Advances in Materials Physics and Chemistry, 2022, 12, 155-162
https://www.scirp.org/journal/ampc
ISSN Online: 2162-5328
ISSN Print: 2162-531X

Calibration of DEM Parameters to Simulate a Planetary Ball Mill

Mohsen Mhadhbi

Laboratory of Useful Materials, National Institute of Research and Physicochemical Analysis, Ariana, Tunisia
Email: mohsen.mhadhbi@inrap.rnrt.tn

How to cite this paper: Mhadhbi, M. (2022) Calibration of DEM Parameters to Simulate a Planetary Ball Mill. *Advances in Materials Physics and Chemistry*, **12**, 155-162.
https://doi.org/10.4236/ampc.2022.127011

Received: June 20, 2022
Accepted: July 23, 2022
Published: July 26, 2022

Abstract

Planetary ball mill is a powerful tool, which has been used for milling various materials for size reduction. The discrete element method (DEM) was used to simulate the dynamics of particle processes in a planetary ball mill. This work includes the calibration of DEM parameters to simulate a planetary ball mill using EDEM Altair 2021.2 software, which provides both faster workflows and results. The iterative input parameters changed to a close correlation between the simulation and experimental results are attained. The results showed that the standard tests could be used to generate various experimental reference values for the calibration. The numerical modeling results agree with the experimental, indicating that the calibrated parameters are accurate.

Keywords

Discrete Element Method (DEM), Calibration, Planetary Ball Mill, Parameters

1. Introduction

The discrete element method (DEM) has become an excellent tool to model and analyze granular materials. Jayasundara and Zhu [1] used discrete element method to simulate the impact energy of particles in a ball mill. The model was then validated by comparing the simulation results with the experimental data. It was observed that the impact energy was influenced by the operating conditions of the ball mill and could be linked to the milling rate. Zeng *et al.* [2] performed the modeling of the grain breakage in a vertical rice mill using DEM simulation. They revealed that the simulation results were consistent with the experimental data. Bibak and Banisi [3] used a combined physical and DEM modeling approach to study particle shape effects on load motion in tumbling mills. They concluded that cubical particles contributed 5% more in the high-energy impact action in comparison with the spherical particles. They also revealed that simulation time has increased 35 times by changing the particles form from spherical to cubic. Jonsén *et al.* [4] used the combination of DEM/FEM models to investigate the movement of the milling media in a tumbling mill. Then, they calculated the mechanical waves, structural response, stress, and strain during the milling process. The effect of contact parameters on charge movement and power draw through DEM modeling was investigated and validated by Boemer and Ponthot [5]. Bian *et al.* [6] applied DEM simulation to study the effect of lifters and mill speed on particle behaviour, torque, and power consumption of a tumbling ball mill. They showed balls decrease in efficiency at low height of lifters. Daraio *et al.* [7] performed the modeling and validation of the grinding media dynamics in an attritor mill via positron emission particle tracking (PEPT) measurements. The result showed a good agreement between the DEM model and experimental results. In a recent work [8], the trajectory, velocity, and distribution of particles of a planetary ball mill have been studied by using DEM modeling.

The calibration of DEM input parameters is necessary for simulation. In this context, many researches have been conducted. For example, Marigo *et al.* [9] concluded that the main difficulty of DEM modeling of industrial scale was related to the calibration parameters. Furthermore, a calibration of the DEM has been proposed to calibrate the parameters for crushed rock particles with a size up to 40 nm [10]. A novel approach based on Latin hypercube sampling and kriging was used to calibrate DEM parameters [11]. The results showed the existence of a solution space inside which different parameter combinations generate similar results. Johnstone [12] used design of experiment (DOE) method to calibrate DEM models for granular materials. Additionally, the calibration strategies for both spherical and non-spherical particles for the DEM modeling of non-cohesive bulk materials were investigated [13]. The obtained results revealed that the draw down test only was adequate to calibrate the rolling and sliding friction coefficients. Zhou *et al.* [14] used a new DEM parameter calibration method for irregular particles based on experimental design method and bulk experiments. They concluded that the simulation result of the dynamic angle of repose was in accordance with experimental, which confirms the usefulness of the proposed method. An inverse calibration method was proposed by Franco *et al.* [15] to determine the parameters for modeling soil-bulldozer blade interaction using DEM. They established the stiffness and friction coefficient based on the direct shear tests and energy principles. Coetzee and Els [16] proposed a new method to calibrate the discrete element parameters and modelled the silo discharge and bucket filling. They revealed that DEM could anticipate fill rates, bucket forces, flow and fill patterns. The perfect mixing model was calibrated to a dry grinding mill utilized to produce iron powder [17]. The results revealed that the calibration could use the same appearance breakage and discharge rates function without loss of fit.

The aim of this research is to calibrate DEM parameters for the simulation of a planetary ball mill by EDEM Altair 2021.2 software.

2. Materials and Methods

2.1. Discrete Element Model

In this study, the simulations were performed by EDEM Altair 2021.2 Software [18] 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 modeling because of its accurate and efficient. The normal and tangential contact forces are calculated based on the Hertz theory [19] and Mindlin and Deresiewicz theory [20], 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 works [8] [21].

2.2. Instrument

The high-energy planetary ball mill fabricated by German Fritsch Company (type Pulversiette 7) [22] was used in the simulations. This mill consists of a rotating support disk (called turn table) and two milling vials, as illustrated in **Figure 1**.

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 [23]. The diameter of the milling balls was fixed as 15 mm. During simulations, the powder particles are considered as spheres in order to reduce the required computation time.

Figure 1. P7 planetary ball mill and milling media used in the experiments.

Table 1. The parameters for DEM simulations [23].

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. Calibration of DEM Input Parameters

The calibration of DEM parameters is very important in simulation to obtain particles similar to the real bulk material and to evaluate the equipment performance. It is an integral part of the DEM modeling methodology. Thus, the calibration process was carried out by comparing simulation and experimental results. The workflow of the calibration process is presented in **Figure 2**. The coefficients of simulation are consistently adjusted by error and trial [24]. In this work, the DEM modeling approach was started with creating a scaled down setup of a planetary ball mill with charge that contains an amount of particles with calibrated coefficients of friction. The influence of particles shape was, then, investigated based on DEM model. The Altair EDEM 2021.2 software was applied to simulate the motion and trajectory of spherical particles inside the vial of mill during milling process.

Additionally, it is very important to consider if the selected calibration target parameters are adequately fine to the parameters to be calibrated [11]. The calibrated model was used to simulate the milling process in order to understand the mechanics of the system and the effect of milling media properties on it.

4. Results and Discussion

Using the suitable parameters, numerous DEM calibration of a ball mill were conducted with the aim of determination of real life input parameters.

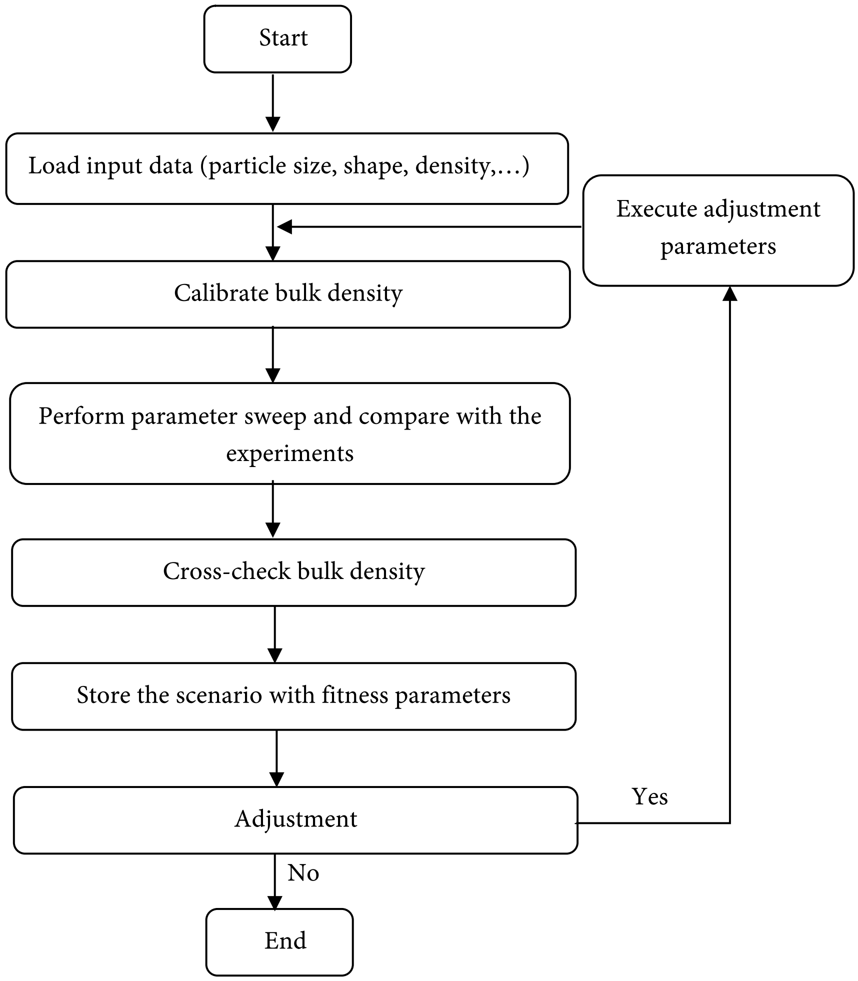

Figure 2. DEM parameters calibration workflow.

Figure 3 shows a comparison of the angle of repose (AoR) between experiment and simulation for the rotating disk experiments. Thus, spherical particles are used during simulations to represent bulk materials where the sliding friction coefficient is higher than the rolling friction coefficient ($\mu_s > \mu_r$). Results show good agreement between DEM simulations and experiments with maximum deviation of 2.1%. This consideration may give an indication of a better model calibration. Furthermore, the consideration of the measurement error is a mandatory step to solve the problem of the ambiguous parameter combinations [24].

Moreover, in terms of the power draw, the planetary ball mill consumes about 600 W. About 5% of this power is dissipated by viscous dissipation in the bearings of the mill, by damped vibrations, etc., which are non-existent in the simulation.

According to the simulation and experimental results, it is clearly that the measurement error should be taken into account particularly during angles measurement. Indeed, the consideration of the measurement error can improves the calibration process.

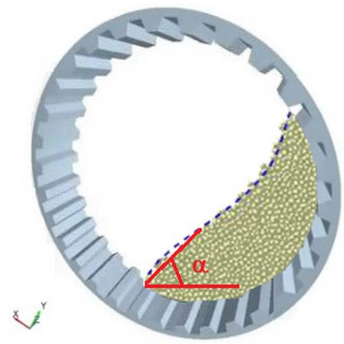

Figure 3. DEM simulation result after calibration of the AoR.

The particle density is one of the major parameters that must be calibrated during simulation process. Thus, the particle density is calibrated as follows:

- Filling of the vial (disk) with materials;
- Measurement of the mass (m) from a known volume (V);
- Calculation of the bulk density (total mass/known volume);
- Comparison of DEM bulk density with the real bulk density;
- Adjustment of particle density and re-run the simulation.

In this study, the adjusted particle density is equal to 4088 kg/m^3, which is obtained after calibration process.

5. Conclusions

This work has provided a successful method for the calibration of DEM input parameters for the simulation of a planetary ball mill. The numerical modeling results agree with the experimental, indicating that the calibrated parameters are accurate.

This study could provide a simulation model for developing equipment via DEM simulation method. Further studies are needed concerning the calibration of other types of mill.

Acknowledgements

The author gratefully acknowledges Altair Community for his assistance and the software license (version 2021.2). The author would like to thank 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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