the basis of conservation of mass, conservation of energy and overall balance. So it can predict throughput, power consumption and particle size distribution of the product. Figure 108.1 is crush schematic diagram of HPGR.

108.2.1 Throughput Model

The center of mass of a band of ore with width *s(a)* is defined by the position of vector *r(a)*, diameter *D*(m), length *F*(m) and operating gap s_0(m). So:

$$r(\alpha) = \frac{1}{2}(D + s_0)\mathbf{i} + \frac{D}{2}\sin\alpha\mathbf{k}. \tag{108.1}$$

The density of the ore band at any angle *a* is *r(a)*. At the beginning of the particle bed compression zone, *r(a)* is equivalent to the feed bulk density *r(a)*. The tonnage of the ore band, G_s (t/h), with *r(a)* expressed in t/m3, is written as a function of the angle *a* in Eq. (108.2)

$$G_s(\alpha) = 3600\rho(\alpha)s(\alpha)LU\cos\alpha. \tag{108.2}$$

The width of the ore band as a function of the angle *a* can be expressed as:

$$s(\alpha) = s_0 + D(1 - \cos\alpha). \tag{108.3}$$

Under steady-state condition, if the amount of material loss is zero, i.e. the feed is equal to the product; we can get the next Eq. (108.4)

$$\rho_a D\cos^2\alpha_{IP} - \rho_a(s_0 + D)\cos\alpha_{IP} + \delta s_0 = 0. \tag{108.4}$$

We can find Eq. (108.4) is a quadratic equation of $\cos\alpha_{IP}$. Because $D = b^2 - 4ac > 0$, the equation has two roots. We can get Eq. (108.5) according to actual situation.

$$\cos\alpha_{IP} = \frac{1}{2D}\left[(s_0 + D) + \sqrt{(s_0 + D)^2 - \frac{4s_0\delta D}{\rho_a}}\right]. \tag{108.5}$$

So Eq. (108.2) can estimate throughput in any position. Specifically at the extrusion zone ($a = 0$), the throughput can be calculated as:

$$G_S = 3600\delta s_0 LU. \tag{108.6}$$

108.2.2 Power Draw Model

The force applied to the material at the particle bed compression zone is called the compression force, F (kN). The rolls operating pressure is R_P (bar). The total power draw is P (kW). Since the HPGR is operated in a choke fed condition, the applied pressure is distributed only in the upper right half of the roll. Then the projected area considered should be $\frac{D}{2}L$

$$F = 100R_P\frac{D}{2}L. \tag{108.7}$$

Then torque t (kN/m) can be written as:

$$\tau = F\sin\left(\frac{\alpha_{IP}}{2}\right)\frac{D}{2}. \tag{108.8}$$

As the power required to spin both rolls is equal to twice the torque multiplied by the rolls angular velocity, then P can be written as:

$$P = 2F\sin\left(\frac{\alpha_{IP}}{2}\right)U. \tag{108.9}$$

The energy consumption W(kWh/t)is written as the ratio between the power draw (kW) and the throughput (t/h):

$$W = \frac{P}{G_S} = \frac{F\sin\left(\frac{\alpha_{IP}}{2}\right)}{1800\delta s_0 L}. \tag{108.10}$$

108.2.3 Particle Size Distribution Model

The HPGR is considered as a series of two size reduction stages. The first stage is single particle compression. The next stage is particle bed compression.

The single particle compression zone is located between the angle a_{SP} and a_{IP}. Particles larger than a certain size C_c are broken. The critical size C_c is got by replacing the inter particle compression angle a_{IP} in Eq. (108.3).

$$\chi_C = s(\alpha_{IP}) = s_0 + D(1 - \cos\alpha_{IP}). \tag{108.11}$$

The product of the single particle compression zone rejoins with the fraction of material of material of size lesser than or equal to the critical size C_c, forming beds of particles with a particle size distribution. Then it starts particle bed compression. According to previous sum up, the particle bed compression is broken into two areas, namely the central area and edge zone. It is also known as edge effects. The pressure profile exerted over the rolls is similar to a parabola, as it is shown in Fig. 108.2. In Fig. 108.2, rolls are divided into N_B equal portions. Because every N_B equal portion is different, every power of N_B equal portions is different and every crush rate of N_B equal portions is different. The intensive property m_{ik} (mass fraction retained by weight in size class i, in each block k) is a function of the vertical position. According to mass balance principle, the model equation consists in a system of $N' \, N_B$ differential equations, each one for the size class i $(i = 1, \ldots, N)$ in each block k $(k = 1, \ldots, N_B)$. As shown in Eq. (108.12)

$$v_z \frac{\mathrm{d}}{\mathrm{d}z} m_{i,k}(z) = \sum_{j=1}^{i-1} S_{j,k} b_{ij} m_{j,k}(z) - S_{i,k} m_{i,k}(z), \tag{108.12}$$

where S_{jk} is the rate of breakage of particles of size i in each block k; b_{ij} is the fraction of particles of size "i". To solve these equations the following border conditions are used:

$$m_{i,k}(z = 0) = f_i^{IP},\ m_{i,k}(z = z^*) = p_{i,k}$$

where $p_{i,k}$ is the mass fraction retained by weight in size class i, in the product of each block k. Z^* is the vertical distance from the entrance to the particle bed compression zone to the extrusion zone.

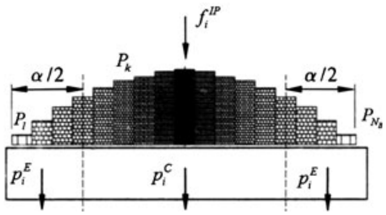

Fig. 108.2 Discretization of the roll

$$z^* = \frac{D}{2}\sin(\alpha_{IP}). \tag{108.13}$$

Equation (108.12) seems to be the batch grinding kinetic equation, which has been solved analytically by Reid [5]. The solution is written (Fig. 108.2):

$$p_{i,k} = \sum_{j=1}^{i} A_{ij,k} \exp\left(-\frac{S_{j,k}}{v_z} z^*\right). \tag{108.14}$$

where

$$A_{ij,k} = \begin{cases} 0 & i<j \\ \sum_{l=j}^{i-1} \dfrac{b_{il} S_{l,k}}{S_{i,k} - S_{j,k}} A_{lj,k} & i>j \\ f_i^{IP} - \sum_{l=1}^{i-1} A_{il,k} & i=j \end{cases}. \tag{108.15}$$

In mathematics, $\lfloor E \rfloor$ is defined as the largest integer less than or equal to E. $\lfloor E \rfloor$ is defined as the smallest integer not less than E. So the particle size distribution of the edges product p_i^E can be calculated as:

$$p_i^E = \frac{1}{E}\left[\sum_{k=1}^{\lfloor E \rfloor} p_{i,k} + (E - \lfloor E \rfloor) p_{i,\lceil E \rceil}\right]. \tag{108.16}$$

The particle size distribution of the total product p_i^{HPGR} is :

$$p_i^{\mathrm{HPGR}} = \frac{1}{N_B}\sum_{k=1}^{N_B} p_{i,k}. \tag{108.17}$$

The particle size distribution of the center product is:

$$p_i^C = \frac{1}{1-a}\left(p_i^{\mathrm{HPGR}} - a p_i^E\right). \tag{108.18}$$

Table 108.1 Data of A ore and B ore

Test	Feed	A1	A2	A3	A4	A5	A6
Operating conditions							
U (m/s)		0.66	0.38	0.66	0.95	0.66	0.65
R_P (MPa)		4.0	6.0	6.0	5.9	7.5	7.5
Size (mm)	Percent passing (%)						
45.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
31.60	97.62	100.00	100.00	100.00	100.00	100.00	100.00
22.60	57.50	98.35	98.91	99.72	99.32	100.00	100.00
15.80	36.60	84.85	96.45x	92.53	92.15	94.92	94.64
11.10	25.70	71.78	88.76	83.84	83.27	84.16	89.16
7.80	20.33	61.83	78.94	74.72	72.02	75.16	81.02
5.50	15.92	52.84	68.92	65.19	62.62	66.72	70.42
2.70	10.51	39.20	54.62	49.90	47.65	51.80	55.51
1.00	6.73	25.23	36.41	32.68	32.01	34.98	38.03
0.50	5.10	19.50	28.68	25.67	24.45	27.76	30.20
0.30	4.35	16.68	24.96	22.29	21.48	24.16	26.41
0.20	3.41	14.05	21.45	19.15	18.64	20.87	22.72
0.13	2.48	11.73	18.36	16.45	15.94	17.83	19.81
power consumption		1.43	2.04	2.01	2.03	2.41	2.45
Test	Feed	B1	B2	B3	B4	B5	B6
Operating conditions							
U (m/s)		0.66	0.38	0.66	0.95	0.65	0.65
R_P (MPa)		3.8	5.9	5.9	5.9	7.4	5.8
Size (mm)	Percent passing (%)						
31.60	96.30	100.00	100.00	100.00	100.00	100.00	100.00
22.60	65.50	100.00	100.00	100.00	100.00	100.00	99.67
15.80	43.20	94.23	96.35	96.64	97.84	96.86	96.58
11.10	31.00	83.13	85.64	85.46	88.46	88.46	86.79
7.80	22.64	70.45	74.15	74.34	77.47	77.21	75.39
5.50	17.30	58.64	64.31	64.56	66.83	67.25	65.42
2.70	11.56	42.56	48.21	48.47	50.45	50.97	49.98
1.00	7.45	26.91	30.63	30.97	33.46	33.75	33.82
0.50	5.46	20.81	23.72	24.42	26.74	26.54	26.46
0.30	4.75	17.16	20.38	21.72	23.93	23.61	23.54
0.20	3.78	15.14	17.69	18.73	19.65	19.87	20.49
0.13	2.56	12.61	14.37	15.46	18.05	17.86	17.54
0.08	1.32	11.42	13.67	13.79	17.06	15.46	15.72
Power consumption		1.37	1.92	2.04	2.07	2.37	1.99

108.3 Experiment

To test the HPGR model, we used a HPGR manufacturing company, Changsha. Its diameter is 600 mm and length is 200 mm. The test uses two kinds of ore. Data are shown in Table 108.1.

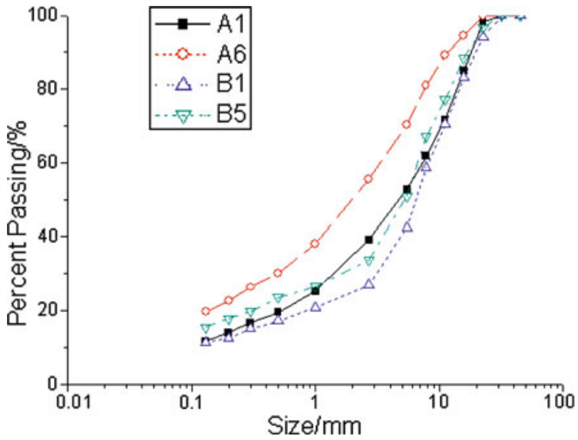

Fig. 108.3 The contrast of test data

These results show that for different operating pressures R_P, different product size distributions are obtained, as can be observed from the comparison of A1 versus A6 and B1 versus B5, under the same ore and different R_P. It is also evident that if the ore is different but the operating pressure is the same, different product size distributions are obtained. However, the effect is very is small, especially with a higher R_P, as can be observed from the comparison of A6 versus B5. With a lower R_P the differences are more evident (A1 vs. B1) (Fig. 108.3).

108.4 Conclusions

In bed compression crush, the crush of bed affects every particle crush. Model reflects the particle breakage and crush energy absorption material obey the basic principles. The smaller particle size, the greater power consumed.

In crush study, equal portions, N_B, of the roller can make throughput, power draw and the particle size more accurate.

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