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Simulation on Extrusion Comminution Model of Roller Press

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Abstract: How to predict the relationship among particle size and among product size, to establish the relationship between the granularity and working parameters in the process of grinding and to determine the optimum operating parameters. With proposing BS squeeze crush model by L. Bass and the idea of roll surface division as the material uneven extrusion force are adopted. Based on field experiments the experimental data is analyzed, the select function and the breakage functions are fitted with MATLAB software, and obtaining their model. The comminution model is determined by the roller division. We obtain the model parameter through the experimental data. Through model analysis shows: the relationship between particle breakage and energy absorption, namely the smaller size of the same power, the lower broken; the breakage diminishes with the decrease of particle size ratio and it will be tending to a small constant when the smaller particle size ratio. The breakage functions rapidly decrease within ratio of between 0.2-0.7. This shows: the energy consumption will rapidly increase when the particle size of less than 0.2 in broken; the selection diminish with the decrease of particle size. Pressure (8-9MPa) should be the most appropriate value.

0 Introduction

Roller press is consisted of a fixed and a moving roller. Materials is smashed by the roll force and its size is connected with roll gap, roll diameter and circumference velocity. In 1948 B. Epstein put forward the new concepts of two crushing function, which is between selection and breakage. All of the grain sizes have a chance of breaking in grinding process, namely a certain percentage of material is selected to break only by the remaining part of this process, but no broken. If this probability uses mathematical formula show, it is called selective function. When the grain size was broken, a broken occurs will have a new set of particle size. The grain size is smashed into the original grain size, which is smaller than the grain size range of the distribution of all proportion, which is called the distribution function, which with B showing the cumulative distribution forms. In 1953 Sedlatscek and Bass advanced a grinding kinetic model that [1] is elicited by the rate of disappearance of the j-class materials, which is proportional to the amount to be crushed. Two concepts both the selection Si and breakage Bi j accord to the principle of mass balance be raised in 1954 L. Bass advanced the first i-level material particle formation rate must be equal to the difference between the i-class that come from the large class and i-class that has been broken to form smaller the size. In 1971/1972 Austin and Bhatia studied the breakage and discovered that B is proportional to the x_i/x_j, nothing to do with the absolute size. Thus B value can be parameterized, which depend on the test. Therefore, the key of kinetic model is obtaining the two functions. M. Torres and A. Casal [2] established the dynamic equation, selection and breakage.

1 Crush Model

The principal of roll press is different with others, whose squeeze crush relies on the pure stress. The crush time is very short and the energy consumption is mainly reflected by the size of the pressure. In this paper, the roller press grinding model is based on mineral properties, equipment size, and operating environment. According to the uneven radial direction force and Morrell's edge effect [3], the equation is further improvement and predicting the production capacity, power consumption and particle breakage.

The basic principle of model is: the mass balance principle, conservation of energy and the total balance principle set up to particle broken. Fig. 1 is a description of the grinding process.

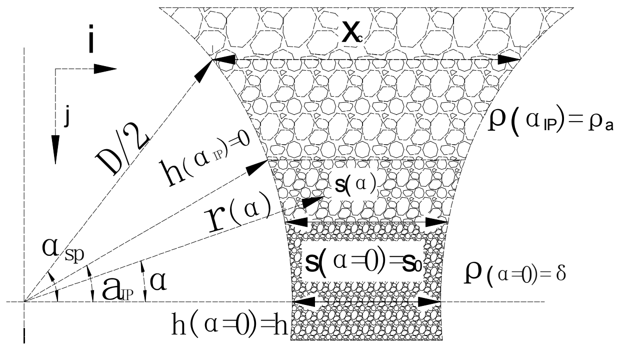

Fig. 1 describes the grinding process and parameters

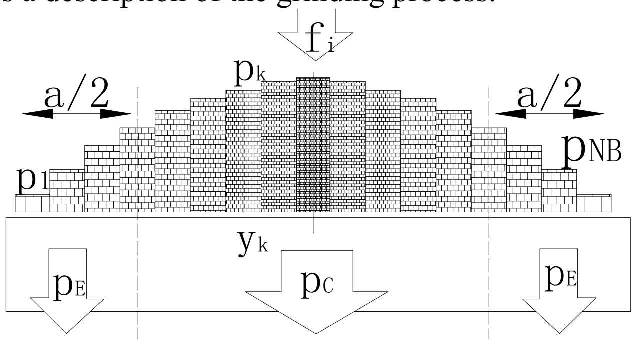

Fig. 2 Schematic diagram of roll force

The material is gradually broken before coming out. Suppose m_{ik} is the first i-level k-portion and based on the mass balance principle. The dynamic model: the first i-level material particle formation rate must be equal to the difference between the i-class which come from the large class and i-class which has been broken to form smaller the size. The equation is [1]:

$$\frac{\mathrm{d}}{\mathrm{d}p} m_{ik}(p)M = \sum_{j=1}^{i-1} s_{jk} b_{ij} m_{jk}(p)M - s_{ik} m_{ik}(p)M \tag{1}$$

Thereinto: m_{ik}——The first i-level amount of material k-portion, kg

s_{jk}——Selection

b_{ij}——Breakage

p——Working pressure, MPa

M——The total volume of feed, kg

Equation (1) is a group of similar dynamic equation. Balance equation is made up of the N × N different equations. Each equation is form of an arbitrary one share k (k = 1 ... ... NB) and any one i (i = 1 ... . N) Component [2].The equation's analytical solution is:

$$m_{ik}(p) = \sum_{j=1}^{i-1} h_{ij,k} \cdot e^{-s_{ik} \cdot p} \tag{2}$$

Thereinto:

$$h_{ij,k} = \begin{cases} 0 & i < j \\ \sum_{l=j}^{i-1} \dfrac{b_{il} s_{lk} h_{lj,k}}{s_{ik} - s_{jk}} & i = j \\ m_{ik}(0) - h_{il,k} & i > j \end{cases} \tag{3}$$

Thus, if you want to calculate the broken particle size under the known conditions, as long as you obtain the selection function s_i and breakage functions $b_{ij.}$ So the key of the model is to seek for the two functions.

For breakage equation B_{ij} [7]:

$$B_{ij} = \begin{cases} \phi(\dfrac{x_i}{x_{j+1}})^{\alpha} + (1-\phi)(\dfrac{x_i}{x_{j+1}})^{\beta} & n \ge i \ge j+1, j \ge 1 \\ 1 & i \le j \end{cases} \tag{4}$$

In the mild of *φ, α, β*, which is the parameter used to adjust the test data .It depends largely on the nature of the materials and work circumstance. B_{ij} is summation that the j-level material is broken into less than or equal to i-level materials. Non-accumulation breakage function b_{ij}(j-class materials is broken into i-level content), that is:

$$b_{i,j} = \begin{cases} B_{i,j} - B_{i+1,j} & 1 \le i \le n \\ B_{i,j} & i = 1 \end{cases} \quad (5)$$

B_{ij} is directly gained by experiment ,which show in Table 1 and with BⅡ method [8] to calculate .Its equation as follows:

$$B_{ij} = \frac{\log[(1 - m_i(0))/(1 - m_i(p))]}{\log[(1 - m_{j+1}(0))/(1 - m_{j+1}(p))]}, \quad i > j \quad (6)$$

Thereinto：j——Maximum grain size relatively

$m_i(p)$——The accumulation less than of i-level，Kg

According to Sedlatscek and bass proposed, which j-class materials should be proportional to the rate of disappearance of the broken material crushed, with the equation as:

$$\frac{-\mathrm{d}m_i(p)M}{\mathrm{d}t} = s_i m_i(p)M \quad (7)$$

On (7) mathematical treatment, there is the following equation that is first-order comminuted Law [1]:

$$\log(m_i(p)) - \log(m_i(0)) = \frac{-s_i p}{2.3} \quad (8)$$

Choice function which derived from the above equation:

$$s_i = a\, x^{\gamma} \quad (9)$$

Thereinto：a、γ——parameters are relating with both the materials and environment

The single crushing materials was mixed with materials, which is less than or equal to xc and then formed the laminated brokenness that is squeezing among materials. According to the summary (Klymowsky et al., 2002; Daniel and Morrell, 2004; Patzelt et al, 2006), it is divided into two regions that is the marginal zone and central zone, also known as edge effect. Lubjuhn [6] thought that the reasons of this phenomenon are the different pressure of the edges and center. According to the size of force we divide the roll into the share NB (shown in Fig. 2). As each force of the NB consumes the different energy, the broken rate of each share is also different. Obviously, the product is rough on the edge, opposite on the center.

The selection sik [2] was proposed, which is based on changing broken rate. The equation is:

$$s_{ik} = \frac{W_k}{H_k} s_i \quad (10)$$

There into：W_k——Power consumption of each share，Kw

H_k——The volume of each share，mm^3

Where *a,* γ is the parameters adjusted the experimental data，which depend mostly on the nature of the materials and work environment. H_k is the volume for each share, which is:

$$H_K = \frac{1}{N_B} G_S \frac{h}{3600U} \quad (11)$$

There into：G_S——Materials production，Kg

U——Roller rotation speed，mm/s

h——Distance from entrance to exit in the vertical direction，mm

As pressure is applied on the entire roll, the power consumption is different on each share and its value can be estimated under:

$$W_k = W \frac{(L^2 - 4y_k^2)}{\sum_{j=1}^{N_B}(L^2 - 4y_j^2)}, \tag{12}$$

Thereinto：L——Roller width，mm

W——Power，Kw

y_k、y_j——The relative position of each share，mm

Estimated using the following formula:

$$y_k = \frac{L}{2N_B}(2k - N_B - 1) \tag{13}$$

2 Fitting function

2.1 Test content. The equipment is Jidong Cement Factory Roll Press. The parameters: motor power (3kw), throughput (10-12t / h), hydraulic (10MPa), and test materials is the material of Jidong Cement Factory. Now materials are divided into several levels and respectively test later. The coarse-level use hand sieve and fine sieve use gas sieve. The data is shown by Table 1.

2.2 Breakage B_{ij}. The data in various size screening are presented in table 1. Using equation (6) calculate the average of B_{ij} breakage function, and shown in Table 2. Then it is plotted on Fig. 4 by a group of similar curves. According Fig. 4, the value of the breakage function is failed to significantly increase with the pressure increases. It shows that the breakage function basically unrelated with the pressure. The breakage diminishes along with the decrease of particle size ratio and it will be tending to a small constant along with the smaller particle size ratio. The breakage functions rapidly decrease within ratio of 0.2-0.7. It shows: the energy consumption will rapidly increase while the particle size of is less than 0.2 in broken;

Table1 The percentage of various size

P / $m_i(p)$ / x_i	feed	The cumulative mass fraction under every pressure					
		6	7	8	9	10	11
20	1	1	1	1	1	1	1
10	0.937	1	1	1	1	1	1
5	0.852	0.958	0.953	0.954	0.98	0.963	0.964
2	0.725	0.82	0.833	0.81	0.881	0.856	0.865
0.9	0.581	0.663	0.695	0.648	0.749	0.729	0.737
0.6	0.454	0.531	0.567	0.514	0.62	0.621	0.617
0.355	0.386	0.46	0.497	0.441	0.54	0.552	0.548
0.15	0.303	0.37	0.408	0.352	0.444	0.456	0.458
0.1	0.212	0.272	0.313	0.258	0.327	0.343	0.351
0.074	0.166	0.225	0.264	0.21	0.274	0.277	0.29

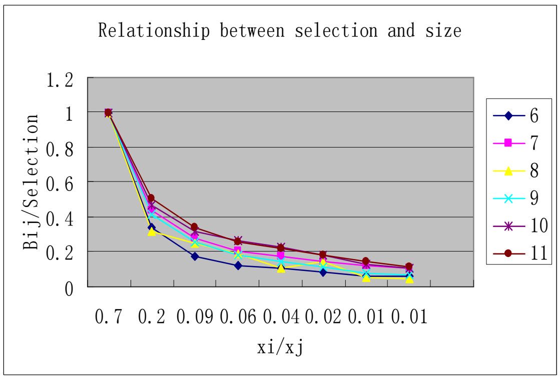

Fig. 3 Relationships between breakage and relative size under the different pressure

According to the equation (4) and Table 2, the parameter was listed in Table 3 neither more nor less then. The B_{ij} shows:

$$B_{ij} = \begin{cases} 0.54(\dfrac{x_i}{x_{j+1}})^{1.65} + (1-0.54)(\dfrac{x_i}{x_{j+1}})^{6.05} & n \geq i \geq j+1, j \geq 1 \\ 1 & i \leq j \end{cases} \tag{14}$$

Table 2 The value of B_{ij} under different pressure

B_{ij} / x_i/x_j \ P	6	7	8	9	10	11
0.5	1	1	1	1	1	1
0.2	0.3365	0.4348	0.3164	0.4185	0.4667	0.5033
0.09	0.1729	0.2768	0.1491	0.2560	0.3143	0.3359
0.06	0.1207	0.2022	0.0996	0.1811	0.2634	0.2558
0.0355	0.1020	0.1738	0.1050	0.1443	0.2274	0.2210
0.015	0.0802	0.1423	0.1397	0.1133	0.1788	0.1814
0.01	0.0629	0.1196	0.0515	0.0788	0.1312	0.1400
0.0074	0.0583	0.1090	0.0464	0.0693	0.1030	0.1161

Table 4 The value of s_i under different pressure

si / xi \ p	6	7	8	9	10	11
5	0.0318	0.0305	0.0281	0.0256	0.0228	0.0200
2	0.0301	0.0293	0.0254	0.0224	0.0206	0.0193
0.9	0.0288	0.0254	0.0210	0.0219	0.0196	0.0172
0.6	0.0255	0.0212	0.0196	0.0188	0.0156	0.0135
0.355	0.023	0.0201	0.0156	0.0137	0.0128	0.0112
0.15	0.0181	0.1634	0.0123	0.0108	0.0097	0.0078
0.1	0.0162	0.0142	0.0104	0.0091	0.0076	0.0065
0.074	0.0102	0.0098	0.0076	0.0065	0.0054	0.0045

Table 3 The parameter values of breakage

Power (P)	φ	α	β
6	0.6415	1.6499	6.4931
7	0.6593	1.7497	7.8706
8	0.5566	1.6253	6.7655
9	0.4477	1.5721	4.9233
10	0.4522	1.6323	5.0589
11	0.4702	1.6729	5.1665

Table 5 The parameters under different pressure

pressure (MPa)	a	γ
6	1.46	0.5
7	1.89	0.64
8	2.05	0.79
9	2.16	0.83
10	2.41	0.91
11	2.79	1.06

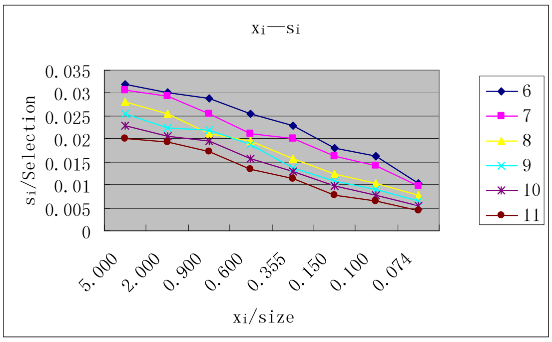

Fig. 4 The relationship between size and selection

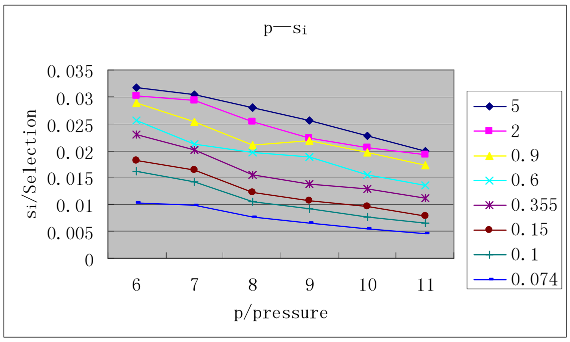

Fig.5 The relationship between pressure and the selection

2.3 Selection. To seek selection function s_i, firstly the value of s_i, is calculated with original data in Table 1 and shown in Table 3.

According to Table 4, the relationship between size and select the function diagram are showed in Fig. 4. The value of selection is diminished with the decrease of particle size and shown in Fig. 5. In the same diameter of particle the selection is reduced with the pressure increases. So the bigger pressure is not better. Test analysis: the selection diminishes with the decrease of particle size. Pressure (8-9MPa) will be the most appropriate value. For the sake of the selection, the value of *a* and *γ* was obtained using Table 4, and shown in Table 5. Taking the average of *a* and *γ* gain equation s_i:

$$s_i = 2.1 x_i^{0.81} \tag{16}$$

Finally, according to equation (10), (11), (12), (13) come to the general formula s_{ik}:

$$s_{ik} = \frac{3600 U N_B W}{G_S h} \frac{(L^2 - 4y_k^2)}{\sum_{j=1}^{N_B} (L^2 - 4y_j^2)} 2.1 x_i^{0.81} \tag{17}$$

3 Conclusion

Basing on the previous dynamic model of roll press, the model presented in this paper considers three aspects (the laminated brokenness, edge effect and dividing the force into N share).

(1) The breakage diminishes with the decrease of particle size ratio and it will be tending to a small constant along with the smaller particle size ratio. The breakage functions rapidly decrease within ratio of between 0.2-0.7. This shows: the energy consumption will rapidly increase when the particle size of less than 0.2 in broken;

(2) In the same diameter of particle the selection is reduced with the pressure increases. So the bigger pressure is not better. Test analysis: the selection diminishes along with the decrease of particle size. Pressure (8-9MPa) will be the most appropriate value. During to the different circumstance and materials, the parameter is different.

(3) As each force of the N_B consumes the different energy, the broken rate of each share is also different. The method divided the roll into N shares, which is more accurate to forecast the product. Prediction results on the site have some practical significance

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