The Influence of the Structure of Double Toothed Roller Crusher on the Crushing Effect based on EDEM

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Abstract. The traditional research on the crushing effect of double toothed roller crusher and the smoothness of crushing process usually consider the single factor. But the crushing process of double toothed roller crusher is a complex process, so there are some limitations to consider the influence of one factor. By means of orthogonal experiment, simulation analysis considers the influence factors of the roller spacing, the rotational speed and the pitch angle. The best test scheme and the order of three influencing factors are obtained, which provides the basis for the design of the double toothed roller crusher.

1. Introduction

With the rapid development of social economy, metallurgy, ore, traffic, building materials and other infrastructure industries are growing in production scale, these industries generally use a large volume of raw materials. In order to study the particle size distribution of the double toothed roller crusher, it is necessary to study the different crushing effect and the stability of the double toothed roller crusher under different conditions.

Lieberwirth H [1] gave the results of fragmentation dynamics under extreme conditions, the particle size distribution of related products, and the effect of mineral structure of various rocks on the impact behavior. Kwon [2] was used to characterize the particle behavior of the broken products of the double roller crusher and to predict the particle size distribution of the broken products. Soni S K [3] had established a model describing the particle breaking behavior of a smooth double roller crusher for the study of product particle size distribution. Cleary P W [4] simulated the crushing model by using discrete element method, and studied the existing jaw crusher based on the estimation of power, particle size distribution, productivity and crusher wear. Li [5] researched the feasibility of the discrete element method to model the performance of a cone crusher comminution machine has been explored using the particle replacement method to represent the size reduction of rocks experienced within a crusher chamber.

In this paper, by analyzing the crusher mechanism of double toothed roller crusher, on the basis of previous research, the author analyzes the influencing factors and the order of crushing effect of double toothed roller crusher. By means of Solidworks software and EDEM discrete simulation method, the particles are bonded into one body to simulate the process of real crushing. The best crushing test scheme is obtained by the treatment method of orthogonal test. It provides a reference for studying the particle size distribution of the crushing products of the double toothed roller crusher.
2. Double toothed roller crusher and material model

2.1. Crushing mechanism and model
The main working part of the double toothed roller crusher is two parallel installed crushing rollers, through which the material is broken by the compaction of the two broken rollers. The double toothed roller crusher is mainly divided into three stages to crush the material, as shown in figure 1-2:
(1). The materials falling into the broken cavity are crushed and bitten (1-1` to 2-2`);
(2). The materials move to the midpoint between the broken teeth and are crushed by the combined action of extrusion and shearing (2-2` to 3-3`);
(3). The materials drop until the broken rod is broken again (3-3` to end).

2.2. Material calibration and model
In order to ensure the accuracy of simulation, the simulation parameters need to be calibrated. The parameters of rock model include macroscopic physical properties and micromechanical properties of rocks. The parameters of macroscopic physical properties refer to Poisson's ratio, density, shear modulus, collision recovery coefficient of rock, static friction coefficient and rolling friction coefficient; The parameters of micromechanical properties of rock refer to the parameters of inter-granular interaction model in discrete element model based on discrete element method, which mainly include the unit area of inter-granular interaction bond, the normal stiffness, shear stiffness, normal ultimate strength, shear ultimate strength and acting bond radius[6]. The uniaxial compression test was carried out, and the cylinder with a diameter of 50 mm and a height of 100 mm was used for calibration, as shown in figure 3.

| Parameter                  | Normal stiffness per unit area(N/m^3) | Tangential stiffness per unit area(N/m^3) | Normal ultimate strength(Pa) | Tangential ultimate strength(Pa) |
|----------------------------|--------------------------------------|-----------------------------------------|-----------------------------|----------------------------------|
|                            |                                      |                                         |                             |                                  |

After repeated tests, the failure form of the rock discrete element is in accordance with the compression test of the material in table 1-3.
Table 2. Macro-mechanical parameters of materials.

| Material     | Poisson ratio | Density (kg/m³) | Modulus of shearing (Pa) |
|--------------|---------------|-----------------|--------------------------|
| Sandstone    | 0.3           | 2600            | 2.7x10¹⁰                 |
| Steel        | 0.3           | 7850            | 7.9x10¹⁰                 |

Table 3. Material interaction parameters.

| Material          | Recovery coefficient | Static friction coefficient | Coefficient of rolling friction |
|-------------------|-----------------------|-----------------------------|--------------------------------|
| Sandstone - sandstone | 0.2                   | 0.5                         | 0.5                            |
| Steel - sandstone | 0.25                  | 0.7                         | 0.01                           |

The following assumptions are made and the model is shown in figure 4:

1. Assuming that the broken material is circular in geometry and made of a large number of small particles bonded by bonding bonds;
2. Assuming that the particle contact model is a soft ball model, a certain amount of extrusion deformation can occur, which depends on the bonding bond and the contact radius of small particles;
3. Assuming that the bonding force between small particles is equal.

3. Test simulation plan

3.1. Test plan design

Because of the large size span of feed and the restriction of discrete element, it is necessary to simplify the particle size of double toothed roller crusher. The grain size distribution is shown in table 4 according to the actual situation in order to guarantee the accuracy of the results.

Table 4. Simplified calculation of feed granularity.

| Particle size grade | Size range (mm) | Ratio (%) | Rock number |
|---------------------|-----------------|-----------|-------------|
| M1                  | 900-1200        | 6.51      | 1           |
| M2                  | 700-900         | 9.19      | 3           |
| M3                  | 500-700         | 10.04     | 9           |
| M4                  | 400-500         | 24.57     | 43          |
| M5                  | 300-400         | 25.55     | 106         |
| M6                  | 200-300         | 24.14     | 338         |

According to the crusher mechanism, the roller spacing, the rotational speed and the pitch angle of tooth are selected and marked as A, B, C. Three levels is selected with orthogonal table L9(3³) in table 5. The test index is the bond fracture ratio, the variance and mean of the resultant force. The fracture ratio directly affects the discharge granularity; the force of the tooth roller directly affects the stress and strain of the roller; the variance of the resultant force reflects the change degree of the resultant force in the crushing process of the double toothed roller crusher. The variance of the resultant force is smaller, the better the stability of crushing is.

Table 5. Factor level table.

| Levels | A: Roller spacing (mm) | B: Rotational speed (r/min) | C: Pitch angle (°) |
|--------|------------------------|-----------------------------|-------------------|
| 1      | 1470                   | 15                          | 0                 |
| 2      | 1490                   | 18.75                       | 12                |
| 3      | 1510                   | 21                          | 24                |

In the EDEM simulation, the particle generation speed was 5,000 per/s and the initial velocity was 9.8m/s². The total bonding number was 152627. The particle replacement time was 0.1s, bonding time...
was 0.1005s and the time step was 1.5%, the total simulation time was 40s and the mesh size was 150mm.

3.2. Simulation results and analysis

3.2.1 Simulation result
Since the double toothed roller crusher is two symmetrical rollers, it is only necessary to study the force on one of the rollers when the resultant force is studied. According to orthogonal table, there were 9 groups, each group was simulated for 3 times, study the bond fracture ratio, the mean and the variance of resultant force, record from the beginning of contact 0.4s, the interval of 0.2s, a total of 100 data and the result was shown in table 6.

| N | A | B | C | M1 | M2 | M3 | Ra(%) | F̄a (N) | σ²a (N) |
|---|---|---|---|----|----|----|------|--------|--------|
| 1 | 1 | 1 | 1 | 1.085 | 0.582 | 0.597 | 0.588 | 17.3 | 14.2 |
| 2 | 1 | 2 | 2 | 0.589 | 0.54 | 0.599 | 0.576 | 11.1 | 15.5 |
| 3 | 2 | 2 | 3 | 0.615 | 0.667 | 0.696 | 0.659 | 10.1 | 9.7 |
| 4 | 2 | 1 | 2 | 0.529 | 0.506 | 0.573 | 0.536 | 18.7 | 19.4 |
| 5 | 2 | 2 | 3 | 0.499 | 0.499 | 0.534 | 0.511 | 15.7 | 14.3 |
| 6 | 2 | 3 | 1 | 0.431 | 0.469 | 0.453 | 0.451 | 15.4 | 14.3 |
| 7 | 3 | 1 | 3 | 0.637 | 0.604 | 0.608 | 0.616 | 21.9 | 12.5 |
| 8 | 3 | 2 | 1 | 0.602 | 0.606 | 0.610 | 0.606 | 21.2 | 18.1 |
| 9 | 3 | 3 | 2 | 0.422 | 0.496 | 0.475 | 0.464 | 19.2 | 15.6 |

Index: Bond fracture ratio
Major factor: A, C, B
Superior level: A, C, B
Optimal combination: A, C, B

| M | 5.47 | 5.22 | 4.94 |
|---|-----|-----|-----|
| M | 4.49 | 5.08 | 4.73 |
| M | 5.06 | 4.72 | 5.36 |
| M1 | 1.82 | 1.74 | 1.65 |
| M2 | 1.50 | 1.69 | 1.58 |
| M3 | 1.69 | 1.57 | 1.79 |
| R | 0.32 | 0.17 | 0.21 |

| σ²a | 2791 | 3816 | 5044 |
|-----|-----|-----|-----|
| σ²b | 3828 | 3111 | 3060 |
| σ²c | 3842 | 3534 | 2357 |

Index: Variance of resultant force
Major factor: C, A, B
Superior level: C, A, B
Optimal combination: C, A, B

| σ²a | 930.3 | 1272. | 1681. |
|-----|-----|-----|-----|
| σ²b | 1276. | 1037. | 1020. |
| σ²c | 1280. | 1178. | 785.7 |
| R | 350.4 | 235 | 895.6 |

| F̄a | 118.7 | 155.9 | 153.1 |
|-----|-----|-----|-----|
| F̄b | 151.0 | 142.4 | 149.9 |
| F̄c | 157.4 | 128.8 | 127.1 |

Index: Mean resultant force
Major factor: A, B, C
Superior level: A, B, C
Optimal combination: A, B, C

Note: the variance of resultant force is multiplied by 10¹²N, and the mean resultant force is multiplied by 10⁴N.
- N represents the number of test groups.
- Ratio represents the bond fracture ratio.
- Ra represents average of bond fracture ratio.
- F̄a represents mean of the resultant force.
\( \sigma_r^2 \) represents variance of resultant force.

From the data in Table 6, do the simulation of the whole process, as shown in the figure 5, the fracture ratio curve is marked as the black line, star icon; the average force curve is marked as the red line, triangle icon; the variance curve is marked as the blue line, diamond icon. At the same time it is necessary to make three index effect curve in order to show the order of three factors and levels more obviously. There is the roller spacing, the roller speed, the spiral angle effect from top to bottom respectively in the figure 6. The variation range is heavier, the impact on the fracture ratio is greater. In the same way, the Mean and variance of force effect curve can be obtained in the figure 7-8.

3.2.2 Analysis of results

According to the figure 5-8, the rollers spacing is the main factor that affects the crushing effect and the mean resultant force of the toothed roller. For the fracture ratio effect curve, the curve decreases first and then increases with the increase of the roller spacing. The pitch angle and rotational speed of the secondary factors may interfere with the fracture ratio lightly in the figure 6; for the mean of resultant force curve, it is surprising that the curve is not decreasing but increasing with the increase of the roller spacing in figure 7; for the variance of resultant force effect curve, the effect of the increasing of roll spacing is the same as the mean resultant force effect curve. The important result of the curve is that the variance of resultant force is decreasing with the increasing of the pitch angle in the figure 8.

The tooth pitch angle is the most important factor in the process of crushing, and also has an important influence on the crushing effect. The greater the pitch angle is, the smaller the variance of resultant force is, which indicates that the process of crushing is more stable.

4. Conclusion

Based on the method of discrete element and orthogonal experiment, this paper draws the following conclusions:
1) The main and secondary factors affecting the bond fracture ratio are the roller spacing, the pitch angle, the rotational speed; The main and secondary factors affecting the variance of resultant force are the pitch angle, the roller spacing, the rotational speed; The main and secondary factors affecting the mean resultant force are the roller spacing, the rotational speed and the pitch angle.

2) According to the analysis of the crushing effect and the force situation, primary factor is crushing effect, design the roller spacing first; primary factor is stability of crushing process, design the pitch angle first.

3) Of course, there are many shortcomings in the paper. Different components of materials will affect the crushing process of double toothed roller crusher. However, this paper puts forward a new idea for studying the particle size and crushing effect, which provides the basis for the design of the double toothed roller crusher.

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