DEM Modeling and Optimization of the High Energy Ball Milling

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Abstract: - The Discrete Element Method (DEM) is a numerical method for simulating the dynamics of particles processes. This present work focuses on DEM simulations of a scale laboratory planetary ball mill through DEM Altair 2021.2 software to optimize and modulate the milling parameters. The simulation results show a good agreement with the experiments. The numerical model is shown to be a promising tool for the knowledge of dry milling in a planetary ball mill.

Key-Words: - High-energy ball milling, Simulation, Optimization, Parameters, Modeling.

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1 Introduction

The discrete (or distinct) element method (DEM) was first developed by Cundal and Strack [1] to simulate granular soil. Xie et al. [2] investigated the influence of filling level on the wear of liner and vibration of a semi-autogenous grinding (SAG) mill by using DEM approach. They concluded that the high-energy collision between liner and milling media was the principal cause for mill vibration and liner wear. Xie and Zhao [3] applied DEM to study the influence of fluid, friction coefficient, and milling speed on the wear rate in a planetary ball mill. The results showed that drag force and torque from fluid could decrease the particle wear and that the rotation revolution radius affected the mill speed. Therefore, the impact energy of the particles, in ball mills, under various operating conditions was analyzed by DEM simulations [4]. It was showed that the impact energy was influenced by the operating conditions of milling. Zeng et al. [5] used DEM approach to investigate the influences of rotation speed and particle shape on flow behaviors in a vertical rice mill. They revealed that effects of ratio on the milling rely on rotation speed and that mean collision rate increase with increasing ratio for a lower rotation speed. Zeng et al. [6] used a numerical discrete element method (DEM) and particle replacement model (PRM) to simulate grain breakage in a vertical rice mill. The simulation results showed that the proposed method was an effective and efficient guidance to explain the mechanisms occurring in rice mill. Xie et al. [7] applied DEM for modeling a SAG mill with spherical and polyhedral media. They revealed that the charging of particles in the polyhedron-sphere milling system was blocked by polyhedral particles and that the energy collision between liner and material has increased remarkably. A combined physical and DEM approach was used to investigate cubical and spherical particles behavior in tumbling mills [8]. It was showed that changing spherical to cubical particles increased the simulation time by 35 folds. Pedrayes et al. [9] used DEM to characterize the load torque of tumbling ball mills in the frequency domain. They concluded that load torque signal contains sufficient information to characterize the load level of the ball mill. Similarly, the effects of filling level on the rice milling accuracy of rice in the friction rice mill were studied using DEM approach [10]. The obtained results showed that with increase of filling level, additional particles penetrate outside ring subsequently principally inner ring.

Powell et al. [11] used DEM modeling to simulate the dynamics of ball movement in an industrial scale ball mill.

Some researchers [12] have validated the DEM simulations using Positron Emission Particle Tracking (PEPT) experiments in rotating drums. They concluded a strong statistical agreement between the tuned DEM and PEPT data. Other researchers [13] studied the influence of contact parameters on charge motion and power draw by DEM modeling of a scale laboratory ball mill. They demonstrate agreement between simulations and experiment.

This paper aims to study the effects of mill speed on the load behavior during milling process. The simulations of the milling media were conducted by Altair 2021.2 software.

2 Materials and Methods

In this section, we provide the software used for the simulation, the instrument used for milling, and the input parameters for DEM simulation.

2.1 Discrete Element Model

The simulations were performed by Altair 2021.2 Software [14] that is designed for the simulation and analysis of bulk particle handling and processing operations. Therefore, the Hertz Mindlin is the contact model used in DEM because of its accurate and efficient. The normal and tangential contact forces are calculated based on the Hertz theory [15] and Mindlin and Deresiewicz theory [16], respectively. The tangential force uses the Coulomb's law of dry friction. The coefficient of restitution is a function of the normal and tangential components. This section was detailed in a previous work [17].

2.2 Instrument

The high-energy planetary ball mill [18] fabricated by German Fritsch Company (type Pulversiette 7) was used in the simulation. This mill consists of a rotating support disk (called turn table) and two milling vials, as presented in Fig. 1.

Fig.1. Pulverisette 7 planetary ball mill and vials used in experiment.

Fig. 2 shows the operating principle of the planetary ball mill. The supporting disk and the vials, containing the balls and powder, rotate in opposite directions.

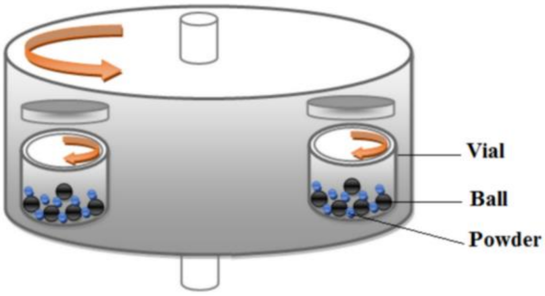

Fig.2. The operating principle of the planetary ball mill.

2.3 Simulation Parameters

The parameters of the materials used in the DEM simulations are shown in Table 1. These DEM parameters were determined from experimental and references [19]. The diameter of the milling balls was fixed as 15 mm.

During simulation, the powder particles are considered as spheres in order to reduce the required computation time. The volume of a powder particle was assumed equal the volume of a sphere with a diameter of 1.2 mm.

Table 1. The parameters for DEM simulations [19].

Parameter	**Value**
Revolution speed (rpm)	350
Rotational speed (rpm)	700
Density of vial and balls (kg/m^3)	7700
Density of powder (kg/m^3)	4000
Poisson's ratio of vial and balls	0.27
Poisson's ratio of powder	0.3
Young's modulus of vial and balls (Pa)	1.8×10^{11}
Young's modulus of powder (Pa)	1×10^{7}
Restitution coefficient of ball-ball and ball-vial	0.75
Restitution coefficient of powder-powder	0.3
Restitution coefficient of powder-ball and powder-vial	0.5
Static friction coefficient of ball-ball and ball-vial	0.5
Static friction coefficient of powder-powder	0.7
Static friction coefficient of powder-ball and powder-vial	0.7
Rolling friction coefficient of ball-ball and ball-vial	0.01
Rolling friction coefficient of powder-powder	0.15
Rolling friction coefficient of powder-ball and powder-vial	0.15
Time step (s)	1.01×10^{-4}

3 Results and Discussion

Fig. 3 shows the ball charge motion inside the mill in different characteristics zones and positions: (1) the head represents the highest point of the liner that is still in contact with the particles (also called the apex of charge trajectory); (2) the shoulder represents the region where the cascading material flows down; (3) the dead zone which is colored blue; (4) the bulk toe represents the point of intersection of tumbling charge with mill shell; (5)

the impact toe (crushing toe) represents the region where cataracting charge impacts shell or bulk charge; and (6) the cascading charge which is colored red.

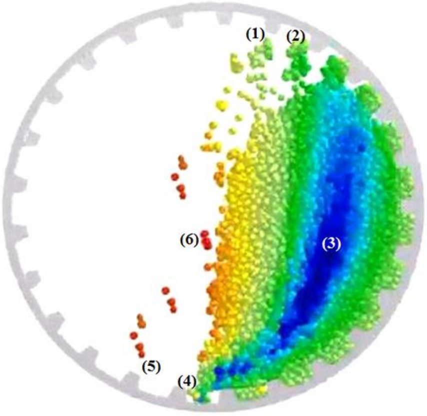

Fig.3. The ball charge motion in characteristics zones and positions.

Fig. 4 shows the snapshots of particles and balls motion during the ball milling process. Thus, the color indicates the particles velocity from blue (slow) to red (fast). By analyzing the trajectory of the milling media during the simulation of milling, the following conclusions can be drawn : at the begining (Fig. 4a), it can be seen that the milling media going up to a lower height. After that, with increasing the milling time (Fig. 4b), it can be seen that that the milling media going up to a great height due to the increase of kinetic energy. Furthermore, when the milling time is increased (Fig. 4c), the milling media were thrown towards the center of vial, which is caused by the centrifugal acceleration created by the planetary motion. Finally, for prolonged milling time (Fig. 4d), it can be observed that the milling media were located at toe and shoulder regions. The motion patterns observed in the simulation were also reported in several studies [20-22].

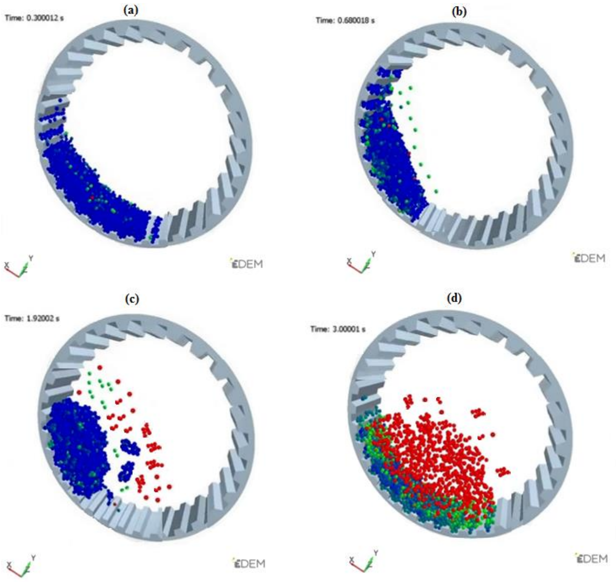

Fig.4. Snapshots of milling media during the ball milling.

In general, it can be seen from the simulation results that the DEM model is able to predict the milling media of the laboratory ball mill for different characteristics zones and positions. Therefore, additional DEM simulations are required to fully understand the milling mechanism.

4 Conclusion

In conclusion, DEM simulations were employed to optimizing and modeling the milling media in a planetary ball mill. DEM simulations can be used to calculate collision rates of balls and powder particles in a laboratory scale ball mill. More work would be complemented in our future research.

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Mohsen Mhadhbi carried out the simulation and wrote the paper throughout.

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