Scientific Research Publishing

Advances in Materials Physics and Chemistry, 2023, 13, 49-58
https://www.scirp.org/journal/ampc
ISSN Online: 2162-5328
ISSN Print: 2162-531X

Effect of Milling Parameters on DEM Modeling of a Planetary Ball Mill

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How to cite this paper: Mhadhbi, M. (2023) Effect of Milling Parameters on DEM Modeling of a Planetary Ball Mill. *Advances in Materials Physics and Chemistry*, **13**, 49-58.
https://doi.org/10.4236/ampc.2023.134004

Received: March 6, 2023
Accepted: April 25, 2023
Published: April 28, 2023

Abstract

The effects of the milling parameters involving shape of powder particles, rotation speed, and ball-to-powder diameter (BPDR) on DEM modeling in the planetary ball mill were investigated. BPDR was varied from 1 to 10. The results revealed that the size and shape of the powder particles do not give a significant change in simulation results when BPDR attains maximum value of 10. The increasing of BPDR leads to the increase of simulation time and size. Hence, the effect of change of the powder particle shape on the calculated data size is not significant. The results also revealed that the increasing rotation speed increases impact energy between powder particles.

Keywords

DEM Modeling, Milling Parameters, Planetary Ball Mill, Particles Shape

1. Introduction

The discrete element method (DEM) has been commonly used by engineers and researchers to simulate granular materials in various fields. A key application of DEM modeling was the construction of the model and the calibration of the input parameters [1] [2] [3] [4].

However, a number of research have been developed to investigate the balls motion inside ball mill based on the DEM simulations [5] [6] [7] [8]. For example, Li *et al.* [9] developed a scale-up model based on DEM modeling to study the performance of tumbling ball mills. They showed that the particle-ball contacts were the principal breakage mechanism of particles during milling. They also revealed that the estimated milling rates of the particles under various conditions were consistent with the experimental results. Jayasundara and Zhu [10] used DEM simulations and data driven approach to simulate the impact energy of particles in ball mills under different operating conditions. The obtained mode was validated by comparing the simulated results with the experimental data. The results showed that the milling performance decreases with increasing mill size and the impact energy was influenced by the operating conditions of the mill. Kim *et al.* [11] investigated the effects of the shape of the powder particles and the ball-to-powder diameter ratio on EDEM simulations and time in a planetary ball mill. They concluded that the simulation time and date size increase with increases in ball-to-powder diameter ratio. Kalpanadevi *et al.* [12] investigated the influence of four rice varieties on rice milling. They revealed that the larger grain length shows the elevated degree of milling. Xie *et al.* [13] used DEM simulation to study the effect of spherical and irregular polyhedral ore on the performance of SAG mill. They concluded that the liner wear of the polyhedron-sphere milling system is harder than pure spherical. Hence, Bibak and Banisi [14] investigated the influence of particle shape on load movement in tumbling mills by using physical and DEM modeling approach. They concluded that the cubical particles contributed 5% more in the high-energy impact action in comparison to the spherical particles. In addition, the simulation time increased by 35 times with changes in particles shape from spherical to cubical. Mio *et al.* [15] investigated the effect of rotation-to-revolution speed ratio and rotational direction on the milling performance using three kinds of planetary ball mill. They showed that the counter rotational direction is very powerful for enhancing the milling performance rather than the normal rotational direction. Hence, the optimum rotation-to-revolution speed ratio can be used to determine an effective milling condition. In this regard, Mori *et al.* [16] carried out the ball mill simulation in wet grinding using a tumbling mill and discussed the correlation between the experimental and simulation results. Moreover, it was found that the specific impact energy determined from the simulation correlates with the milling rate of the sample, showing that the energy is the most influential factor used in the control of wet milling.

Additionally, Cleary [17] analyzed the effect of rock shape representation in DEM on flow and energy utilization by using a pilot SAG mill. The results showed that the rock shape has a greater influence on the big size classes in the charge. In the research of Liu *et al.* [18], the electrical system and multi-body dynamics model (EMBD) was combined with DEM method to explore the performance of a semi-autogenous (SAG) mill under various conditions. It was shown that the fluctuation of motor load torque, current, and mill speed in the initial stage is very greater than that in the stable running stage. Li *et al.* [19] studied the performance of vertical roller mill (VRM) by changing the material properties and operating conditions based on DEM simulation and experiment. They revealed that the crushing characteristics of VRM are very powerful for the operation parameters and optimization of the equipment. Oliveira *et al.* [20] conducted DEM simulation on a ball mill to study the effect of mill geometry, milling medium size, milling speed, and percent solids on apparent breakage rates. They concluded that the breakage rates increase considerably with stirrer speed and the increase in the milling media lead to an increase of breakage rates. Based on DEM simulation combining particle replacement model, Zeng *et al.* [21] investigated the modeling of grain breakage of in a vertical rice mill. It was found that the results obtained from the simulation are in agreement with those from experiments. Orozco *et al.* [22] used DEM simulations to study the breakage of particles in a 2D ball mill. They showed that the change in balls size has little effect on the evolution of milling. They also concluded that the milling rate increases with the number of balls of the same size. Lv *et al.* [23] studied the effect of various initial modes on the performance of a ball mill based on the electromechanical coupling model. It was found that the simulation results are consistent with the experimental data. Chimwani and Bwalya [24] used DEM simulation to investigate the effect of mill fill rate, end liner configuration, shape, and ball size on the distribution of forces acting on the liner. They revealed that the forces (radially and tangentially) increase with the increase of mill filling and with bigger balls. Based on DEM simulation, Cleary [25] investigated the effect of changes in mill operating conditions and particle properties on both the charge properties and mill power. It was found a sensitivity of mill behavior to the charge properties and the crucial significance of different hypothesis used DEM. Ji *et al.* [26] studied the influence of blockiness, particle aspect ratio (AR), and rotation speed on the mixing rate based on super-quadratic DEM simulations. It was found that the rotating speed has a great influence on the mixing rate. Jiang *et al.* [27] investigated the effects of number of lifers, filling degree, drum diameter, and rotation speed on the mixing uniformity of irregular gravel and sand materials in a rotating drum. They concluded that the rotation speed was the very important factor that affecting mixing, whereas the diameter of the drum was the lowest important. Bor *et al.* [28] used DEM simulation to study the effects of rotation speed, ball material, and milling time on the coating characteristics using two kinds of ball mills. The results showed that the impact forces have less affect in the coating than the contact number. In addition, the ball material properties influence no more difference in the coating.

The objective of this work is to investigate the effect of milling parameters, including shape of powder particles, rotation speed, and ball-to-powder diameter (BPDR) on DEM simulation results in a planetary ball mill and to develop a method to minimize the calculation cost during simulation.

2. DEM Model and Simulation Conditions

2.1. Apparatus Description

A high-energy planetary ball mill (Fritsch Pulverisette 7) was used in the simulation. This ball mill consists of supporting disc, two vials with volume of 15 ml, and balls with diameter of 15 mm. The operating principle of the planetary ball mill is illustrated in **Figure 1**.

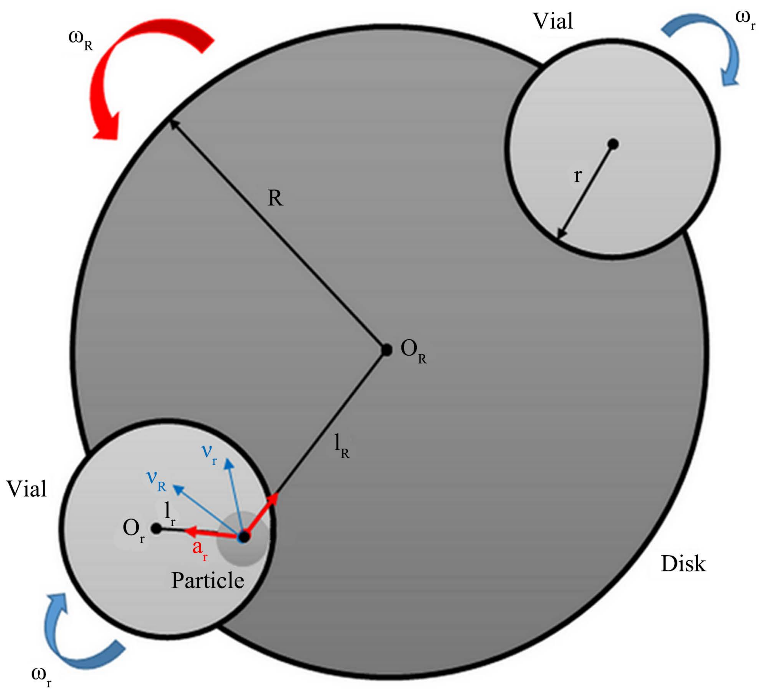

Figure 1. The operating principle of the planetary ball mill.

2.2. Simulation Conditions

In this work, the simulation was started by mixing of powders with balls. The mill then rotated at a fixed speed to lift the ball-particles mixture. After that, the flow reached a steady state. Details on the discrete element method and simulation parameters can be found elsewhere [29] [30].

The simulations were carried out using DEM simulation software EDEM Altair 2021.2 [31]. This software gives various methods for theory and simulation. Thus, Hertez-Mindlin contact model, based on Hertzian contact theory and Mindlin Deresiewicz model, was used in DEM simulations because of its useful and precise force calculation. Therefore, the shapes of the powder particles are illustrated in Figure 2. The volume of particle and balls was assumed to equal the volume of a sphere. However, the simulation method has been validated in a previous work [1].

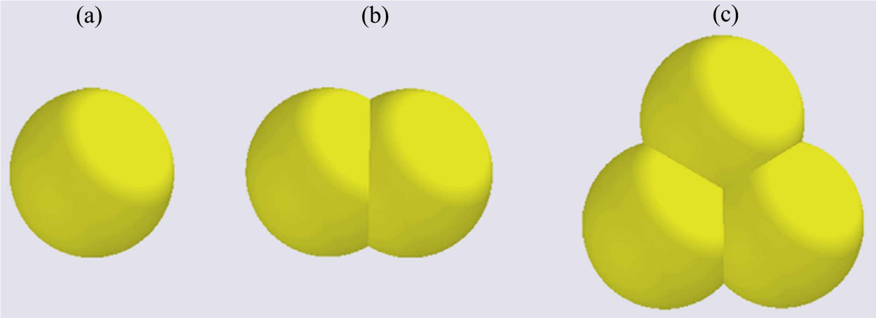

Figure 2. The different shapes of the powder particles used during simulation: (a) Single sphere; (b) Dual spheres; (c) Triple spheres.

3. Results and Discussion

In this study, the effect of the milling parameters on DEM modeling of a planetary ball mill was investigated at a laboratory scale. The results are detailed below.

3.1. Effect of the Shape of the Powder Particles

Figure 3 shows the snapshots of particles and milling balls at various particle shapes. As shown in the figure, there is no great difference in the motion patterns that all have cascading regime. This suggests that the shape of powder particles does not having a great effect on the motion patterns inside planetary ball mill. Feng *et al.* [32] concluded that the size and shape of the particles do not give a big effect in the motion pattern and simulation results when BPDR is over 20/3.

However, some works [33] [34] [35] assumed that the process of the planetary ball mill is very complex and the optimal parameters strongly depend on milling materials and operation conditions.

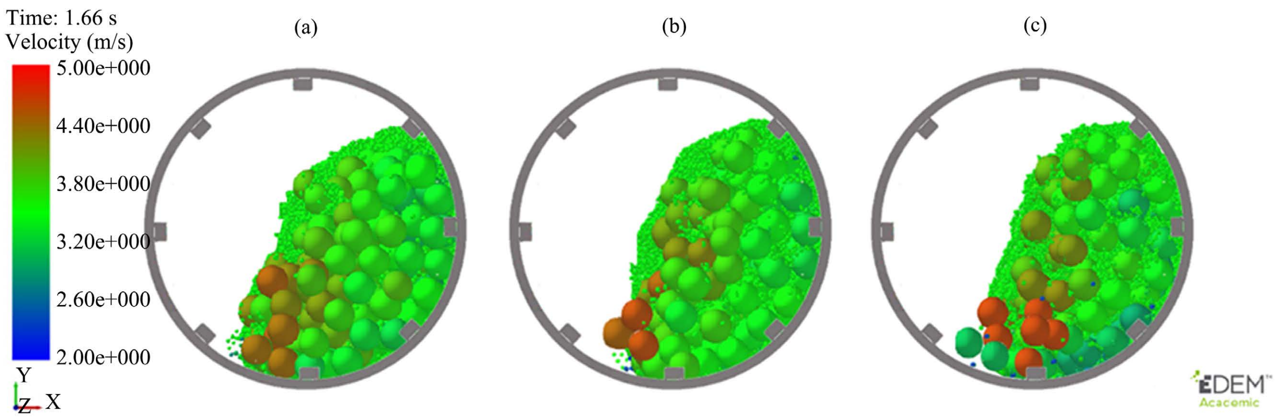

Figure 3. Snapshots of particles and milling balls at various particle shapes.

3.2. Effect of the Ball-to-Powder Diameter Ratio

Figure 4 presents the snapshots of particles and milling balls at various ball-to-powder diameter ratio (BPDR = 1, 3, 5, and 10). In this part, we assumed that the particle shape was a single-sphere. We can observe a slight difference in the motion patterns with increasing of BPDR from 1 to 10. For the case of BPDR equal to 1 and 3, we noted a cataracting regime. For the case of BPDR equal to 5 and 10, we noted a cascading regime, which the ball-to-ball contacts could be limited because of the contacts between the powder and the balls are retained for a prolonged milling time. On the other hand, the increase in BPDR leads to an increase in the number of ball-powder contacts. This indicates that the size of particles does not affect the motion pattern in the vial when BPDR reach a max value of 10. Thus, this phenomenon was also reported by several researchers [7] [36] [37] [38].

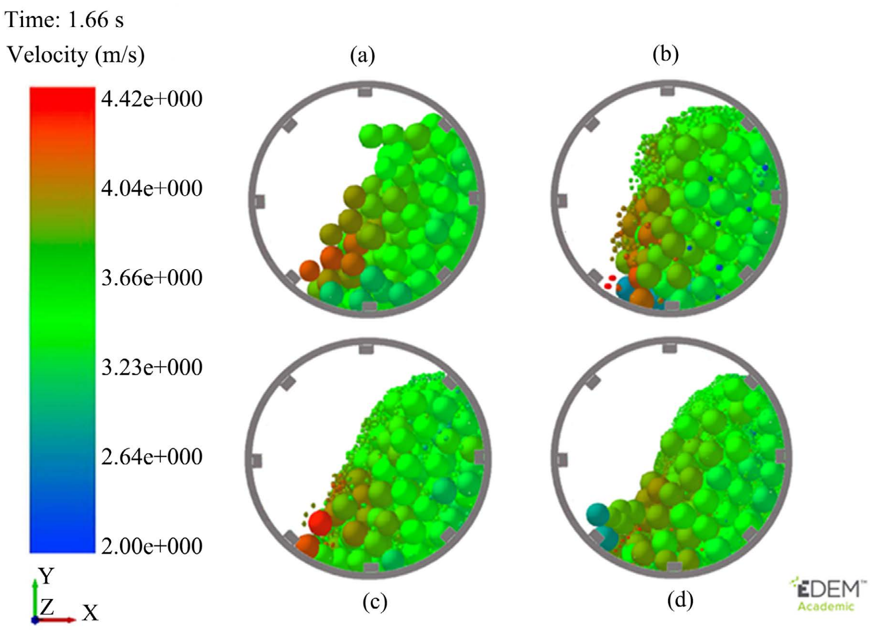

Figure 4. Snapshots of particles and milling balls at various ball-to-powder diameter ratio: (a) BPDR = 1; (b) BPDR = 3; (c) BPDR = 5; (d) BPDR = 10.

3.3. Effect of the Rotation Speed

Figure 5 illustrates the snapshots of particles and milling balls at various rotation speed (100, 300, and 500 rpm). As shown in the figure, there is a significant difference in the motion patterns with increasing rotation speed. However, the rotation speed has a significant effect on DEM simulation in the planetary ball mill. Indeed, the figure demonstrates an acceptable agreement between the experimental and simulation results. On the other hand, the particles are represented by different colors based on their speeds. Thus, these results were similar to those in the ref. [7]. As explained by Li *et al.* [39], the rotation speed can affect the average packing density: the density is greater at small rotation speed. In their work, Jayasundara *et al.* [40] investigated the effects of rotation speed and media loading on particle flow and milling performance in a horizontal stirred

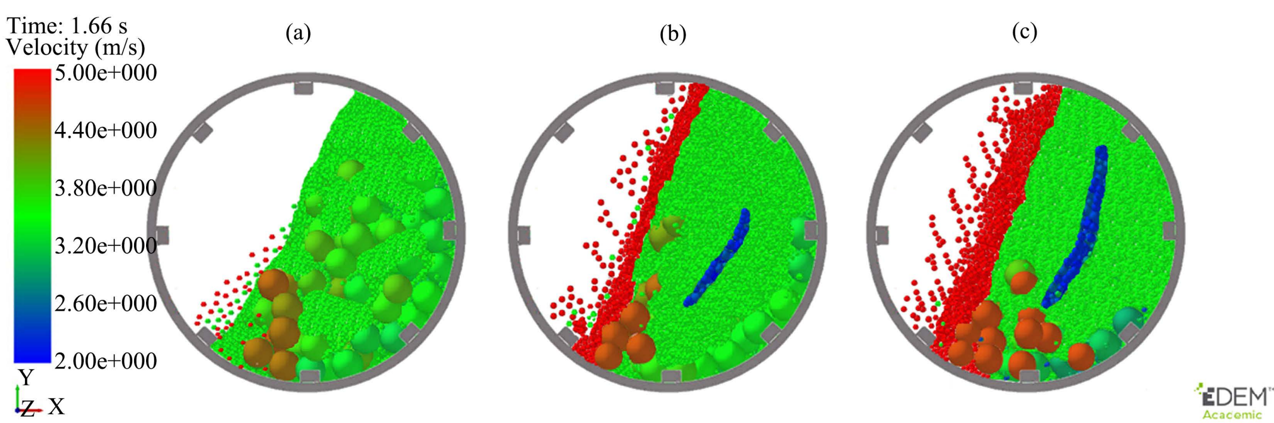

Figure 5. Snapshots of particles and milling balls at various milling speeds: (a) 100; (b) 300; (c) 500 rpm.

mill. They revealed that the increase in mill speed resulted as an increase in the velocities of particles, which induces greater collisions between particles. However, Xie and Zhao [41] revealed that the effect of mill speeds is related to the rotation-revolution radius. They also concluded that the rotation speed is strongly related to the rotation-revolution speed ratio. Additionally, Zeng *et al.* [42] used DEM simulation to investigate the particle flow in a vertical rice mill. They showed that the influence of aspect ratio on the milling strongly depend on rotation speed.

4. Conclusion

Numerical modeling based on DEM approach has been performed on planetary ball mill. The effect of the shape of the powder particles, the ball-to-powder diameter ration, and the rotation speed of a planetary ball mill was investigated by simulating the behavior of the particles and milling balls through DEM modeling. The shape of powder particles does not affect significantly the motion patterns and simulation results. The simulation time increase with increasing the ball-to-powder diameter ratio. The increase of rotation speed greatly affected the motion patterns and simulation time. The results suggest that the ball-to-powder diameter ratio and rotation speed should be adjusted appropriately before milling.

Acknowledgements

The author would like to thank ALTAIR DEM for the EDEM software through the Academic License Program. The author also thanks Ms. Y. F. Zhang (Yavonne) for her technical support.

Conflicts of Interest

The author declares that there is no conflict of interest.

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