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Optimization of Process Parameters for a Vertical Shaft Impact Crusher through the CFD-DEM Method

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In this study, the process parameters of a vertical shaft impact (VSI) crusher are optimized. Different feed size distributions, material physical properties, and product size distribution requirements are considered to determine the optimal material particle bond cleavage ratio. First, a numerical model is developed to simulate the crushing effect by adopting a CFD-DEM method. Then, the relationship between the crushing effect and the rotor speed, feed size distribution, and feed rate is revealed by analyzing the bond cleavage ratio of smaller-size distribution feed crushing to the specified particle size. The optimized working parameters of the crusher are determined under different feed size distributions. The results show that the feed size distribution of 8 mm, 20 mm, and 40 mm account for 20%, 30%, and 50% of the feed, respectively. Based on the results, it is implied that a feed rate of 120 t/h and a rotor rotational speed of 1800 r/min can be selected for crushing production. When the feed size distribution varies, this method can also be used to select a suitable feed rate and the rotor speed for crushing production. Overall, this study guides for optimizing the working parameters and improving the crushing efficiency.

Keywords: VSI crusher, working parameters, optimization, CFD-DEM

1 Introduction

VSI crusher is an increasingly used production equipment in different industries, such as mineral grinding, metallurgy, and building aggregate processing. These crushers offer good crushing production size distribution, small volume, and low operating costs [1,2]. Research on the mechanism of material crushing shows that the crushing process works on the kinetic energy that is obtained by the cohesive force by displacing the particles inside the material and doing work [3]. When more kinetic energy is obtained by transforming the material into crushing energy, the feed is crushed better. According to the working principle of VSI crushers, the kinetic energy obtained by the feed comes from the high-speed rotating rotor. The size of the rotor kinetic energy is determined by the rotor speed which plays a decisive role in the crushing effect of the feed. The movement of material in the crushing chamber is extremely complex [4]. The energy obtained by a single particle is participated by the rotor as well as the interaction between the material particles. According to the reports on crushing production, feed size distribution, feed rate, and hardness of materials greatly impact the crushing effect of the material [5,6]. Therefore, it is important to investigate the working parameters of the crusher to achieve a better crushing effect and meet the production requirements of sand-making enterprises, such as feed size distribution, hardness, and crushing product size distribution [7].

In recent years, numerous studies in the form of simulation analysis and optimizing the working parameters of VSI crushers have been reported. For instance, Bengtsson et al. established a material flow quality model considering the inlet of the VSI crusher. They studied the trajectory of the material particles in the crushing chamber and predicted the absolute speed of the material particles leaving the rotor [8]. Djordjevic et al. analyzed the movement and interaction of material particles in the crushing chamber by employing PFC3 D software and discrete element technology. They established the movement law of material particles along the rotor impeller. In their study, while using the DEM (discrete element method) simulation, they simplified the geometry of the crusher, hence reducing the number of material particles[9,10]. In the simulation of the gas-solid two-phase flow field, Jayasundara et al. conducted an in-depth gas-solid two-phase simulation study on the flow field of a high-speed stirring mill cavity. They considered the interaction between air and crush particles, and confirmed that the CFD-DEM (computational fluid dynamics and discrete element method) model can accurately simulate the particle flow [11,12]. Sinnott and Cleary simulated the crushing of spherical particles in a VSI crusher and found that the performance of a VSI crusher can be predicted accurately when the effect of airflow on the material crushing is fully considered [13].

Several studies have been reported on optimizing crusher working parameters. For example, Wang established the internal flow field model of an RP109 VSI crusher in EDEM by analyzing the acceleration of the material particles at different feed rates. They developed the relationship between the acceleration effect of the material and the feed rate and obtained the influence law of the feed rate on the impact crushing[14]. Ye applied the bonding model in a discrete element software EDEM to evaluate the crushing impact. The crushing effect was measured by the number of bond breaks of the superior material. The study revealed that the rotor speed greatly influenced the crushing effect of material particles, and a better crushing effect was achieved by increasing the rotor speed [15]. Li developed a material bonding model in EDEM for the VSI crusher and obtained the relationship between the crushing effect by analyzing the bond cleavage ratio of material particles to the specified particle size, impact speed, and optimized rotor speed [16].

In most of the reported studies, while studying the relationship between the working parameters of the crusher and its crushing effect, the feasibility of the bonding model is verified in EDEM, and the influence law of the working parameters on the crushing effect is described by the number of bond fracture. However, in the actual crushing process, the feed size distribution keeps on changing, which affects the acceleration, collision, the impact energy of material particles, and hence affects the crushing effect. To the best knowledge of the authors, in the reported studies, the effect of the feed size distribution on the crushing effect is not considered until now. Considering this, in this study, the FLUENT-EDEM joint simulation method is adopted to establish the simulation model of the crushing effect for the VSI crusher and realize the two-phase numerical simulation. By analyzing the bond cleavage ratio of different feed size distributions to the specified production size, the relationship between the crushing effect and the rotor speed, and feed size distribution and feed rate are defined. Method is proposed to determine the optimal working parameters of the crusher under different feed size distributions. It provides a reference guide for the optimization of VSI crushers operating parameters.

2 Analysis of main working parameters affecting the crushing effect of VSI crusher

In actual production, rotor speed, feed size distribution, feed rate, physical properties of materials, and rotor structure have a great influence on the crushing effect. This paper studied the influence of three working parameters on the crushing effect of the VSI crusher, including feed size distribution, rotor speed, and feed rate.

2.1 Determination of the feed size distribution

The size and shape of the feed are different when the VSI crusher is operating. The material particles appear to be spheres with varying diameters, and the influence of material shape on the crushing action is neglected [6] to accurately replicate the operating state of the crusher. Since VSI crushers mostly use the material that has already been crushed and sorted to particular particle sizes, therefore, in this study, the maximum input particle size is often not more than 40 mm, and the sizes of the product are typically less than 4.75 mm. Since the bonding model in EDEM can only replace the particles with specific particle sizes, to reduce the solution convergence issues, the material particles are divided into large, medium, and small corresponding to the feed sizes of 40 mm, 20 mm, and 8 mm, respectively. According to the commonly used process flow of sand production enterprises, each partial size is fed in a proportion of 20%, 30%, and 50% respectively [17]. The feed size distribution schemes are given in Tab. 1. Scheme 1 shows that the feed size of 8 mm is accounted for 20 % of the feed, 20 mm accounts for 30 %, 40 mm or 50 %, and so on.

Tab. 1 *feed size distribution of the VSI crusher*

Feed size distribution（mm）	8	20	40
Scheme 1	20%	30%	50%
Scheme 2	30%	50%	20%
Scheme 3	50%	20%	30%

2.2 Rotor speed

For material crushing, the crack theory proposes that the energy consumed in material crushing depends on the particle size and the material's contact stiffness. The crushing energy consumption of material particles can be calculated as follows:

$$W = k_n V \times \left(\frac{1}{\sqrt{D_h}} - \frac{1}{\sqrt{D_q}} \right) \quad (1)$$

Where:

W …The energy consumed during a material particle crushing,

k_n …The particle contact stiffness in N/m;

V …The particle volume in m³;

D_h …The particle size after crushing in m,

D_q …The particle size before crushing in m.

Studies have shown that the relationship between the impact velocity and the particle size of the material can be used to decide the energy consumed in the crushing process [6]. The impact velocity can be obtained as:

$$V_c = \frac{4k_n}{\rho(1+e^2)} \times \left(\frac{1}{\sqrt{D_h}} - \frac{1}{\sqrt{D_q}} \right) \quad (2)$$

Where:

ρ …The material density in kg/m3,

e …The material elastic recovery coefficient.

The Bund work crushing index W_i is used to represent the crushing energy consumption of the material. This index is established by specifying particle size in unit volume [18]. Equation (1) can be transformed into equation (3):

$$W_i = \frac{W}{V} = k_n \times \left(\frac{1}{\sqrt{4}} - \frac{1}{\sqrt{40}} \right) \quad (3)$$

The material studied in this paper is limestone with an elastic recovery coefficient of 0.6 [19]. For the VSI crusher, the particle size of the product is normally below 4.75 mm. Hence, in this study, the material particle size after crushing is selected as 4 mm. The elastic recovery coefficient of material after the collision is between 0 and 1. According to the hardness grade of limestone (soft ore), the crushing power index W_i is selected as 6 [20]. Through Equations (2) and (3), the impact velocities of different particle sizes (8 mm, 20 mm, 40 mm) to the specified particle size (4 mm) are calculated as 62.4 m/s, 73.6 m/s, 98.5 m/s, respectively. Here, the impact velocity refers to the velocity of the material particles after they are thrown out after a collision with the impact plate. The relationship among impact velocity, rotor speed ω, and feed velocity V_A [21]are used to deduce Equation (4) and the rotor speed corresponding to impact velocities 1083 rpm, 1352 rpm, and 1985 rpm are calculated.

$$V_c = R_c\omega + \frac{eV_A \sin\sigma}{\sin(\delta + 25^\circ)} \quad (4)$$

Where:

R_C …The impact plate installation radius in mm,

ω …The rotor speed in rad / s ,

σ …The angle between the tangential component of throwing velocity V_A and impact velocity Vc in degrees,

δ…The installation angle of the impact plate,

e…The material collision recovery coefficient,

V_A …The calculation method of throwing velocity in m/s.

V_A is expressed as:

$$V_A^2 = C_1^2 r^2 \omega^2 (\cos\alpha + f\sin\alpha)^2 + r^2\omega^2 \quad (5)$$

Where:

$C_1 = (1+f^2)^{1/2} - f$,

f…The friction coefficient between the material and guide plate,

r…The inner radius of the rotor in mm,

α…The guide plate installation angle in degrees,

ω…The rotor speed in rad / s.

From the theoretical calculation, the rotor speed to break the particle sizes of 8 mm, 20 mm, and 40 mm to 4 mm is 1083 rpm, 1352 rpm, and 1985 rpm, respectively. Therefore, to study the influence of different rotor speeds on the crushing effect, the rotor speed is studied at 1000 rpm, 1400 rpm, 1800 rpm, and 2000 rpm.

2.3 Feed rate

The processing capacity of the VSI crusher is related to rotor structure parameters, rotor speed, and feed mode. In this study, feed rates of 80 t/h, 120 t/h, 160 t/h, and 200 t/h are used to study the impact of feed rate on the material crushing effect [22].

3 Model for simulating the crushing effect of a VSI crusher

3.1 Simulation model for crushing chamber and rotor

In this study, a secondary-acceleration type rotor (PL840 VSI crusher rotor, Guizhou, China) is studied with an improved design (Fig. 1 (a)). Its structure includes a rotor body, split cone, guide plate, and impact plate. As shown in Fig. 1 (b), an impact plate is added. While working, the material particles fall from the inlet to the high-speed rotating split cone which evenly disperses the material onto the guide plate. On the guide plate, under the action of centrifugal force and material extrusion pressure, the material particles move to the outer edge of the rotor with a constant acceleration. The material particles are thrown from the throwing head at the end of the guide plate and the first acceleration of material particles is achieved. The material particles thrown from the guide plate move backward on the rotor and collide with the impact plate (at the edge of the rotor body). At this stage, the secondary acceleration of the material particles is accomplished and the greater impact kinetic energy is obtained. Subsequently, the material accelerates towards the anvil plate (installed in the cavity). During this movement, the material particles and crusher components experience multiple impact collisions. The crushing of material particles is accomplished by converting kinetic energy into crushing energy. For the original rotor, after material particles are accelerated by the guide plate, these collided with the anvil plate and crushing takes place.

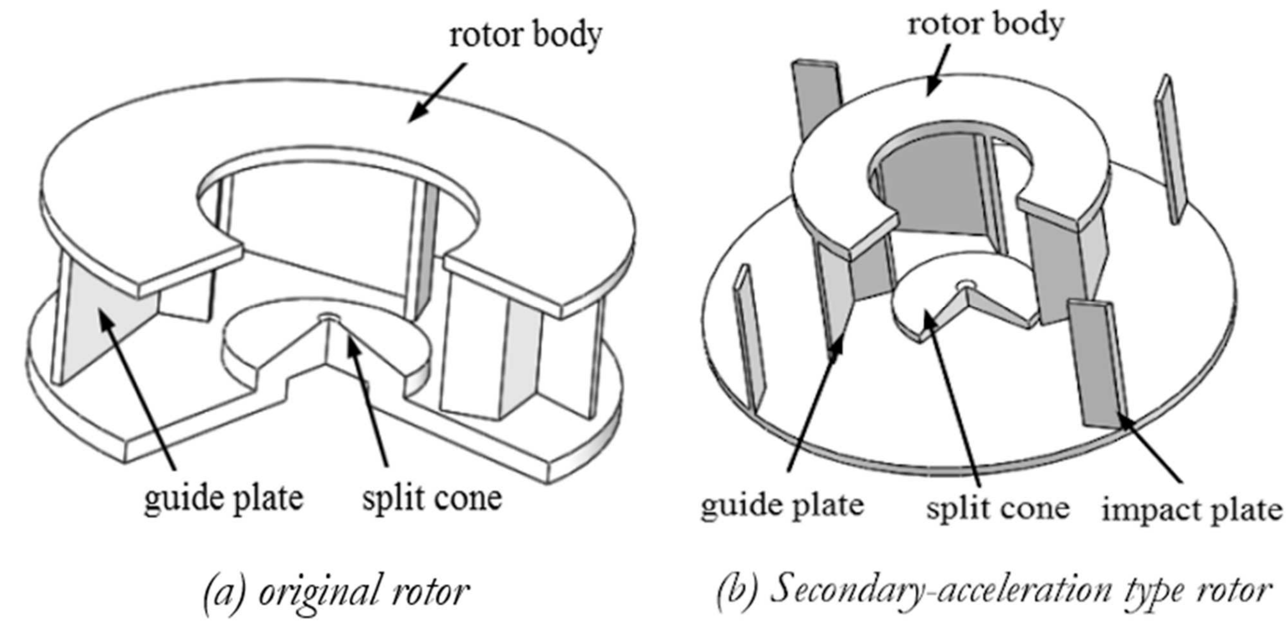


Fig. 1 *Sketch of the rotor structure*

The crushing chamber and the rotor structure are simplified and these did not affect the simulation results. The simulation models of the rotor and the crushing chamber were developed by employing SolidWorks, as shown in Fig. 2. In the model, the rotor diameter is 800 mm, the inclination angle of the split cone is 15°, the installation angle of the guide plate is 42.5°, and the installation angle of the impact plate is 28°.

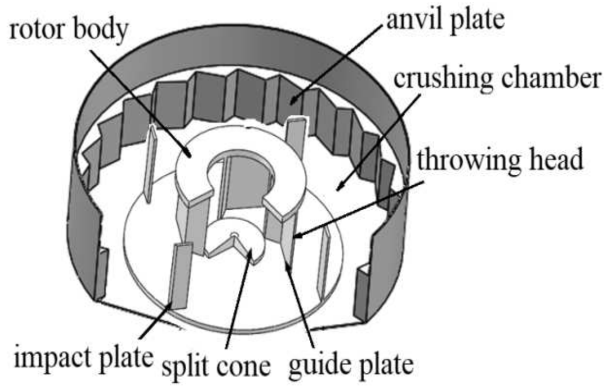


Fig. 2 *Simulation model of rotor and crushing chamber*

3.2 Material bonding model

In this work, the EDEM method was used to compute the motion and force of the material particle system, and FLUENT was employed to solve the motion of the crushing chamber flow field. The two software completed the numerical simulation of the gas and solid phase flow field and conducted the joint FLUENT-EDEM simulation of the crushing impact for the VSI crusher. The two software exchanged information for mass, momentum, and energy under the coupling interface.

The material crushing conducted in the crushing chamber was simulated through the Bonding model in EDEM. The crushing effect under different working parameters was reflected by the cleavage ratio of bonds between particles. During the simulation of material crushing, the feed particles were replaced by several agglomerates of small material particles and connected by bonds, as shown in Fig. 3. To make small material particle agglomerates meet the structural size and physical properties, the bonding parameters between small material particles were selected considering the normal and tangential contact stiffness coefficient, compressive strength, shear strength, and bonding radius between particles. When material particles collided with the press block, the crushing force of large material particles was greater than the bonding force between small material particles (calculated by EDEM software with bond parameters), which helped in breaking the bond between small particles, and the internal structure of the material was crushed.

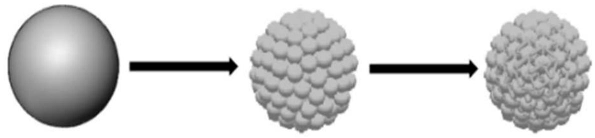


Fig. 3 *Material particle generation model*

The feed size distribution for the simulation model was chosen based on the study of the first part. Feed particles consist of three particle sizes 8 mm, 20 mm, and 40 mm. The small particles (4 mm) were bonded together. According to the empirical Equation (6) [23], the number of small particles required for the three particle sizes was calculated to be 5, 70, and 560.

$$\alpha \cdot V_d = n \cdot V_s \quad (6)$$

Where:

α …The filling volume fraction with an empirical value of 0.56,

n…The number of small particles needed to fill the ore,

V_d …The volume of the large solid in m³,

V_s …The single small solid volume in m³.

The normal contact stiffness coefficient and tangential contact stiffness coefficient of the material particles can be calculated by Equations (7) and (8) [24].

$$K_n = \frac{4}{3}\left(\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}\right)^{-1}\left(\frac{r_1 + r_2}{r_1 r_2}\right)^{-1/2} \quad (7)$$

$$K_\tau = (1/2 \sim 2/3)K_n \quad (8)$$

Where:

K_n …The normal contact stiffness coefficient of the material particle (N/m3),

K_τ…The tangential contact stiffness coefficient of the material particle (N/m³),

ν_1 and ν_2 …The Poisson ratio of large and small material particles, respectively, with a value of 0.2.

E_1 and E_2 …The elastic moduli of large and small material particles, respectively, and their value is 7.5×10^{10} Pa.

The parameters r_1 and r_2 are the radius of large and small material particles with values of 10 mm and 2 mm, respectively. The normal contact stiffness coefficient K_n of limestone was calculated at 6.72×10^9 N/m³ and the tangential contact stiffness coefficient K_τ was 4.48×10^9 N/m³. According to the literature [25], the compressive strength of limestone is 9.6×10^7 Pa, the shear strength is 1.7×10^7 Pa, and the bonding radius is 3 mm.

3.3 Reliability of the crushing model

Since the simulation of material crushing is extremely complex, it is difficult to establish the bonding and physical parameters of the crushing model. It was necessary to verify the model's reliability because the model's formation and parameter selection were obtained using theoretical formulae. In this paper, the maximum crushing force of the material model was calculated by the single-particle crushing mechanism, then, the bonding parameters of material particles were set in EDEM by the inversion method. The simulation data of the maximum crushing force was derived in the post-processing module. The crushing model is verified by comparing the theoretical value of the maximum crushing force with the simulation value.

3.3.1 The crushing force of material particles

The crushing of material particles occurs because the material is thrown by the rotor with a certain impact speed. The ball deformation was applied by Hertz to the process of impact collisionschongji. The impact velocity in different crushing methods was calculated through different formulations [26]. For VSI crushers, the mass of the impact component is greater than that of the material particle, and its contact curvature radius at the impact point is greater than the material particle at the impact point, therefore, the impact velocity can be calculated by:

$$V = 1.06\sqrt{\frac{1}{\rho}\frac{\sigma^{5/6}}{E_1^{1/3}}} \quad (9)$$

The impact time includes when the material particle contacts the press block until it is crushed. In the literature [27], the formulation which is used to calculate the impact time for VSI crushers is expressed as Equation (10). The calculations performed by equation (10) are found consistent with the recording of the high-speed photographic film [28].

$$t = \frac{2.7r_1}{V^{\frac{1}{5}}}\left(\frac{\rho}{E_1}\right)^{\frac{2}{5}} \quad (10)$$

The crushing force is calculated according to the momentum theorem:

$$P = \frac{m_1 m_2}{m_1 + m_2}\frac{V}{t} \quad (11)$$

Where:

m_1 and m_2 …The masses of limestone and press block in kg, respectively.

For the VSI crusher, ρ=2640 kg/m³, σ=9.6×10^7 Pa, E_1=7.5×10^{10} Pa, m_1=0.011kg, m_2=3.7 kg were substituted in equations (9), (10), (11), and the crushing force was calculated at 11827 N.

3.3.2 Validation of the material crushing simulation model

The simulation model of the VSI crusher is based on CFD-DEM. The particle bonding and physical parameters are set according to the theoretical calculations, and the single particle crushing model is simulated. The relationship of the anvil plate impact force with time is obtained. Fig. 4 shows the relationship curve of the impact force and time of the anvil plate in the first simulation. From Fig. 4, it can be observed that the maximum impact force of the particle is 12038 N. Three crushing simulations are conducted, and the average maximum impact force of the three simulations is calculated at 12,107 N, which is consistent with the maximum impact force (11827 N calculated by the theoretical formula. Therefore, the comprehensive effect of the bonding parameters and simulation physical parameters on the material is set in the crushing model.

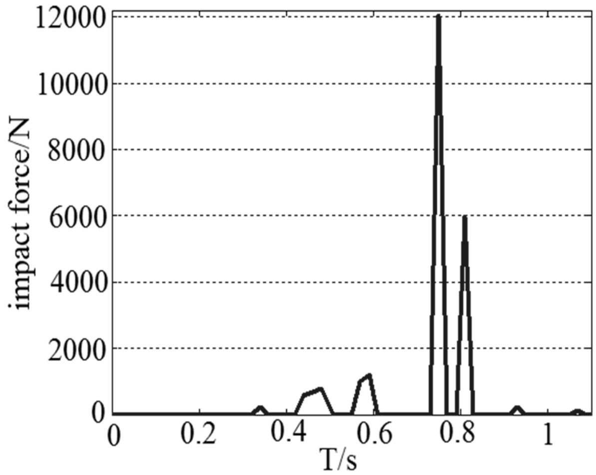


Fig. 4 *Variation of sustain force on anvil plate with time (single-particle simulation)*

4 Simulation of crushing effect and optimization of VSI crusher parameters

4.1 Simulation of crushing effect

To analyze the effect of working parameters including rotor speed and feed rate on the crushing effect of VSI crushers with a different feed size distribution, three types of feed size distributions are used which are given in Table 1. To simulate the real feed condition, the product size is specified as 4 mm. The rotor speeds are taken at 1000 rpm, 1400 rpm, 1800 rpm, and 2000 rpm with corresponding feed rates at 80 t/h, 120 t/h, 160 t/h, and 200 t/h respectively. A total of 16 types of simulation tests are performed.

Different bond models are generated according to different feed size distributions, which are replaced by small material particles at 0.3 sec. The large material particles are formed by bonding force between the particles. The simulation time is set at 1.5 sec. The simulation of the material crushing effect is shown in Fig. 5.

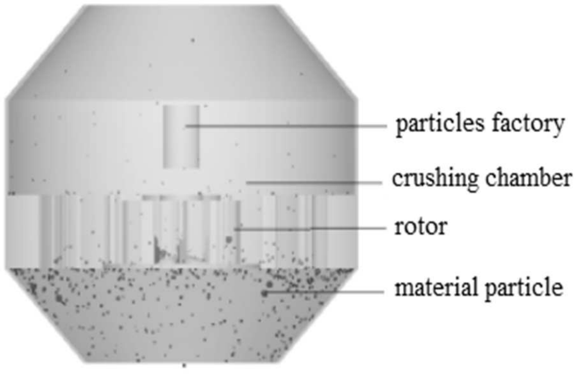


Fig. 5 *Simulation of material crushing effect*

4.2 Optimization of working parameters of VSI crusher

The bonding model in the discrete element software EDEM was developed to analyze the influence of feed size distribution, rotor speed, and feed rate on the crushing effect. The relationship between the three factors and the crushing effect was thoroughly analyzed. Due to different feed rates, the number of bonds is different. So, the quality of the material crushing effect couldn't be measured by the number of bonds cleavage, and the bond cleavage ratio was used to analyze the material crushing effect. The crushing effect was measured by the cleavage ratio of bonds to determine the reasonable rotor speed and feed rate of the crusher under different feed size distributions. To analyze the crushing process of material particles in the crushing cavity, the collision acceleration and motion trajectory of material particles were analyzed.

Fig. 6 *Collision acceleration area of material particles*

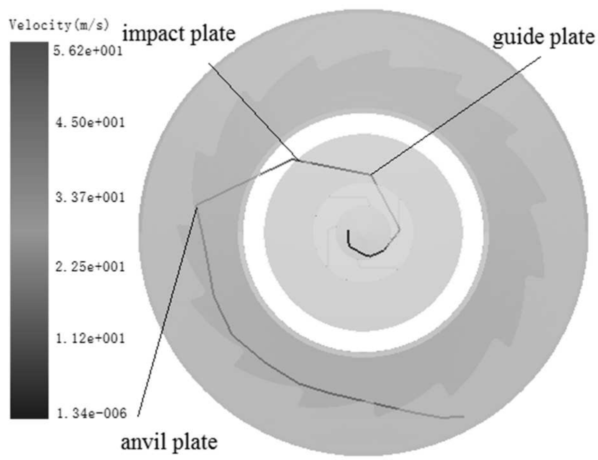
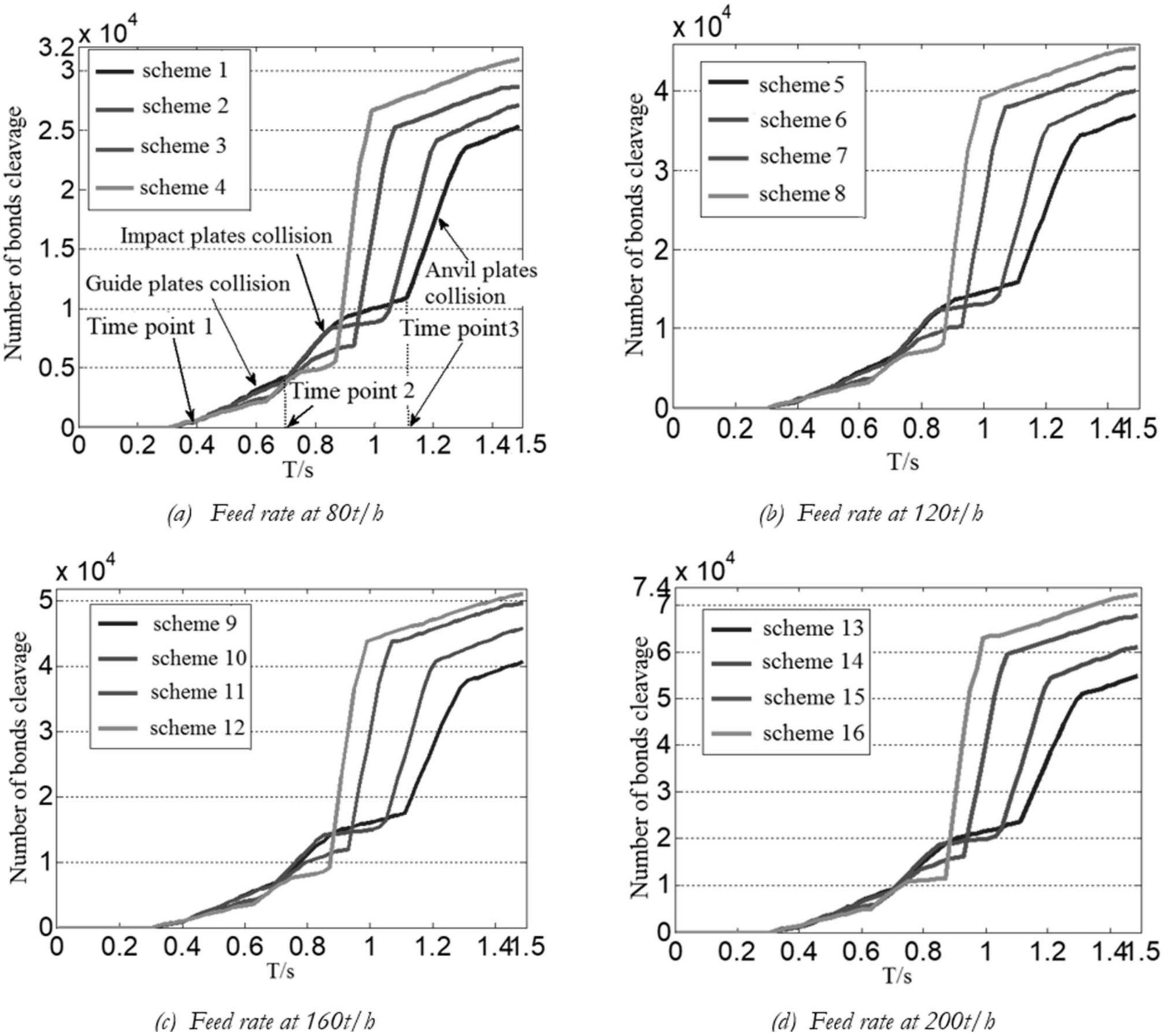


Fig. 7 *Movement trajectory of a single material particle*

The collision acceleration of material particles in the crushing cavity is focused on guide plates, impact plates, and anvil plates, which are shown in Fig. 6 as A, B, and C regions. The collision acceleration areas of material particles with different particle sizes under different working conditions are found similar to be to those in Fig. 6. When the material particles are accelerated by guide plates, they form a stream of material, which is collided by the impact plates and produce a secondary acceleration, finally, the particles collide with the anvil plates and crushing cavity is completed. The movement trajectory of a single material particle is shown in Fig. 7. At the turning point of the motion trajectory, the material particle collides with the guide plate, the impact plate, and the anvil plate, as shown in Fig. 7.

To simulate the real feed condition, the feed size distribution of scheme 1 is used, which is given in Table 1. The feed sizes of 8 mm, 20 mm, and 40 mm account for 20%, 30%, and 50% of the feed, respectively. Bonding models are generated according to different feed size distributions, which are replaced by small material particles at 0.3 sec. The simulation time was set at 1.5 sec. The production size was set as 4 mm. The rotor speeds were set at 1000 rpm, 1400 rpm, 1800 rpm, and 2000 rpm, with the corresponding feed rates at 80 t/h, 120 t/h, 160 t/h, and 200 t/h, respectively. A total of 16 schemes were designed for simulation tests. The number curve of bond cleavage of different test schemes is shown in Fig. 8, and the data is presented in Tab. 2.



(a) Feed rate at 80t/h *(b) Feed rate at 120t/h*

(c) Feed rate at 160t/h *(d) Feed rate at 200t/h*

Fig. 8 *Number of bands cleavage curves*

Fig. 8 shows the 16 schemes of crushing test curves, where the x-axis and y-axis are the crushing time and the number of bonds cleavage between particles, respectively. Since the replacement of simulated particles begins at 0.301 sec, the small particles connected by bonds begin at 0.301 sec, so the number of bonds cleavage is 0 until 0.301 sec. After that, the material particles are moved in the crushing chamber and collide with each other, so that the bonds between particles start breaking, and the number of bonds cleavage keeps rising over time.

By observing the crushing test curves of 16 schemes, it can be observed that the number of bonds cleavage follows the same change rule with time. There is a significant increase in the number of bond cleavage at each of the three time points, and the latter two-time points moved towards the T=0 moment as the rotor speed increases for the same feed rate. By combining with the motion trajectory of the material in the crushing chamber (Fig. 6 and Fig. 7), it can be implied that these three time points correspond to the bond's cleavage occasion (caused by the collision at guide plates), impact plates, and the anvil plates. When the speed increases, the centrifugal force of material particles increases, hence the speed of material particles inside the rotor is increased, and material particles collide with guide plates, impact plates, and anvil plates and completed the breakage instantly. As shown in Scheme 1, when the speed is 1000 rpm (at the time of 0.4 sec), the material particles come into contact with guide plates and get accelerated with the small number of cleavage bonds. At 0.7 sec, the particles are thrown out by guide plates and collide with impact plates to achieve secondary acceleration, and some bonds are broken. At 1.1 sec, the material particles are fully accelerated by the rotor and collide with anvil plates to produce a larger energy transformation, so the number of bonds cleavage is increased. However, in Scheme 4, when the speed is 2000 rpm, the time when the material particles collide with guide plates, impact plates, and anvil plates are T=0.4 sec, T=0.6 sec, and T=0.85 sec time, respectively. The collision time at impact plates and anvil plates is compared to the rotor speed at 1000 rpm.

Tab. 2 *Simulation results*

scheme	Feed rate (t/h)	Number of bonds	Speed（r/min）	Number of bonds cleavage	bond cleavage rate （%）
1	80	35019	1000	25318	72.3
2			1400	27104	77.4
3			1800	28680	81.9
4			2000	30991	88.5
5	120	52528	1000	37084	70.6
6			1400	40026	76.2
7			1800	43125	82.1
8			2000	45436	86.5
9	140	61283	1000	40814	66.6
10			1400	45839	74.8
11			1800	49823	81.3
12			2000	51110	83.4
13	200	87547	1000	54979	62.8
14			1400	61195	69.9
15			1800	67848	77.5
16			2000	72488	82.8

From the simulation data (Tab. 2), it can be analyzed that under the same feed rate, the number of breaking bonds and cleavage ratio of bonds increases with the speed increasing. Under the same speed, the cleavage ratio of bonds decreases with the increasing feed rate. This is because when the feed rate increases, the number of material particles also increases, and the interaction force between material particles becomes prominent. As a result, some material particles do not get sufficient kinetic energy under the extrusion between the particles, and they are thrown out by the rotor body and collide with anvil plates. Because of the insufficient crushing kinetic energy, the number of bond cleavage cannot increase proportionally, which decreases the bond cleavage ratio.

In schemes 4, 8, 12, 15, and 16, the number of bonds cleavage is caused by the collision of anvil plates at speeds of 1800 rpm and 2000 rpm. Especially in case 16, the number of bond cleavage is 72% of the total number of bond cleavage. This shows that the number of material particles colliding at anvil plates is more than that of guide plates or impact plates. If the large material particles (40 mm) occupy a substantial proportion of the feed, when the feed rate and the rotor speed increase, more large material particles are broken down due to the anvil plates' collision.

Although the material particles are broken by the collision of anvil plates, which increases the timeliness of anvil plates collision, the kinetic energy of material particles is instantly transformed, which causes serious wear on anvil plates and reduces the service life of the crusher. Therefore, under this feed size distribution, the rotor speed and the feed rate should be minimum. The crushing effect is found better in schemes 3, 7, and 11, and the bond cleavage ratio is noted at about 81% at a speed of 1800 rpm. With the increase of feed rate, the number of large material particles increases, which causes rotor blockage, and affects the crushing effect. After a detailed investigation, a feed rate of 120 t/h is chosen, and the bond cleavage ratio is found at 82.1%. From the results, it can be concluded that when the sizes of feed particles are 8 mm, 20 mm, and 40 mm, these account for 20%, 30%, and 50% of the feed respectively. It can be implied that the feed rate of 120 t/h and the speed of 1800 rpm can be selected for crushing production.

The proposed method may also be applied to choose an appropriate feed rate and rotor speed for crushing production when the feed size distribution fluctuates, considering the bond cleavage ratio and the crushing capacity. The simulation results show that a feed rate of 120 t/h and a speed of 2000 rpm can be selected when feeding is according to Scheme 2 (Tab. 1), and the size distribution of the feed is according to Scheme 3 (Tab. 1). It means a feed rate of 200 t/h and a speed of 1400 rpm are the optimal parameters for crushing production.

5 Conclusions

By analyzing the material crushing mechanism, the relationship between the particle size and the rotor speed was obtained, and the CFD-DEM simulation model was verified by the theory of single-particle crushing. Feed size distribution, speed of the rotor, and feed rate were selected for the material crushing simulation test. The optimal operating parameters were decided for bond cleavage ratio and production efficiency. The results show that when the sizes of feed particles are 8 mm, 20 mm, and 40 mm, these account for 20%, 30%, and 50% of the feed, respectively, and the feed speed of 120 t/h and a rotor speed of 1800 rpm can be selected for crushing production. The optimal operating parameters for crushing production are also obtained with other feed size distributions.

Acknowledgement

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