

Study on the influence of liner parameters on the power of ball mill and impact energy of grinding ball

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Abstract. The impact energy of grinding ball and the moving state of medium are the direct factors that affect the grinding effect of ball mill. The structure of liner is closely related to both. In order to further study the influences of impact energy and medium motion on the grinding effect of liner structure, especially stepped liner structure, the paper studies the effect that the friction angle of liner, the height difference of liner and the arc angle of liner on these two aspects of the ball mill by the method of control variables and discrete element analysis. Through the research of the paper, the power of the ball mill increases with the increase of the friction angle. The higher the energy is, the less the number of impact is, the number of impact on the liner with the lower friction angle will reduce quickly. The effect of the mill's power is minimal; the stepped liner has a high number of impact at low energy and a low number of impact at high energy. The research results provide theoretical support and scientific basis for the reasonable design of liner and the efficiency of ball mill.

1. Introduction

The grinding efficiency is related to mill power and grinding effect. The factors that directly affect the grinding efficiency are the impact energy of grinding ball and the moving state of the medium. The structure of the liner is closely related to both. This paper studies the influence of liner parameters on the grinding effect by the method of control variables and discrete element analysis.

2. Determine of the ball mill parameters

The paper takes $\phi 1500\text{mm} \times \phi 3500\text{mm}$ ball mill of overflow type as the research object. In the simulation of EDEM discrete element, part of the axial length of the ball mill is used to replace the length of the ball mill ^[1-2]. In the simulation, the axial length of the ball mill is taken as 500mm, the diameter of the grain ore is taken as $\phi 10\text{mm}$, and the effective volume is taken as 5.39 m^3 .

2.1. Determine of the medium diameter

Too small or too big of medium ball size will reduce the grinding effect of the ball mill ^[3], according to the test of experts on the relationship by the ball diameter and the grain ore size (Figure 1), the paper selectes the mine diameter of 10mm, and the corresponding ball diameter is about 50mm.



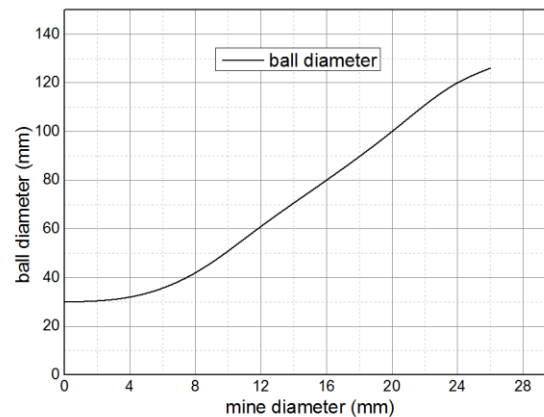


Fig1. The relationship of ball and grain ore size.

2.2. Critical speed of ball mill

The effective diameter of ball mill is $D=1400\text{mm}$, into the formula $n_c=30/\sqrt{R}$, obtained $n_c=35.8\text{r/min}$.

In generally, the real rotation rate of ball mill is between 76% to 86%, and the working speed of the ball mill can be the following value: $n = (0.76\sim 0.86) n_c$.

In the EDEM simulation, choose 0.75, 0.8 and 0.85 rotation rate to do the comparative test, calculated by the formula of their speeds were: $n_{0.75}=26.85\text{r/min}$; $n_{0.8}=28.64\text{r/min}$; $n_{0.85}=30.43\text{r/min}$.

2.3. Ratio of ball

In this paper, the medium filling rate is 20%. In the simulation experiment group, both Φ_m of 150% and void ratio of 0.38 are selected. Calculate the mass of grinding ball $M1 = 744\text{kg}$, the mass of material $M2 = 237.6\text{kg}$.

3. Settings of simulation data

There are many factors that affect the grinding effect of ball mill. However, this paper studies the effect of stepped liner on grinding effect at different rotation rates and the relationship between them, and the friction angle of the structural parameters of the stepped liner, height difference h_2 , and effect of variation of arc angle and rotational rate ψ on grinding performance of ball mill. The rotation rate ψ in the simulation range of the paper is set to 0.75, 0.8 and 0.85, the height difference h_2 is set to 40mm, 60mm and 80mm, the specific simulation data is shown in Table 1.

4. Simulation modelling of EDEM

Models used in the simulation are: 1. Ball mill liner model; 2. Ball and material particle model; 3. Particle factory model; 4. Boundary conditions model. Here's how to model about these models.

4.1. Model of liner

The main research object of the simulation is the influence of the structural parameters of the stepped liner of the ball mill on the grinding effect of the ball mill, and the curve of the stepped liner of the ball mill adopts the Archimedes logarithmic spiral, and all the simulations are respectively calculated according to the formula set of curve equations, and come to its polar equation.

The simulation objects are the structural parameters of the stepped liner, in order to shorten the simulation time, liner model will be simplified as follows:

- (1) Ignore the connection between the liners; all liner will be built as an entity;
- (2) Ignore the hole and chamfer of liner.

Through using the generated liner curve, figure 2 shows a three-dimensional model of the stepped liner generated by drawing commands that is SOLIDWORKS.

Tab1. Simulation data

Simulation number	Liner number z	Liner arc angle (°)	Friction angle (°)	Liner height difference (h2)	rotation rate ψ	Rotating speed(rpm)
1.1	24	15	12.15	40	0.75	26.85
1.2				60	0.8	28.64
1.3				80	0.85	30.43
2.1			40	0.75	26.85	
2.2			60	0.8	28.64	
2.3			80	0.85	30.43	
3.1	30	12	23.91	40	0.75	26.85
3.2				60	0.8	28.64
3.3				80	0.85	30.43
4.1			40	0.75	26.85	
4.2	34	10	15.06	60	0.8	28.64
4.3				80	0.85	30.43
5.3			29	80	0.85	30.43
6.3			33.63	80	0.85	30.43

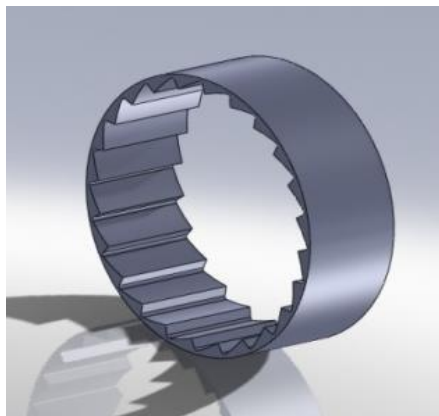


Fig2. CAD model of the stepped liner.

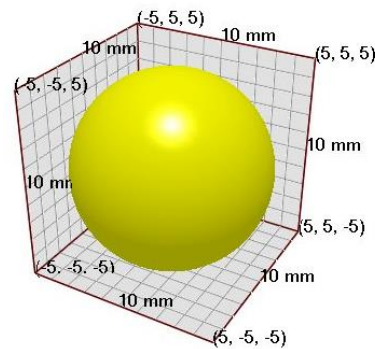


Fig3. Material model.

4.2. Particle model of ball and material

Grinding balls were created using internal modelling modules from EDEM software. Therefore, it is necessary to simplify the geometric model of the material particles into a regular sphere (Figure 3). Based on the calculation time, the material particle model is also generated by using the EDEM software's internal modelling module.

4.3. Factory model of particle

Figure 4 shows the factory model of particle (in the red region) whose role is to define the spatial region generated by the particle model of the material and the ball. Therefore, the factory model of particle should be built into a virtual space using EDEM software, not included in the solid geometry model. And the shape is selected as a cylinder.

4.4. Boundary conditions

The role of the boundary condition model is used to constrain the entire simulation, so the boundary condition model is modelled using the EDEM software's internal module, which is the largest boundary of the solid cylindrical liner of ball mill. The completion of the simulation model is shown in Figure 5.

5. Simulation analysis by EDEM

Simulation time is set to 10s; the simulation factor is 40%. This section will analyze the influence of the design parameters of the liner on the grinding effect of the ball mill from three aspects: the friction angle of the liner, the height difference of the liner and the arc angle of the liner.

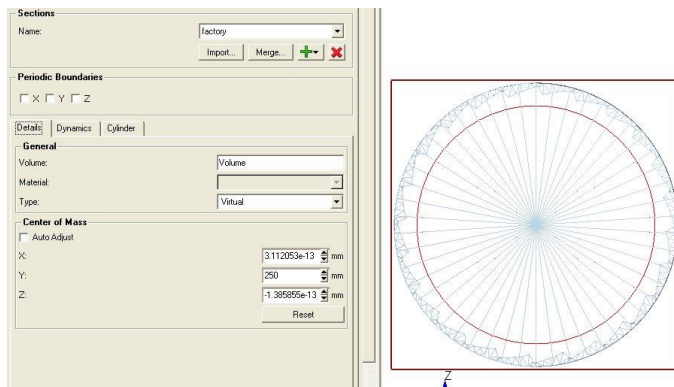


Fig4. The Factory model of particle.

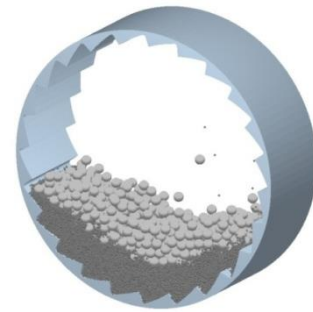


Fig5. Simulation model

5.1. Friction angle of liner

(1) The influence of friction angle on ball mill power

The friction angle of the stepped liner is an important factor affecting the power of the ball mill. When the arc angle of stepped liner is 15° , the relationship between the friction angle of the stepped liner and the power of the ball mill at different rotation rates is shown in Figure.6.

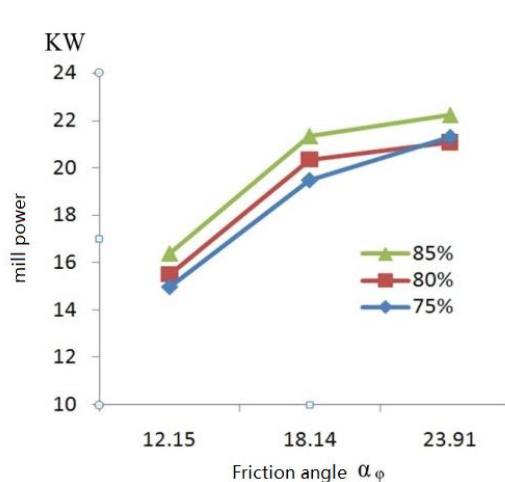


Fig6. The effect of Friction angle on power of ball mill when the arc angle of liner is 15°

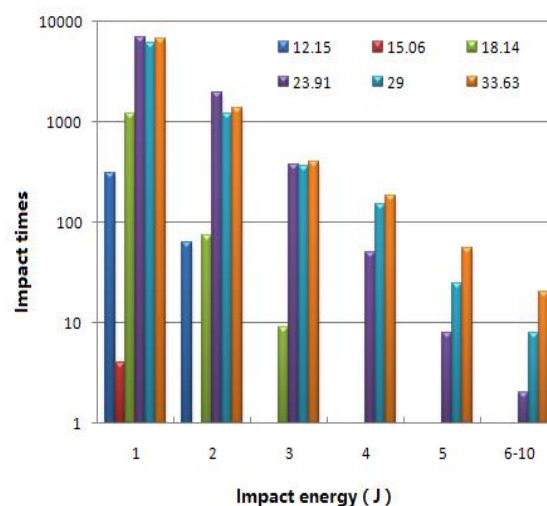


Fig7. The relation between the friction angle and impact energy

As can be seen from the figure, with the friction angle increases, the power of the ball mill gradually increases; at the same time, as the rotation rate increases, the power of the mill ball is also gradually increased. When the friction angle is between 18.14° and 23.91° , the output power of ball mill decreases obviously.

(2) The effect of friction angle on the impact energy

Select from Table 1 numbered 1.3, 2.3, 3.3, 4.3, 5.3 and 6.3 these six groups of data for comparison. Figure 7 shows the relationship between the friction angle and the impact energy and the number of impact.

As can be seen from Figure 7, the higher the energy, the smaller the number of impact, and the lower the number of impact of the liner with the lower friction angle, and the slower the number of impact with the larger friction angle, the slower the deceleration and the higher the energy.

5.2. Height difference of liner

(1) The effect of the height of the liner on the ball mill's power

In order to study the effect of height difference h_2 on the power of the ball mill, the height difference of 40 mm, 60 mm and 80 mm were selected when the arc angle of the liner was 15° and the rotating rate was 0.85.

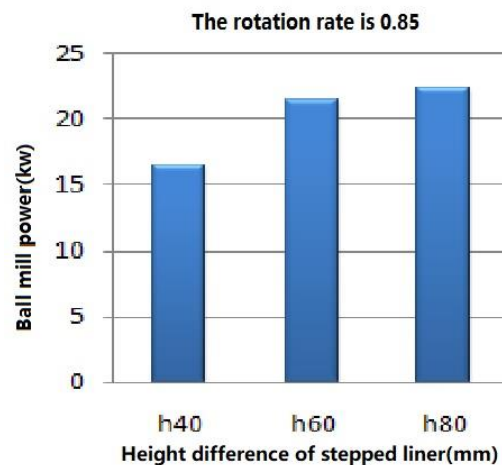


Fig8. The influence of height difference of stepped liner on the power of ball mill

It can be seen from Figure 8 that the power of the ball mill is not obviously increased when the height difference of the stepped liner reaches 60mm and above. The increase of the power of the ball mill is not obvious when the height difference of the stepped liner reaches 60mm and above, mainly the larger material diameter accounts for more in the simulation experiment.

(2) The effect of height of liner on impact energy

In order to study the effect of the height of the stepped liner, h_2 were selected for the 40mm, 60mm and 80mm. When the arc angle of the liner is 15° , the impact energy of the ball is changed as shown in Figure 9, when the rotation rates are 0.75, 0.8 and 0.85.

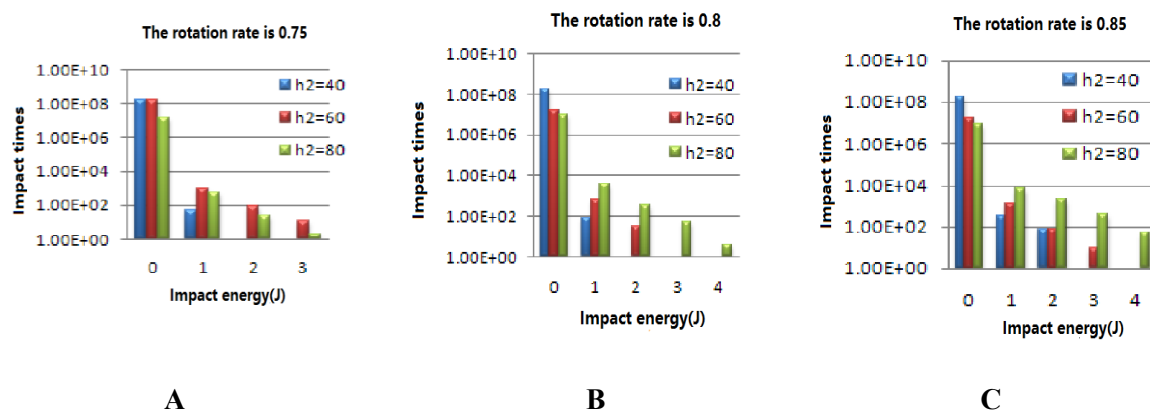


Fig9. The number of different impact energies.

As shown in Figure 9a, the stepped liner with height difference of 60mm has high energy impact times in each stage. As shown in Figure 9c, the stepped liner with height difference of 80mm has much higher impact times in the high energy region, as shown in Figure 9b, the number of impact with a height difference of 80 mm increases more rapidly than the others with increasing speed.

Combined with the above analysis results, when the large volume of materials accounted for a larger case, you priority can choose the larger height difference stepped liner to achieve the grinding work. If the small volume of materials accounted for a larger case, you can give priority low height difference of stepped liner to achieve grinding work.

5.3. arc angle of liner

(1) The influence of arc angle on the power of ball mill

There are three kinds of arc angle of the stepped liner, which are 15° , 12° and 10° . In order to study the influence of the arc angle of the stepped liner on the power of the ball mill, the rotation rate is chosen as 0.85.

As can be seen from Figure 10, when the arc angle of the stepped liner increases, the power value of the ball mill has tended to be a stable interval with little change. Therefore, when the arc angle of stepped liner increases to a certain value, you can ignore the effect of the arc angle of stepped liner on the power.

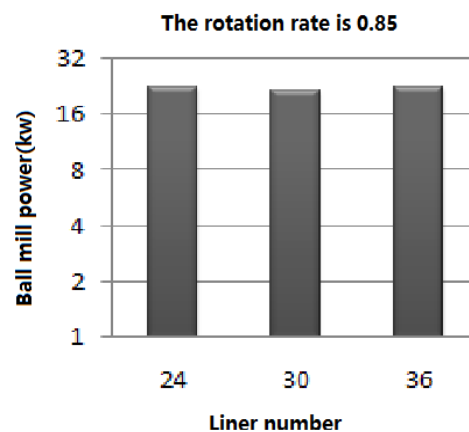


Fig10. The influence of the number of stepped liner of ball mill on power

(2) The influence of arc angle on the impact energy

The arc angles of the stepped liner are 15° , 12° and 10° , respectively, and the rotation rate is 0.85. The influence of the arc angle of the stepped liner on the number of impact and the energy distribution in each stage are shown in Figure 11.

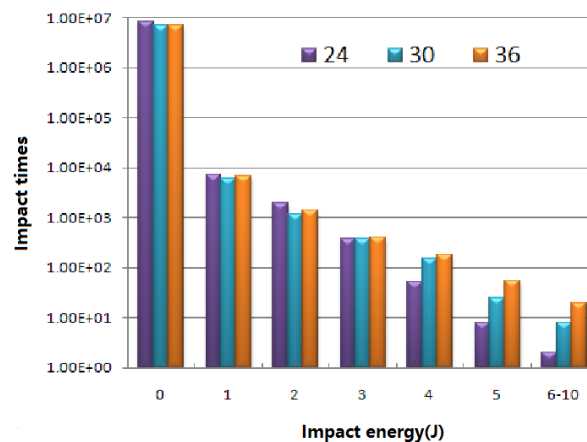


Fig11. The influence of arc angle of stepped liner on impact energy

As can be seen from Figure 11, the stepped liner has a high number of impact at low energy and a low number at high energy. The number of impact at a large arc angle in the high energy zone is significantly greater than that at a small arc angle more.

6. Summary

Through the establishment of the simulation model of the stepped liner, the paper analyzes the influence of the key parameters of the stepped liner on the mill power and the impact energy of the ball by EDEM software.

Through the research of this paper, we can draw the following conclusions:

- (1) As the friction angle increases, the power of the ball mill gradually increases; at the same time, the power of the ball mill gradually increases with the increase of the rotational rate;
- (2) The higher the energy is, the less the number of impact is, and the lower the number of impact of liner with low friction angle is, the slower the number of impact with high friction angle is, and the energy is relatively high.
- (3) The power of the ball mill is not very obvious when the height difference of the stepped liner reaches 60mm and above, mainly because there is a large proportion of material diameter in the simulation experiment.
- (4) The number of impact with height difference of 60mm is higher in each stage; the number of impact with height difference of 80mm is higher in the high-energy stage and the number of impact with height difference of 80mm increases with the increase of rotational rate than the others faster.
- (5) The effect of the arc angle on the power of the ball mill is negligible because the arc angle of the stepped liner has little influence on the power of the ball mill.
- (6) The stepped liner has a high number of impact at low energies and a low number of impact at high energies.

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