EXPERIMENTAL AND NUMERICAL ANALYSIS OF DEVELOPER FLOW IN A DEVELOPING MACHINE

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Key words: DEM, Developer, Friction, van der Waals Force, Hamaker Constant

Abstract. Behaviors of developers flowing in a simplified developing machine was analyzed by evaluating torques of mixers in both experiments and numerical simulations in this research. In spherical and non-cohesive particles, the simulation result is in good agreement in the experimental result by adjusting the coefficient of friction. In non-spherical or cohesive particles, the simulation result can coincide with the experimental result by adjusting the coefficient of friction and Hamaker constant.

1 INTRODUCTION

In the developing machine of MFP (Multi Function Peripheral), the developer is circulated by rotating two mixers as shown in Fig.1. The developer, consisting of billions of toners and carriers ranging from 5 to 50 μm in diameters, is needed to be transferred stably and mixed thoroughly by rotating mixers. However, the behaviors of discrete particles are so complicated that it requires much time and labor to optimize the rotational velocity of mixers, the quantity of developers and the design of the developing machine experimentally. Therefore a numerical method which can predict the particle behaviors is needed in order to reduce the number of experiments and accelerate the product development speed. A non-Newtonian fluid simulation had been applied to simulate the developers, however, the results were not in good agreement with the granular behaviors well.

In this research, DEM (Discrete Element Method) [1] was applied to simulate the developers since granular materials could not be simulated well by a fluid simulation. However, there are some problems in DEM to simulate the developer flow. Firstly, the accuracy of DEM has not been validated sufficiently. Secondly, the way to choose the simulation
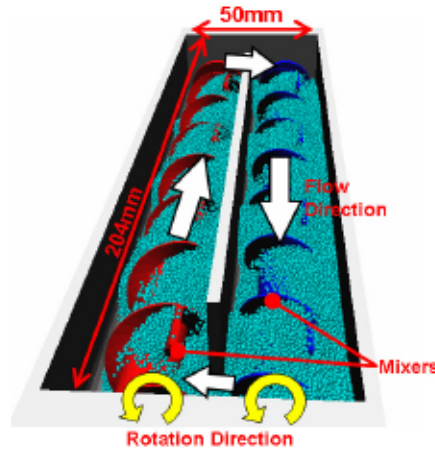
Figure 1: Conceptional image of the developing machine

parameters has not been confirmed yet. Therefore, the objective of this research is to validate the DEM accuracy and to develop a method to determine the simulation parameters by comparing results of experiments and simulations. Experiments were conducted using a simplified developing machine to find out the relationship between the rotational velocity and the torque on the mixers. The corresponding numerical simulations were also performed, where the coefficient of friction and Hamaker constant were parameterized.

2 EXPERIMENTS

The outline of experiments is shown in this section. A conceptional image of the simplified developing machine, which was used in this research, is shown in Fig.1. In the real developing machine, the mixed toners and carriers are transferred, however, toners are so small that it is difficult to analyze the developer. Therefore the toner was neglected in this research, in other words, single kind of particles in each experiment was circulated. Three kinds of experiments were conducted, whereby 40 μm of carriers, 100 μm of Zirconia balls and 800 μm of Zirconia balls were used respectively. The properties of the carriers and the Zirconia balls are shown in Table 1. The carrier is non-spherical and on the other hand the Zirconia ball is spherical which is easier to analyze.

The torques on the mixers were measured. The rotational velocity of mixers ranged from 50 to 300 rpm. Although the densities of carriers and Zirconia balls are different, their volumes are almost the same, having 230 grams of carriers and 300 grams of Zirconia balls. The results of experiments are shown Fig.2.

In 800 μm of Zirconia balls, the torque increased as the rotational velocity increased. Reversely, the torque decreased in 40 μm of carriers. In 100 μm of Zirconia balls, the torque is not dependent on the rotational velocity. This is the intermediate property between 800 μm of Zirconia balls and 40 μm of carriers. It is supposed that the torque tends

Table 1: Properties of particles

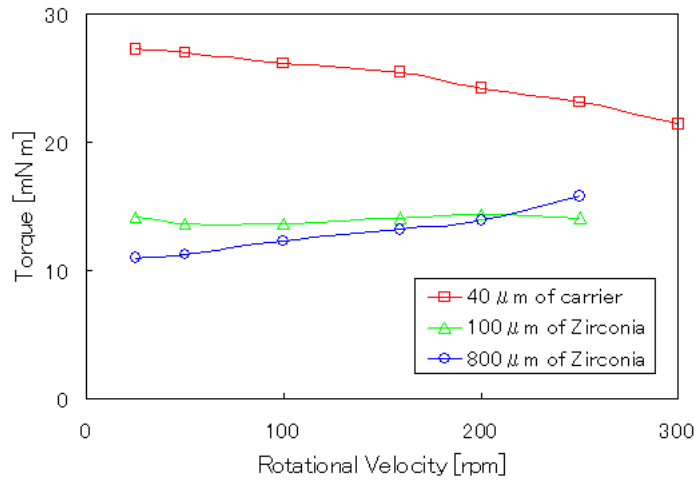|		carrier	Zirconia
Diameter	μm	40	100 & 800
Density	kg/m^3	4700	6090
Mass	g	230	300
Shape		Non-Spherical	Spherical

Figure 2: Torque versus the rotation velocity in the experiments

to decrease more in the smaller particles as the rotational velocity increases. However, it still remains unknown whether the relationship between the torque and the rotational velocity is caused by the particles size itself or that the cohesive force increases as the particles gets smaller.

The magnitude of torques were similar in 800 and 100 μm of Zirconia balls. However, the torque of carriers was about twice larger than that of Zirconia balls. There are three explanations. Firstly, the coefficients of friction are different between carriers and Zirconia balls and the coefficient of friction of carriers might be greater than that of Zirconia balls. Secondly, the carrier is not spherical and the shear forces would act greater than Zirconia balls. Lastly, the carrier is so small that the cohesive force can not be neglected.

3 SIMULATIONS

Corresponding simulations were performed. The diameter of simulation particles was 800 μm. 800 μm of Zirconia balls were spherical and cohesive forces were neglected and therefore they can be simulated directly using DEM accurately. Some simulations were

conducted using different coefficients of friction, the torque was matched well with the experimental results when the coefficient of friction was 0.40 as shown in Fig.3. It is cleared that the coefficient of friction in simulation is determined uniquely using spherical and non-cohesive particles.
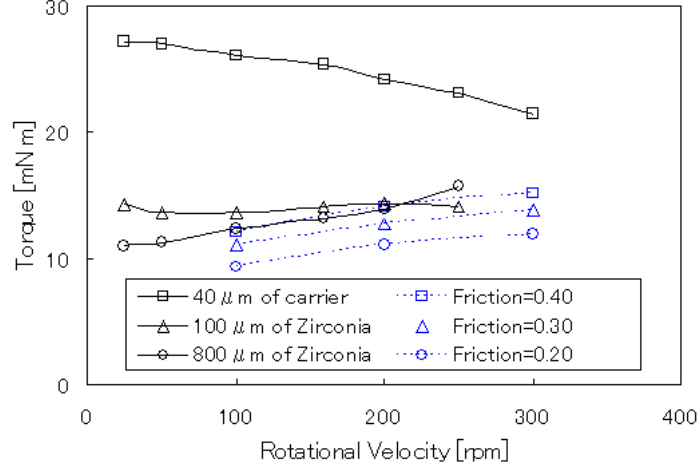

Figure 3: Torque versus the rotation velocity in some frictions

In the case of the particle diameter below 100 μm, too much particles exist to be simulated. Moreover, cohesive forces can not be ignored in such small particles and the phenomena come to be complicated. Sakai[2] has proposed a method to simulate the van der Waals forces of actual fine particles using larger particles in simulations. In this method, the van der Waals force between particles is represented as

$$\boldsymbol{F} = \frac{H^* L}{12h^2} \boldsymbol{n} \tag{1}$$

where L is the particle diameter, h the distance between particle surfaces, $\boldsymbol{n}$ normal direction. H^* represents Hamaker constant in simulations. In the Sakai's formulation, when the diameter in a simulation is l times larger than the actual one, Hamaker constant in a simulation H^* should be

$$H^* = l^3 H \tag{2}$$

where H is Hamaker constant as the physical property. Since the actual Hamaker constant is unknown, Hamaker constant in a simulation is treated as a simulation parameter and adjusted to fit torques between experiments and simulations. Note that the difference of contact forces between particles as the size of particles is assumed to be neglected.

The simulation results using some Hamaker constants are shown in Fig.4. When Hamaker constant is zero and neglecting the cohesive force, the torque increased as the rotational velocity increased. This result was well agreed with the one of 800 μm of Zirconia. When the van der Waals forces were considered, particle behaviors changed. When Hamaker constant is 2.0e-18 J, the simulation result was in good agreement with the result of 100 μm of Zirconia balls. When Hamaker constant is 9.0e-18 J, the simulation result was in good agreement with the result of 40 μm of carriers.
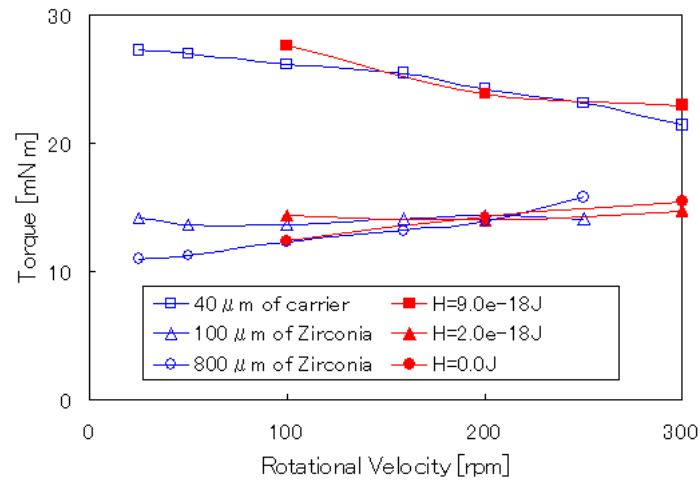

Figure 4: Torque versus the rotation velocity in some Hamaker constants

4 DISCUSSIONS

In Zirconia balls, the coefficient of friction could be determined using non-cohesive large particles. Therefore Hamaker constant could be determined uniquely to make simulation results agree with the experimental results. However, the coefficient of friction and Hamaker constant could not be determined uniquely since the frictional force and the cohesive force could not be separated. There is supposed to be many combinations of the two parameters.

Another problem is that the carrier is not a spherical particle. In this case, the shearing force is greater and the particle shape should be modeled somehow. The shape model and the method to determine the two parameters uniquely are future works.

5 CONCLUSIONS

Experimental and numerical analyses of developer flows using simplified developing machine were conducted. The simulated torques of carriers and Zirconia balls were in good agreement with the experiment results. Using spherical and non-cohesive large

particles, the torque was in good agreement with the experiments and the coefficient of friction could be determined uniquely.

To consider cohesiveness and change Hamaker constant, the torque of actual fine particles can be simulated accurately. However, there are still some problems such as the particle shape and the method to determine parameters uniquely.

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