Simulation of tumbling granulation by Granuleworks

As a pioneer of barrel finishing, Tipton Corp., since the time when it invented the world's first centrifugal barrel finishing machine, has continued to develop barrel finishing machines with various types of barrel motions such as vibratory motion, centrifugal disc motion and rotary motion, and has steadily expanded its development field by working on various types of finishing methods including blasting, brushing, etc. In this way, Tipton Corp. has established a firm position as an unrivaled comprehensive manufacturer in the field of barrel finishing. Presently, it is engaged in a comprehensive service ranging from product development to manufacturing and marketing of all three items for barrel finishing (barrel finishing machines, abrasive media and compounds), boasting the top market share in Japan. Recently, we visited the Development Department of Tipton Corp., where we interviewed Mr. Tatsuki Kawahara, Assistant Manager of the Machine Development Section, about the simulation of tumbling granulation of powder and granular material utilizing Granuleworks[1].

Please tell us about your company's business.

We are a small company with about 200 employees in Nagoya that started its business with the production of grindstones. Presently, we are engaged in the production of barrel finishing machine as our core business, and we also produce and sell abrasive materials for that machine. Barrel finishing techniques are mainly used for deburring and polishing parts of industrial products, and for finishing electronic components inside smartphones and PCs as well as other items such as household goods and jewelry. We are also a user of Particleworks, a fluid simulation software using the Moving Particle Simulation (MPS) method, and we started to work on simulation because of barrel finishing. Since the finishing process is basically performed in a sealed container, it is not easy to visualize the inside, and even when it becomes possible to visualize the inside, it is still difficult to understand how much finishing effect is produced by its motion, so we introduced simulation software with the aim of analyzing finishing behavior. In addition to simulating barrel finishing behavior, we use Particleworks to simulate the inside of a pump (**Fig.1**).

Mr. Tatsuki Kawahara,
Assistant Manager,
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Development Department, Tipton Corp.

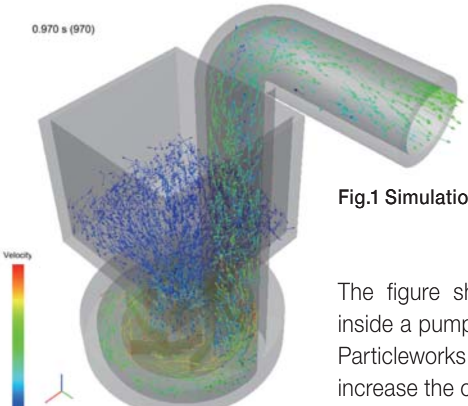

Fig.1 Simulation image of a pump

The figure shows how the flow inside a pump was evaluated with Particleworks in an attempt to increase the capacity of the pump by optimizing its impeller geometry. In addition to predicting the wear of flow passage by observing the flow, we conducted experiment verification by outputting the shape that was predicted to have good performance from the data on discharge pressure and flow rate with a 3D printer. Evaluation results showed a similar trend, so we realized that Particleworks is reliable enough to be used for qualitative evaluation.

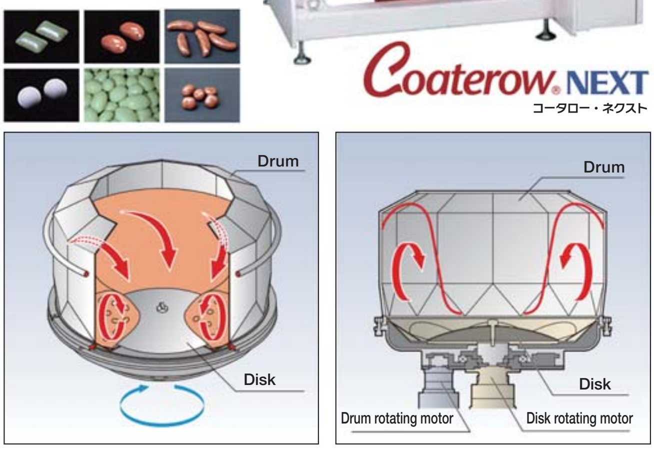

Fig.2 Coaterow NEXT food coating machine (awarded with the Nagoya City mayor's prize at the Nagoya City Industrial Technology Grand Prix), and the principle of its centrifugal disk coating

As an example of our product, I would like to introduce Coaterow in **Fig.2.** In this product, techniques for barrel finishing are applied to food coating. A rotary drum is commonly used for food coating machine, but it has problems in that powder stagnation is likely to occur in its container and dispersion force is weak, which were previously dealt with by the skills of experienced workers. In contrast, this machine has a polyhedral-shaped drum at the top and a polyhedral-shaped disk at the bottom. Spiral flow is generated by the independent rotary motions of the uniquely shaped drum and disk. This flow prevents powder stagnation from taking place in the container, ensuring that the machine has excellent dispersion performance. The introduction of the machine enables everyone, including workers without special skills, to perform the coating process evenly on food products. In addition, this method makes it possible to complete the process in less than half the time that it took for the traditional method. In recognition of its unique and creative features, Coaterow was awarded with the Nagoya City mayor's prize at the Nagoya City Industrial Technology Grand Prix.

Mr. Kawahara, please tell us what exactly your role is.

I'm engaged in the design and development of new barrel finishing machine and coating machine. After conceiving ideas needed for commercialization, I verify the effectiveness of the ideas, and then, after the process of verifying the execution design of a new product and its mass production trial, I can finally work on the commercialization of the product. Actually, I'm responsible for all of them. Particleworks and Granuleworks are mainly used at the upstream stage of product development. For example, when I come up with a new idea, I verify the idea with simple experimental machine, but in some cases, it is difficult to conduct observation only with the experimental machine. In that case, I carry out an appropriate simulation corresponding to the experimental machine used and compare the simulation outcome with the experiment results. By observing ideas from various aspects in this way, it has become easier to understand phenomena and evaluate ideas. In recent years, the level of performance requested by customers is getting higher and higher, and instead of getting satisfied with good results (data), they want to understand what has produced good results, and moreover, they expect us to make further improvement. Therefore, developers have come to realize that it is necessary to have a deep understanding of the principle of a new product and of phenomena that can take place in it. In this regard, I think visualization by computer aided engineering (CAE) helps us. When we can visualize what is taking place, we become more interested, which motivates us to deepen our understanding.

Please tell us the background of the introduction of Granuleworks.

The flow phenomenon of the powder and granular material handled by our company is made up of a combination of various phenomena. Traditionally, it was thought that since it was theoretically difficult to predict the phenomena, we could do nothing but accumulate experiment verifications to understand the phenomena empirically, but this required time for development and was costly. Also, we had to address the challenge of how to pass on techniques to young workers. Since we had experience of using Particleworks, we consulted Prometech Software, Inc. in order to simulate the flow phenomenon of powder and granular material, and started the trial use of the prototype version of Granuleworks, software to simulate the motion of powder. Since simulating granulating phenomena was difficult, we could not replicate the experiment. But Granuleworks was still at the development stage, so we decided to continue technical discussions, while Prometech presented us with their expert ideas. Thus, Prometech and we addressed the challenge together. Developers from Prometech supported us even by being present with us at the experiment and we accumulated ideas and proposals in discussions, all of which made it possible for us to solve challenging tasks in a shorter time than I had expected and to make another step forward. Without doubt, I believe that this enthusiasm with a sense of urgency is what we need to tackle challenging tasks. It is about one and half years since we started to use Granuleworks, which I like because it is fully equipped with basic functions such as those to reproduce contact and rebound between particles and to reproduce motion that are similar to those of powder by considering the geometry effect of particles. In the granulating phenomenon that we are working on, additional factors such as adhesion play crucial parts, so if Granuleworks was not reliable in its basic functions, it would be impossible to proceed with discussion and consideration of adhesion and to expect the agreement between simulation and the actual phenomena.

Please tell us about some examples of using Granuleworks.

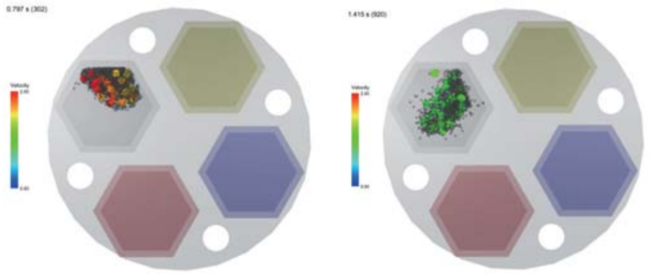

Fig.3 Simulation image of the flow of abrasive materials in a centrifugal barrel finishing machine (left: centrifugal force is sufficiently large, right: jumping phenomenon)

First, I would like to introduce an example of a centrifugal barrel finishing machine. With regard to its fundamental structure, four hexagonal containers are connected to a single large rotating disk, in which the four containers rotate in conjunction with the large rotating disk while automatically revolving in conjunction with each other. In the containers, work pieces to be finished and abrasive materials are contained, and the work pieces are finished by the effect of interactive motion. The effect of the centrifugal force can induce strong polishing performance force that is 20 to 50 times stronger than the polishing performance produced simply by rotating a container on its own axis. Actually, it was confirmed from the experimental results that contents jump in a container when the centrifugal force and the gravity are balanced by lowering the rotation speed, but it was impossible to observe the impact of this phenomenon on the work pieces in the experiment. So we reproduced the flow of abrasive materials by using Granuleworks in order to observe its impact on the work pieces (**Fig.3**). As a result of the simulation, we were able to reproduce the jumping phenomenon, and also confirmed that this phenomenon takes place only within a certain range of centrifugal force. Additionally, on the basis of the simulation outcome, we were able to confirm how much damage a product experience when the jumping phenomenon takes place and the minimum centrifugal force required to prevent the occurrence of the phenomenon.

What kind of simulation are you engaged in for granulation?

There are a lot of granulated products around us, including sugar, salt, soda, foods and pharmaceuticals in the form of tablets, and chemical products such as detergents and deodorizers. They are all applied with granulating processes to adjust the size of particles depending on their intended use. Roughly speaking, there are two types of granulating methods: pressing powder-particles to form grains, and crushing a large lump into small pieces. Well-known methods of the former type include, for example, the tumbling granulation method, the fluid-bed granulation method, the extrusion granulation method and the spray dryer method. I would like to take this opportunity to introduce two of these methods and examples where they were applied. One is the extrusion granulation method, in which material is extruded with a mold to produce grains, and the other is the tumbling granulation method, in which interactive movements of particles is produced by the rotation of a container to dredge the particles with raw material to enlarge the particles.

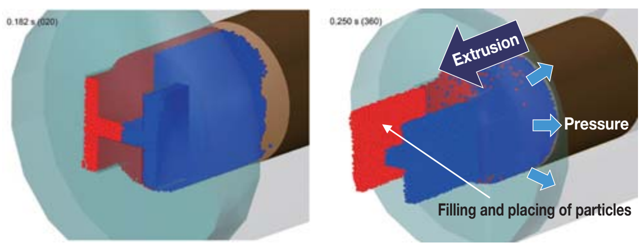

Fig.4 Simulation image: Simulation of extrusion granulation

Fig.4 shows an example of extrusion granulation using an adhesion model. In the extrusion granulation, a clay-like material is pressed against a die serving as a mold to make an elongated granulated substance. After that, simply by cutting it and firing it in a kiln, you can complete a product. By simulating all this, it becomes possible to examine the segregation of material, including bending, warpage, mixing state in the previous process, density distribution, etc., which makes it easier to consider the shape of the die and flow passage. In the extrusion granulation, before passing the die, material behaves like a liquid due to the pressure applied to the die, but after passing the die, the material behaves like a solid. Since we knew that if we could successfully reproduce these contrasting conditions in the same state by simulation without changing physical property values, complicated setting would become unnecessary, in which we found practical value, we worked on the reproduction of these conditions in the simulation. In the simulation, two types of particles with the same physical property value are filled and placed separately into right and left, and then they are extruded. Since high pressure is generated inside the device, they are extruded while maintaining the shape of the hole (**Fig.4**). The benefit of conducting the simulation with a discrete element method (DEM) lies in that since this method allows for discrete treatment, a series of phenomena in the device including mixing in the previous process and cutting in the following can be simulated at one time by using the same device.

Next, I would like to introduce an example of tumbling granulation. In the tumbling granulation, particles serving as nuclei are dredged with raw material to become larger particles. At that time, the raw material is adhered to the particles by using a liquid adhesive material called a binder for the formation of a granulated body, which, however, is not strong enough. Therefore, it is necessary to consolidate it in a container with its rotational motion and increase its strength; the particles become larger by repeating this procedure. At the stage of nuclear particles, particle size distribution is quite wide, but through this granulation operation, the particle size distribution narrows. In the tumbling granulation, it is important to maintain stable quality in the design of machine and the establishment of a production system using such facility; however, when adhesion is too strong, particles firmly adhere to the surface of the machine and particles, which form aggregates, stick to each other. Thus, there are some problems to be addressed (**Fig.5**). They result in the significant degradation in quality, so we conducted a predictive simulation to solve these problems.

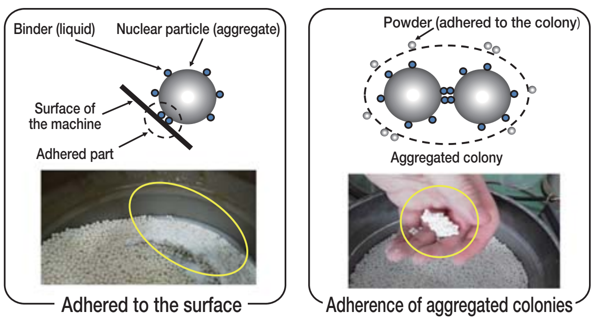

Fig.5 Factors that significantly affect granulation quality

To successfully simulate granulation, it is necessary to develop various physics models such as those on contact force, which is a basic technology, geometric effect, etc. After having a lot of discussions with Prometech with a focus on the adhesion of particles to the wall and the adherence of aggregates between each other that took place during the granulating process, we asked Prometech to develop a new physics model, an adhesion model. This simulation is intended for situations in which relatively large particles with a particle size of millimeter order are used. In addition, the bonding force acting between particles was set in such a way that adhesion phenomena would be handled stably and extensively with fewer parameters. Unlike potential force, bonding force does not always act between all particles by a chemical reaction and by the operation of high viscosity liquid, so conditions for bonding and releasing particles are required, and such conditions can be independently set by the user. In the experiment verification, we adopted a centrifugal tumbling granulation method, which enables experimental work to be conducted stably even in a relatively small-scale experiment. Experimental machine used in the centrifugal tumbling granulation method consists of a fixed cylinder and a rotating dish. By rotating this rotating dish, interactive movement is given to the entire particle group, and also, strong compressive force is given by centrifugal force to consolidate it. First of all, parameters related to adherence, bonding and fracture of the adhered model were determined to be indexes for identification, and the rotating dish was stopped with the binder evenly distributed throughout the particles. And then, the collapse state at that time was used as an evaluation index. The process of dripping a fixed amount of binder and leaving it with the rotating dish rotating, and the collapse shape that changed the adhesion force was adopted (**Fig.6**). In this experiment, after the binder was dropped nine times, the condition of the collapse shape became optimum for granulation, which was reproduced by simulation.

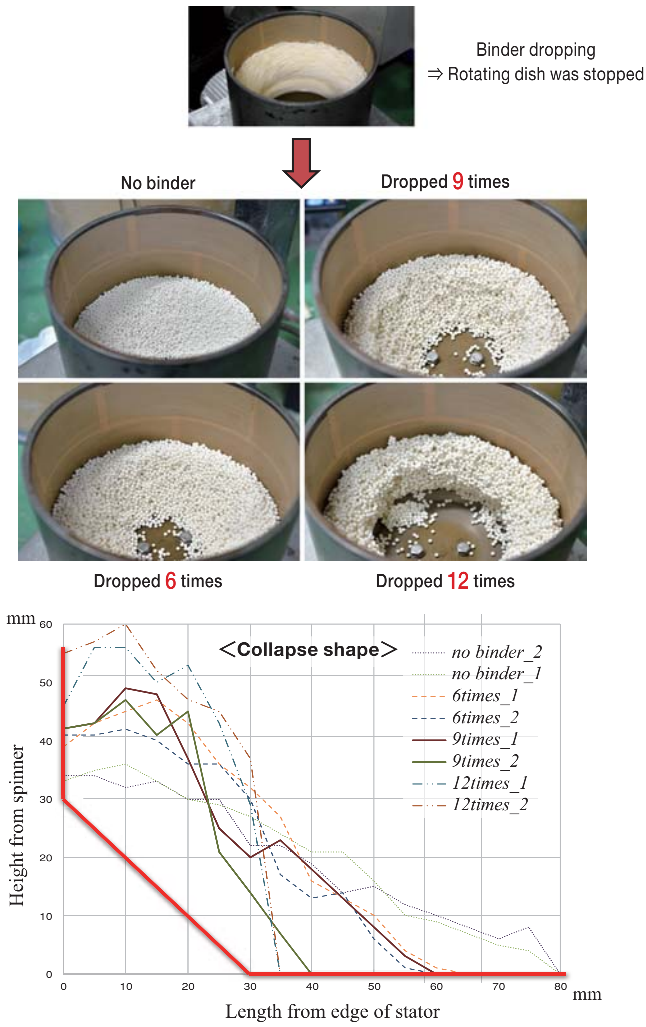

Fig.6 The number of binder dropping and collapse shape

After trying approximately 80 conditions as case studies in the simulation, we conducted an overall evaluation of the simulation; in the experiment, the collapse took place locally, whereas in the simulation, the collapse took place entirely. Thus, there was some difference between them, which, however, was not a major factor in the generation of adhesion force. Therefore, we decided to adopt a parameter with which the collapse shape closest to that in the experiment was produced, and to conduct a qualitative evaluation in the state where particles were in movement and adhered firmly with each other and to the wall surface. Comparison of results from the simulation using the optimum parameter and those from the experiment is shown in **Fig.7.** After consultation with Prometech, we decided to make it possible to separately visualize the adherence of particles between each other and the adherence of particles to the wall surface in the simulation. If you look at the aforementioned granulating phenomenon after dropping the binder nine times, you can see particles move while

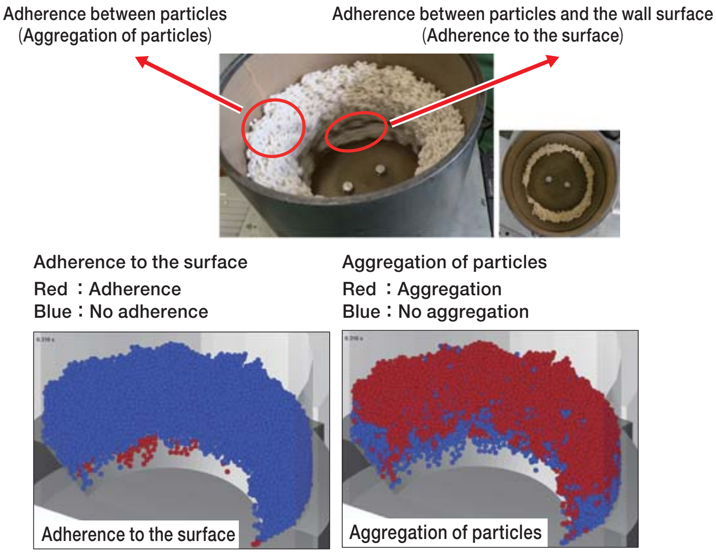

Fig.7 Comparison of the adhered state in the experiment with that in the simulation during granulating

clinging to each other by the adhesion force. Also, particles are adhered to the inclined part of the rotating dish. When stopping the machine to compare the adhered state on the wall surface in the simulation with that in the experiment, we found that adhesion had taken place at the same location, so we concluded that this evaluation method was promising.

What benefits have you found after introducing Granuleworks?

With regard to the adhesion phenomenon during granulation, which is the problem to be addressed, we have made steady advancement toward its solution. The introduction of Granuleworks has increased the depth of discussion and consideration. A simulation takes a method of making a prediction based on a physical phenomenon from a micro viewpoint and obtaining results from a macro viewpoint. Since the behavior of powder and granular material is, when seen from a micro viewpoint, consists of the combination of simple physical phenomena, simplifying complex phenomena is an appropriate approach to understand it. Even when actual results and simulation results do not agree, the differences between them may have important implications. The effect of visualization is also important. Measurement of the flow of powder and granular material is very difficult in the non-virtual world, but it is possible to display even the distribution of entire physical quantity in simulation, so it helps to understand the phenomena. In addition, even though Granuleworks displays results in a way that appeals to intuition and is understandable, in order to discuss the details of granulation phenomenon, for example, if it can respond to the interacting force between particles and to the display of physical quantities unique to powder and granular material, it would be greatly appreciated.

Please let us know your requests and future expectations for Granuleworks and Prometech.

I want Granuleworks to be the world's first granulation simulator. For that purpose, it is necessary to develop new physical models such as those for spraying, liquid transfer/distribution, liquid infiltration/dispersion and drying. I believe that when we can realize them, we will be able to conduct granulation simulation in the true sense of powders gathering to become grains. I feel the strength of Prometech lies in that users and developers feel they are very close and things are being advanced with a sense of urgency, so when I'm working with them, I'm also stimulated to work with enthusiasm. There are many types of DEM software, but I heard that there are almost no pieces of software suitable for industrial use. We want Prometech to continue to pay attention to dialogue with users and develop Granuleworks into the world's first software with a high level of expertise that can be fully used in the industrial world.

Thank you very much for taking time out from your busy schedule for the interview and for sharing your valuable opinions. The entire staff of Prometech would like to continuously offer our support so that we can keep contributing to the development of even better products.

Reference
Granuleworks Special Seminar in Nagoya (2016/12/22) Lecture Materials
Note (1): Granuleworks mentioned above is the one as of December in 2016, which is a prototype version available before its official release. For details of the function, please contact us.

Interviewed on December 22, 2016

Tipton Corp.

Tipton Corp.
Address: Nagoya City, Aichi Prefecture
Established: July 8, 1939
Businesses: Production of barrel finishing machines, abrasive media and compounds, fillers of oil refining and petrochemical industries, food coating machines, grinding wheels, etc.
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