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Efficiency of Discrete Element Method in Analyzing Particle Flow and Impact Energy in Ball Mills for Ore Crushing Optimization

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ABSTRACT: This study employs the Discrete Element Method (DEM) to simulate particle flow in a ball mill under varying operational conditions. The model enables a comprehensive analysis of flow structure and impact energy of particles, considering different milling conditions. Results indicate that impact energy is contingent upon mill operating conditions and correlates with ore crushing rates. Overall, the computational time required for determining impact energy in mills can be significantly reduced..

KEY WORDS: Discrete element method, ball mill, impact energy, productivity, specific electrical energy consumption, rotation moment, rotation speed.

I.INTRODUCTION

Currently, there is an increase in the processing of minerals in the mining and metallurgical industry and the need to increase the energy efficiency of production. The most energy-intensive precious metal processing process is the grinding process, which accounts for about 40% of total energy consumption [1-6]. Grinding equipment includes various types of mills, including the most common wet autogenous mills (WAM) and ball mills (BMCL, BMG), the installed capacity of which reaches 4000 kW.

As our research shows, the operating mode of a ball mill depends on many factors: the physical properties of the material being ground, its specific gravity and hardness, the degree of filling of the mill with ore and balls, the rotation speed of the ball mill, etc. This mode also determines the consumption of electrical energy. In addition, the operating mode of the mill and its energy consumption depend on the degree of wear of the mill lining. As is known, the lining in the process of contact with the crushed ore and metal balls is subject to wear, which leads to a change in the trajectory of the crushed mixture and an increase in electrical consumption [7-10].

The specific productivity is determined by the formula given below, depending on the size of the mill.

$$q = \frac{Q}{V_m} \text{ t/m}^3 \cdot \text{hour} \quad (1)$$

The performance of a ball mill in class -0.16 + 0.2 mm will be as follows.

$$q_{0,16} = \frac{Q^{0,071}}{V_m} \text{ t/m}^3 \cdot \text{hour} \quad (2)$$

Table 1 shows the distribution of ore from the MMC-70x23 mill in the form of ore pieces and balls when loaded with ore and balls and their main characteristics. As we know, the action of spheres on ore crushed in a ball mill is carried out in the form of a compressed impact pulse (CIP), quantitatively expressed by the ratio of the mass of crushing bodies in the mill to the mass of ore crushed at a time. This ratio is determined by the formula:

$$CIP \frac{m_{mm.}}{M_{im}}, \quad (3)$$

Where: m_{mm} – mill mass, kg;
M_{im} – mass of simultaneously crushed material, kg.

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Table 1. Dependence on density and hardness of ore and spheres

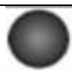
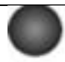
o. n/n	Material	Diameter, mm	Form	Weight, t	Density
1.	Piece of Ore	300		1.19	5000
2.	Piece of Ore	200		1.864	5000
3.	Piece of Ore	150		2,737	5000
4.	Piece of Ore	100		3.57	5000
5.	Piece of Ore	71		15.94	5000
6.	Piece of Ore	32		34,099	5000
7.	Ball	100		16.33	7600
8.	Ball	90		10,295	7600
9.	Ball	70		7.1	7600
10.	Ball	50		1.77	7600

Figure 1 shows the arrangement of balls under normal (standard) load, and Figure 2 shows the arrangement of balls of the same diameter during grinding in cascade mode.[4]

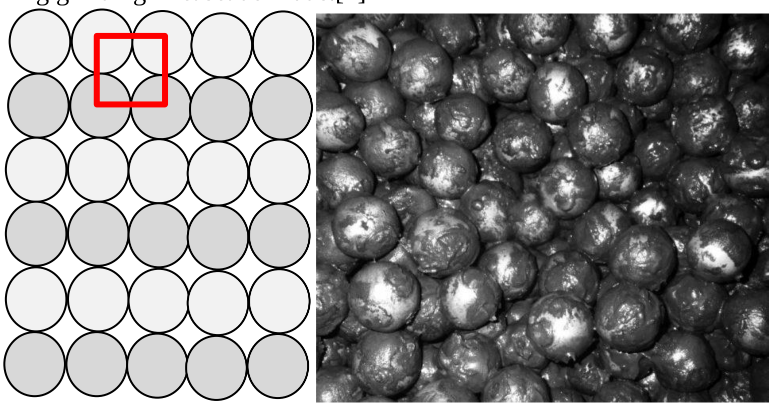


Figure 1. Ball placement under normal load.

According to Figure 2, when balls of the same diameter are arranged, the internal volume of the mill is distributed in the following ratio: 52% is the volume of small spheres, 48% is the volume of the cavity. To achieve maximum crushing, it is necessary to load balls with different diameters, which leads to a decrease in gaps during the crushing process. In the cascade mode (Fig. 3), you can consider the following: by loading balls of different diameters, you can reduce the volume of space by almost half.[3-4]

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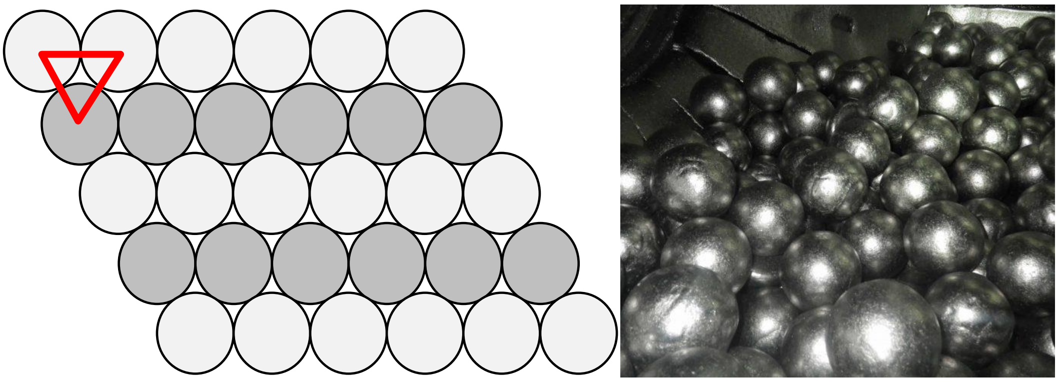

Figure 2. Placing balls of different diameters during grinding in cascade mode.

With such a dense load, the entire volume is distributed as follows: 74% is the volume of crushed spheres, 26% is the volume of voids. When using a dense load, the shock compression rate increases significantly, which directly affects the quality of grinding. To calculate, we use the above formula and get the following results.[6,7,8]

CIP (loading standard balls) = 7.3 kg/kg.

CIP (load in a dense state) = 14.43 kg\kg.

II. RESULTS AND DISCUSSIONS.

The results showed (Table 2) that the operation of a mill plant loaded in a dense condition (as shown in Fig. 3) is twice as efficient as that of a standard load (as shown in Fig. 2).

Table 2 The degree of ball loading depends on several factors.

Load type	Mass of 1 cubic meter of balls	Volume of balls in loading, cubic meters	Volume of voids in loading, cubic meters	Ball Load Density	Grinding fineness	
					passed through sieve 008, %	beat surface, sq.m/kg
Normal rated load	4.64	4.83	3.37	4.63	90.4-91.5	Wed 290
Dense loading	5.90	4.83	1.61	6.10	97.3-97.6	Wed 380

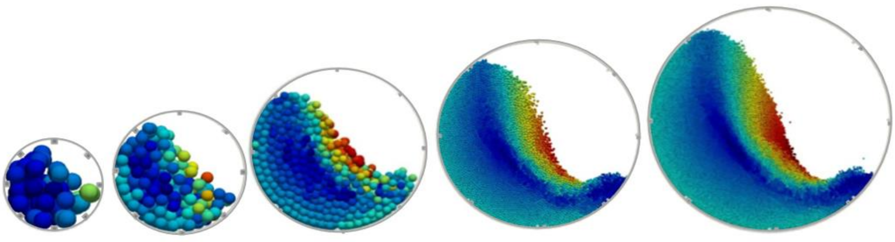

Figure 3. Ball mills of different sizes and load flow diagrams in them. (a) 100 mm; (b) 250 mm; (c) 400 mm; (d) 1000 mm; (e) 2500 mm, M* = 0.6 and N* = 0.5.

Figure 3 shows load flows in mills of different sizes, with different colors representing particle velocities. The DEM (Discrete element method) simulation is also designed for the crushing tool without considering only the crushed small particles.

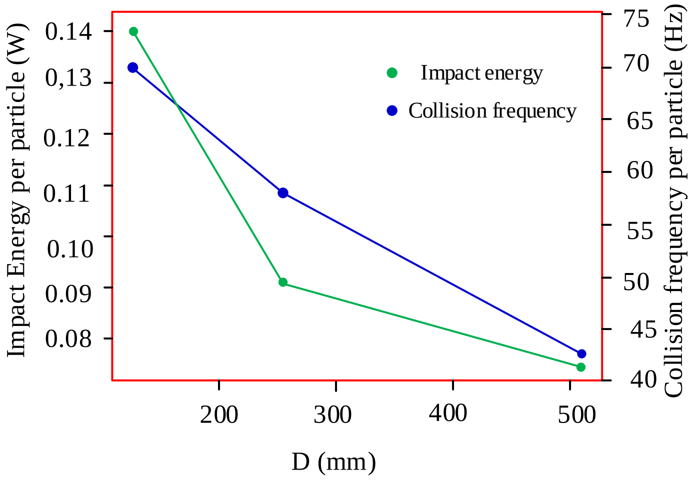

Figure 4. Impact energy and collision frequency for different size of mills when d = 15.4 mm, M* = 0.6 and N* = 0.5: (a) impact energy per unit time and collision frequency; and (b) variations of impact energy and collision frequency per particle with mill size.

Compared with abrasives, the number of crushed particles is significantly less and the influence of fine particles on abrasives is insignificant. For mills of different diameters, the movements of the balls are the same at the critical speed. Balls near the bottom are lifted by lifters and pulled around the booking covers. They lose contact with the drum part in the second position, and most of the balls fall from the vertical free surface with a certain speed towards the horizontal area of the bottom part of the drum. This is usually described as the cascading part of the load flow. As soon as the balls reach the bottom of the drum, they rise again to the top. The particles reach their maximum velocity below the center of the mill. Very slow moving particles are shown in light blue. As the diameter of the mills increases, the ore particles rise to a higher height and fall under the force of gravity. This helps the ore particles to reach the highest speed. [7]

III. CONCLUSION

In conclusion, our theoretical investigations into the dynamics of crushing load movement within the ball mill's crushing chambers have led to the development of contemporary methodologies for optimizing the interaction between the crushing mechanisms and the processed material. The manipulation of ball rotation and positioning in the mill has become feasible. Leveraging the Discrete Element Method (DEM) for describing the movement of loaded balls in the mill allows for precise determination of ball motion parameters in different regions of the crushing chamber.

The strategic accumulation of ore balls in the drum core serves to minimize the occupied space within the crushing chamber. Notably, the extent of ball loading significantly influences electricity consumption. Identifying the optimal level of ball loading, considering ore quality indicators, becomes crucial. By regulating ball loading levels, one can enhance the mill's electrical energy efficiency. For instance, the standard loading of 60 tons per hour in the CDBM (Central Discharge Ball Mill) can be increased to 90 tons per hour through the implementation of a cascade mode. Consequently, operating the mill in cascade mode, as opposed to its normal mode, results in a reduction in relative electrical energy consumption. The outcomes of our study underscore a decrease in the energy intensity of raw material preparation, leading to a tangible reduction in processing requirements.

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