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Original Research Paper

# Influence of processing parameters on grinding mechanism in planetary mill by employing discrete element method

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ABSTRACT

Evaluation of process parameters and performance of planetary mills is considered an important issue in optimization of their predicted efficiencies. The current research deals with a computer simulation based on discrete element method (DEM) employed to evaluate the grinding mechanism of a planetary mill. The effect of rotational speed, the volume percentage of the balls and powders on impact energy, the frequency of the impacts, the abrasion of the balls and the dissipated energy have been investigated. It was realized that by increasing the rotational speed, the impact energy and the number of impacts of ball–ball, ball–container, ball–powder, powder–powder and dissipated energy were increased. By increasing the balls filling ratio, the impact energy value of ball–ball remained almost constant after a critical point while those of ball–powder impact energy and the dissipated energy were slightly increased. With an increase in powders filing ratio, a maximum value was observed for the ball–powder impact energy; however, the ball–ball impact energy remained almost constant and the dissipated energy indicates a reduction in rate.



## 1. Introduction

Planetary mills are known as the most powerful tools in synthesizing particles of narrow and wide distribution size and morphologies. In planetary mills the size of the fabricated powders depends on impact energy and the number of impacts experienced during that period. At the same time, abrasion of the balls and the container is considered a big concern for the quality of the final powders, and depends on the impacts among the balls and those between the balls and the container.

Planetary mills have significant industrial and scientific importance and, to date, considerable researches have been carried out on their operation mechanisms and performance [1–4]. In synthesizing nanoparticles and nanocomposites by mechanical alloying, a knowledge on the frequency of the impacts and the energy that is transferred to the powders during milling is also of great importance. There are three major aspects in a planetary mill that one may consider while working with. The first one is the impact energy between balls and powders that is directly related to the grinding operation. Secondly, knowing the frequency of impacts is helpful to estimate the necessary grinding time. The third parameter that one should pay attention to is abrasion, which is related to the impact energy and collision frequency between ball–ball and ball–container [2]. For a particular milling case, understanding the ball milling dynamics can provide a better insight into the grinding mechanisms which consequently may lead to the improvement of existing designs and optimization of milling conditions.

Till now, several types of mills such as AG mill, Tower mill and Two Chamber Cement mill have been modeled using DEM [5–7]. Planetary mills have been modeled using DEM, too. Most models have been established on the basis of the assumption of several dynamic features of the milling process and; in particular, the patterns of impact energy and collision frequencies. Feng used DEM in a local model to consider the dynamic behavior of particles [1]. Sato used DEM and performed some experimental tests to compare the relation between impact energy of balls and their abrasion with no powder in the container [2]. Chattopadhyay used a mathematical model to analyze the mechanics of milling in a planetary mill, and the dissipated energy was calculated for various conditions of milling [3]. Kwon, on the other hand, performed some experimental research on the ball temperature during mechanical alloying and Jiang used DEM to predict the energy dissipation rate for various charge ratios [4,8].

Even though there are several scientific research works that have proposed the grinding mechanism, to the best of our knowledge, the dynamics of milling in planetary ball mills, has not been fully understood to date. The difficulty is mainly associated with the complex physical phenomena such as non-linear behavior of

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**Table 1**
DEM simulation parameters.

| Simulation parameter | Value |
|---|---|
| Normal stiffness ($K_n$) | 400,000 N/m |
| Tangential stiffness ($K_t$) | 300,000 N/m |
| Coefficient of restitution of sphere–wall ($e$) | 0.5 |
| Coefficient of restitution of sphere–sphere ($e$) | 0.6 |
| Coefficient of friction ($\mu$) | 0.6 |
| Density of powder ($\rho$) | 7850 kg/m$^3$ |
| Density of ball ($\rho$) | 7850 kg/m$^3$ |

**Table 2**
The specifications of simulated planetary mill.

| Description | Values |
|---|---|
| Transmission ratio, grinding bowl/planetary disc | 1:−2 |
| Effective diameter of main disc | 140 mm |
| Container height | 40 mm |
| Container diameter | 30 mm |

a multi-physics and multi-scale nature of the process. This problem, together with a considerable number of operation parameters and their combinations, make experimental investigation of the process details almost impossible. As such, computer simulation is a helpful alternative to study the process variables.

A discrete element based numerical simulation was utilized in this research in order to evaluate the mechanism of milling of a planetary mill in a comprehensive model in the presence of powders. The dynamic behavior of balls and powders was considered for different operational conditions. Furthermore, the relations between impact energy, kinematic energy, frequency and dissipated energy with various operational parameters such as rotational speed and ball–powder filling ratio have been investigated, and are presented in this paper.

## 2. Simulation

### 2.1. Discrete element method

In DEM simulation the motion of each particle and the container is calculated through cycling process of small time steps $\Delta t$ [9]. The general DEM methodology and its variants are well established and are described in the review article of Walton [10].

In DEM, the particles are allowed to overlap typically with an average less than 0.5%. The amount of overlap ($\Delta x$), normal ($v_n$) and tangential ($v_t$) relative velocities determine the collision forces

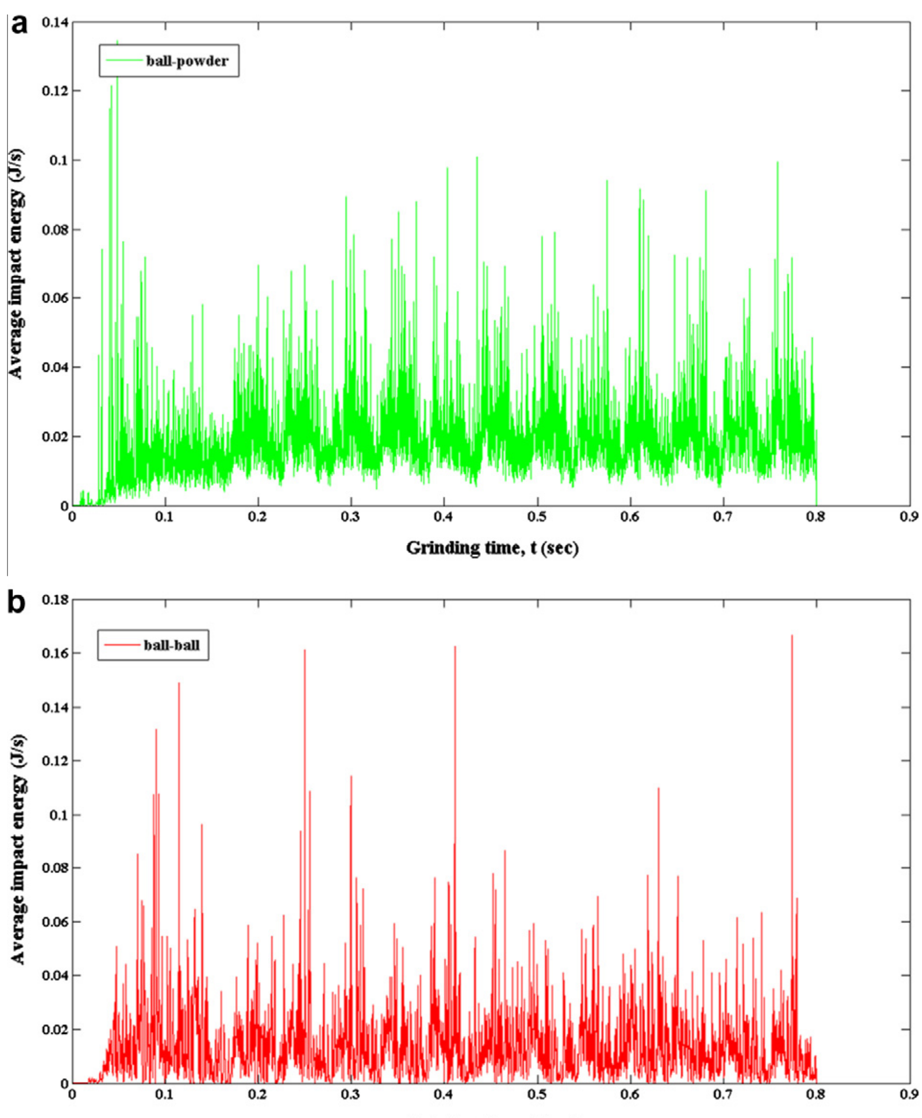


**Fig. 1.** Average impact energy as a function of time (disc rotational speed = 600 rpm, Jp = 20%, Jb = 14%, db = 6 mm): (a) ball–powder and (b) ball–ball.