Analysis of Powder Behavior Inside the Mortar During Tableting Process

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Abstract: Tableting machines are used to make tablets from food, pharmaceutical, and other powders. It is well known that the quality of tablets formed by tableting machines varies greatly depending on the compression conditions, such as compression speed and compression force. Therefore, it is important to clarify the behavior of powder inside the mortar during the compaction process. In this present research, we designed and manufactured a thin-walled cylindrical mortar. A special strain gage was attached to the mortar to measure the force acting on the mortar wall during tableting. Based on these results, a discrete element method (DEM) simulation is performed, we compare and discuss the behavior of powder inside the mortar during the tableting process.

1 INTRODUCTION

A tablet machine is a device that makes tablets from powder by compression molding, and is widely used in the pharmaceutical and food industries. The advantage of using powder as tablets is the reduction of transportation and storage costs due to the reduced volume, which is expected to be applied not only in the food industry but also in the materials industry (Kamiya, 2022). Typical performance requirements for compression molding of powders include high-speed molding to improve productivity and high-hardness molding to prevent tablets from disintegrating easily (Danjo, 1998). However, the dynamic behavior of the powder during the compression process seems to be unclear. One of the problems with the current product is that strength of the top and bottom corners of the tablets are weak, resulting in defective tablets during transportation.

In the manufacture of tablets for various kings of pharmaceuticals, it is a major issue to optimize tableting conditions according to the physical properties of the various raw material powders, from prototyping to mass production (Natsuyama, 2001). Powder simulation is a useful solution to this issue, and there are two major methods for this: the DSMC and the DEM method. The DSMC method treats particles as hard spheres. This method calculates the time for the next collision across the system and uses that time as a time step to translate and rotate the particles. When particles collide, the direction of velocity is reversed, and the velocity after repulsion is calculated from the relative velocity before collision and the coefficient of repulsion. The DEM method represents a material as a collection of DEM particles, and solve the equations of motion for the translational and rotational motion considering the contact force (repulsive force, frictional force), gravity, and adhesive force (van der Waals force, liquid bridge force) acting between particles. By using this method, the dynamic behavior of powder can be reproduced and predicted (Yamanoi, 2018). The DEM method is recently gathering attention as a simulation tool for treating with various technical problems in the pharmaceutical, food, and lumber processing industries using powder (Hassanpour 2010).

There are also two advantages to using the DEM method. First, since particle collisions are considered as soft potentials, large time steps are possible. As a result, it can be applied to large-scale systems. The second is applicable to high concentration systems. In

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the case of compression molding, the particles are always in contact, so the DSMC method, which treats them as rigid spheres, is not realistic. For the above reasons, this paper uses the DEM method.

In our previous studies, we found that the hardness of compression-molded tablets varied depending on the height position and confirmed that the hardness was lower at the top and bottom of the tablets. From these results, it was considered that the force applied to the powder in the mortar was not uniform. In this present research, we designed and manufactured a thin-walled cylindrical mortar. A special strain gage was attached to the mortar, by using this, the force acting on the mortar wall during tableting was measured. Furthermore, based on the compressive forces measured in actual tableting, the forces acting on the powder in the mortar were calculated by simulation using the DEM method and we discuss the behavior of powder inside the mortar during the tableting process.

2 EXPERIMENTAL DEVICE

2.1 Tableting Machine

Figure 1 shows the overall structure of a tableting machine. There are two types of tableting machines: the single-shot type and the rotary type. In this research, the single-shot type was adopted because the purpose of tableting is prototyping and the tableting conditions can be changed.

The tableting machine consists of a base plate and three plates for installing each component on an aluminum frame, insert a long bolt into each of the left and right hollow shafts and fix them. the upper and lower pestles are operated by an electric cylinder consisting of a servo motor and a ball screw. The pestle moves 5 mm per rotation of the motor. The specifications of the upper and lower servo motors are rated torque 1.15 N·m, rated current 2.8 A, and voltage AC 200 V.

2.2 Tableting Experiment

Compression molding is performed by moving the pestle by numerical control using a host device (PMAC made by OMRON). In this case, the upper pestle was used as a dynamic pestle.

The experimental procedure is, first, the sample (powder) is weighed using an electronic balance with an accuracy of 1.9995 g to 2.0004 g and the sample throw inside a 20 mm-diameter mortar. Next, run the numerical control program and form a tablet. First, the initial position of the pestle is that the lower pestle is 10 mm into the mortar, and the upper pestle is 50 mm from the top of the mortar. The compression procedure is divided into two parts: the lowering and rising motions of the upper pestle. The descending motion performs acceleration, uniform motion, and deceleration over a distance of 61.5 mm. The speed of uniform motion is 1 mm/s. After the descent ends, it begins an upward motion without stopping. The rising motion also accelerates, moves at a constant velocity, and decelerates over a distance of 61.5 mm. The speed of uniform motion is 50 mm/s. This completes one tableting motion.

After compression molding, the tablet height is measured using a laser sensor, and the tablet mass is measured using an electronic balance. The material of mortar is aluminum (A5052). The shape of the mortar is thin-walled cylindrical, a diameter of 20 mm and a wall thickness of 1 mm. A special strain gauge was attached the mortar to measure circumferential strain. Figure 2 is a photo of the mortar attached to strain gauge and their locations are shown in Figure 3. The numbers in Figure 3 are in mm.

2.3 Experimental Results

In the tableting experiment, the compression force of the upper pestle was 1467 N, the compression force of the lower pestle was 803 N, and the diameter of the upper pestle was 19.9 mm, so the upper pestle pressure was 4.72 MPa. Although not shown in the graph, these are the measurement results of the load cell installed at the base of the upper and lower pestles. These results are the average of the three experiments.

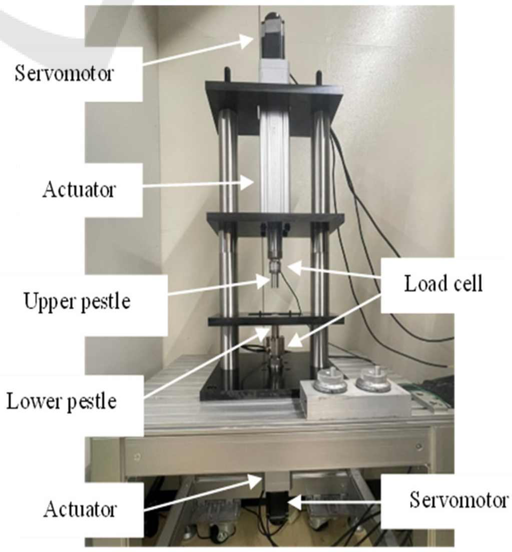


Figure 1: Tabletting machine.

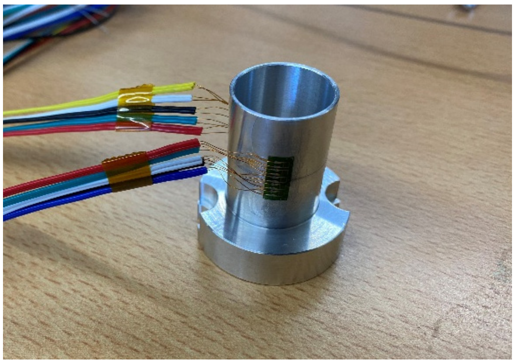


Figure 2: A mortar with a strain gauge.

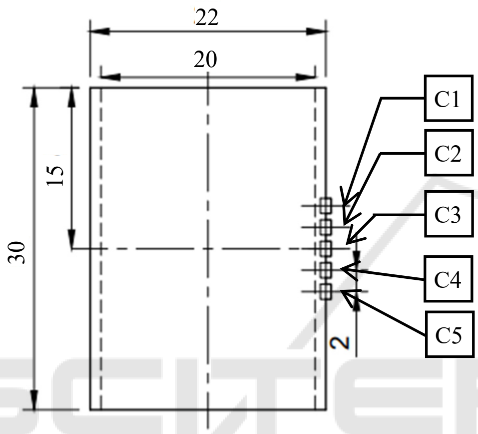


Figure 3: Strain gauge position.

Figure 4 shows the measurement results of the circumferential strain obtained in the experiment. Using the following relational expression for a thin-walled cylinder, The calculated internal pressure acting on the inner wall of the mortise is shown in Table 1. These results are the average of the three experiments, where, σ_θ : circumferential stress, P_{in} : internal pressure, E : Young's modulus, ε_θ : circumferential strain, r : radius of the inside of the mortar, t : wall thickness.

$$\sigma_\theta = E\varepsilon \tag{1}$$

$$\sigma_\theta = \frac{P_{in} r}{t} \tag{2}$$

According to Table 1, the strain in the height direction was the largest for C3 and the smallest for C1. When the pressure acts uniformly in a pressure vessel, the strain generated on the wall surface is considered to be constant, but this experiment revealed that the force acting on the inner wall of the mortar has adistribution. We also found that even the highest C3 value is lower than the pressure calculated from the

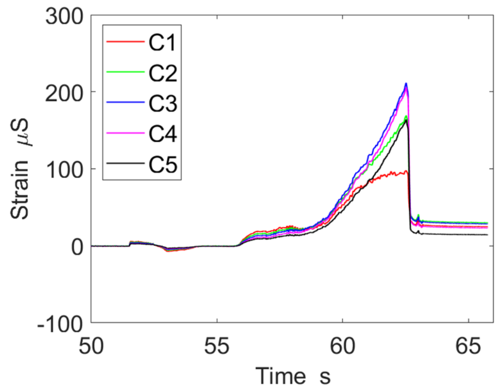


Figure 4: Circumference strain.

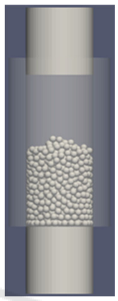


Figure 5: Overall structure in simulation.

Table 1: Comparison of strain and internal pressure.

Determination of position	Circumferential strain μS	Internal pressure MPa
C1	93.9	0.639
C2	166	1.12
C3	212	1.44
C4	205	1.39
C5	164	1.11

upper pestle compressive force. It was found that the pressure applied to the wall of mortar was about 30.5% of the pressure of the upper pestle.

3 SIMULATION

3.1 Discrete Element Method

DEM is a numerical method for predicting mechanical dynamics such as position, velocity and motion of individual particles. The basic principles of DEM are as follows. (a) Forces exerted by adjacent particles or boundaries of each particle are computed in a single time step using the contact model. (b) Apply Newton's second law to calculate the particle velocity. (c) Based on the same principle, the rotational momentum balance is solved to track the rotational velocity of the particle. (d) New positions of the particles are computed for the length of the time step. This procedure is applied to each particle in a single time step and repeated for each time step (Su, 2019).

3.2 DEM Simulation Condition

The conditions of the DEM simulation were as follows. The tableting conditions were single stroke tableting at 1 mm/s, the same as in the experiment. The size of the mortar was set to 1/10 the diameter in order to shorten the calculation time. In this analysis, since we focused on equalizing the pressure applied to the powder, although the actual compression pressure was 4.72 MPa, the simulation compression pressure was 3.85 MPa. As a result, both pressures are almost equal at 4 MPa.

The particle size of the powder is assumed to be 200 μm. It should be noted that the average particle size of the actual powder is about 200 μm, but which is not so uniform. Figure 5 shows how the powder was filled in the mortar used in the simulation.

3.3 DEM Simulation Result

Figure 6 shows the frictional forces on the upper pestle, lower pestle, and wall calculated from the tableting simulation. The force acting on the pestle and wall is calculated as the sum of the forces acting on the particles in contact with the pestle and wall.

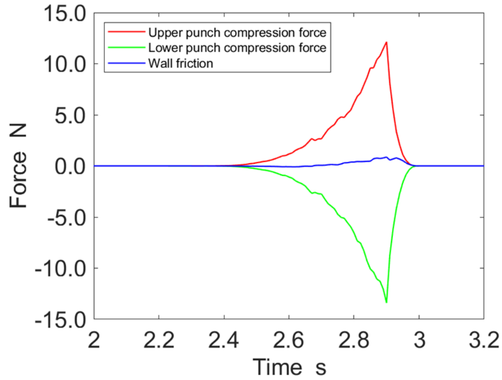
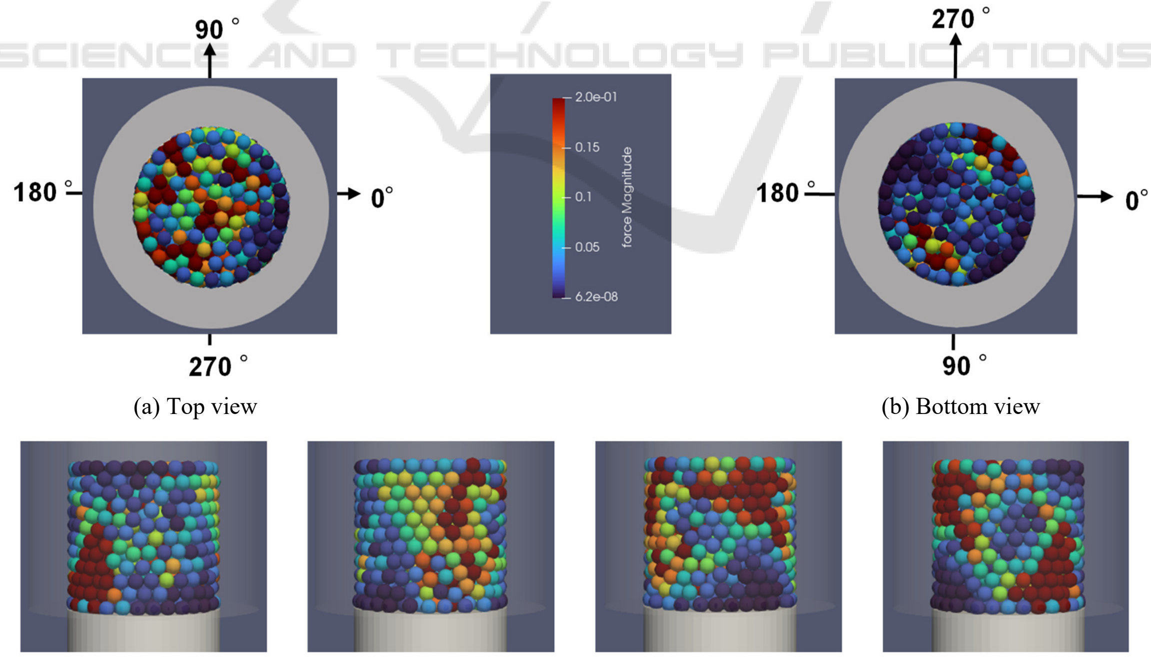


Figure 6: Upper and lower pestle compression force, wall friction force.

Basically, it can be found that the upper pestle compressive force plus the wall friction force are equal to the lower pestle compressive force.

The forces on the particle at the instant of maximum compression are shown in Figure 7. Where, the results are viewed from (a) top, (b) bottom, (c) 0 degree side, (d) 90 degree side, (e) 180 degree side, and (f) 270 degree side, respectively. First, from



(a) Top view (b) Bottom view

(c) View from 0° direction (d) View from 90° direction (e) View from 180° direction (f) View from 270° direction

Figure 7: Force on particles at maximum compression.

Figure 7(a) and (b), it is clear that the force does not reach the lower pestle in the case of upper pestle compression, although there are variations. Therefore, it is expected that the hardness of the upper part will be higher. The results in Figures 7(c)-(f) also show that there is variation in the state of the lateral surfaces. Compared to the strain measured in the Figure 4, the force at the upper end C5 is smaller, indicating that the distribution is close to the condition shown in Figure 7(c). In the future, it will be necessary to improve the accuracy of the experiment, including the position of strain measurement.

4 CONCLUSIONS

In this paper, the behavior of the powder inside the mortar the tableting process is analyzed by experiment and simulation. In the experiment, we measured the strain in the circumferential direction of the mortar and found that the force acting on the formed tablets varied in the height direction. In the simulation, there was validity between the analytical results of the upper and lower pestle compressive forces and the measured results. In the case of upper pestle compression (upper pestle is driving pestle), it was confirmed that the force acting on the upper part of the tablet is large. It was confirmed that the force from the upper punch was not fully transmitted to the bottom of the tablet, and that not much force was acting on it.

However, when looking at the side surface, the force acting on the powder varied depending on the angle. This was a new discovery. This suggests the possibility that the hardness changes depending on the direction in which the hardness test is performed.

In addition, we were able to confirm the rearrangement of the powder, which was not seen in the actual tableting process. It is necessary to pay attention to the rearrangement of particles because it greatly affects the quality of tablets (Furukawa, 2017). In the future, we plan to conduct analysis using a mortar that is more realistic, and to proceed with verification by comparison with experiments.

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