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Analysis of the Influence of Mixing Teeth on the Productivity of Wet Granulator

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Abstract: Carbon black is a commonly used reinforcing agent in the rubber field. After the carbon black is added to the rubber, the tensile strength of the colloidal body is significantly improved, and the disadvantages of the rubber itself are greatly improved. At present, wet granulation is the most widely used carbon black production technology. Carbon black and water are added to a stirred-tooth wet granulator. After mixing, moistening, and stirring, spherical particles with stable binding are formed and then dried. In addition to water. The formation of carbon black by wet granulation can solve the disadvantages of dry granulation of carbon black with weak interparticle forces and easy destruction of spherical particles, and can solve the problem of pollution in the later stage. At present, most studies on wet granulation concentrate on the effects of granulation water components and the amount of granulation water on the granulation effect. There are very few studies on agitator shafts. This paper focuses on the mixing density of the granulator and the annulus of the commutator. The effects of grain effects were studied in depth.

Keywords: Carbon black, wet granulation, mixing density, spur ring gap.

1. INTRODUCTION TO WET GRANULATION

In the wet granulation process of carbon black, the powdery carbon black, granulation water, and binder are injected into the granulator at a certain ratio, and the granulation is performed by high-speed stirring of the stirring shaft. This is an application of intermolecular forces. The method of physical granulation, which mainly involves the following five major steps.

(1). Stirring degassing of carbon black

The stirring and degassing process of carbon black takes place in the initial stage of stirring. The raw materials are uniformly added to the granulator according to a certain feeding speed. Under the high-speed stirring action of the spiral blades and the stirring teeth, the external force destroys the raw material particles. In the secondary structure, the gas on the surface of the raw material is discharged during this process. At the same time, the density of the particles within the unit volume of the external force increases, and the chance of the particles coming into contact with the particles increases, which accelerates the formation of carbon black particles.

(2). Particle Infiltration and Penetration

After the degassing of the carbon black raw material, the number of carbon black particles per unit volume increases, and the increase of the number of particles accelerates the mixing of the carbon black raw material and the granulation water. After the rapid stirring of the stirring teeth, the surface of the particles is wetted and infiltrated. Particles will quickly become larger.

(3). Adsorption between particles

After the carbon black particles are wetted with the granulation water and the binder, the adhesion force on the surface of the particles is increased, and the carbon black particles reach the effect of adsorption and agglomeration through the squeezing action of the stirring teeth on the particles and the mutual collision between the particles.

(4). Stirring granulation

Under the action of the high-speed stirring of the stirring teeth, the carbon black particles adsorbed together in the previous process will move to the cylinder wall under the action of the centrifugal force. According to the Inertial Theorem, particles with larger masses will more easily reach the wall of the cylinder. The particles with larger particles will be broken by the mixing teeth. After breaking, the smaller particles will continue the previous process and re-adsorption. After several times, the particles will be broken into pellets. Meet the required particle size and move to the outlet under stirring.

(5). Particle Densification and Polishing

The initially formed particles, whose specifications and tightness cannot meet the requirements, still require further agitation. After several times of granulation and crushing in the agitator cylinder, the particles are finally produced with uniformity and appearance quality that meet the qualification requirements. After the particles are molded, they go to the next step and are dried.

2. MATHEMATICAL MODEL ESTABLISHMENT

The discrete element method is a numerical simulation method proposed by Cundall in 1971. The object of the treatment is a system composed of discrete particles. It is widely used for the simulation of particulate matter. Its intrinsic idea is to reflect the interaction of microscopic particles and reflect the whole The macro evolution of the medium.

2.1 Hertz contact model

In the simulation of particulate matter, the most common interaction is the mutual collision between particles, which is also an important part of the discrete element method. The whole collision process of particles can be divided into three phases: pre-collision, collision, and post-collision, as shown in Fig.1 to 3. In the numerical simulation, the velocity before particle collision is a known quantity and does not need to be calculated. The only thing that needs to be calculated is the velocity after the collision, but the velocity after collision is determined by the interaction force of particles in the collision. Therefore, the solution of the force during the collision of particles is the key to the collision problem. As long as the force received by the particles in the collision can be calculated, the motion state after the particle collision can be completely determined. There are many models for calculating forces in collisions, the most famous of which is the model Hertz model.

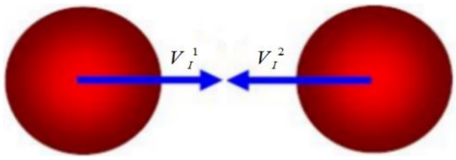

Fig 1. Particle collision before

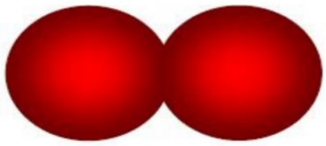

Fig 2. Particles collide

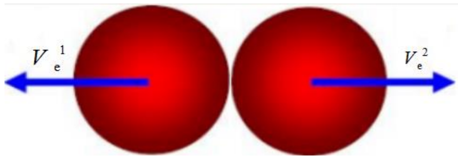

Fig 3. Particles collide and separate

The Hertz contact model describes the relationship between the particle overlap area and the repulsive force when particles collide, as shown in Figure 4. When the particles colliding with each other are elastic balls, and the Young's modulus, radius, and speed of the balls are known, the repulsion force of the particles due to the collision is along the line connecting the two colliding ball spheres. The interparticle effect can be expressed by the following formula:

$$P = \frac{4E\sqrt{R}}{3}\delta^{\frac{3}{2}}$$

$$\delta = \mathrm{R}_1 + R_2 - \mathrm{d}$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{E} = \frac{1-U_1^2}{E_1} + \frac{1-U_2^2}{E_2}$$

Where R is the radius of the particle and d is the distance between the sphere centers of the two particles.

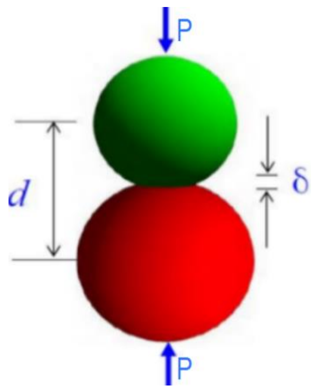

Fig 4. Hertz contact model

2.2 Adhesive force model

In addition to the repulsion caused by mutual collisions during the granulation process, there is an important type of force, namely the attraction between the particles due to the granulation water and the binder. In this paper, a simplified JKR-Johnson-Kendall-Robert (SJKR) model was used to simulate the interparticle cementation. The model calculates the interparticle attraction through the cohesive energy of the particle surface. The force is written as:

$$F = \mathrm{k}A$$

Where A is the contact area between the particles and k is the cohesive energy density at the surface of the particles. The unit is J/m3. For two spherical particles to collide, the particle contact area A can be written as:

$$A = \frac{P_i}{4} \times \frac{(d - R_i - R_j) \times (d + R_i - R_j) \times (d - R_i + R_j) \times (d + R_i + R_j)}{d \times d}$$

3. THE ESTABLISHMENT OF GEOMETRIC MODEL AND SIMULATION CALCULATION

3.1 Discrete elementary open source software lights

LIGGGHTS is a discrete element open source software developed by Sandia National Laboratories in the United States. LIGGGHTS has two goals. First is to implement the discrete element (DEM) algorithm in a reliable and complete way; secondly, the developed software can be effectively applied. Engineering practice, so LIGGGHTS supports the introduction of complex CAD geometry, moving meshes, and other functions that are actually effective for engineering.

3.2 Setting of boundary conditions and setting of calculation model

The following will take the input file of this project as an example to illustrate the format and main content of the input file. The first part is the definition of some common content in the simulation, including the type of particle, the type of simulation boundary, and the unit system used to describe the simulation. The second part is still a general definition, but it is a little deeper than the first part, including the simulated area, defining the threshold for judging potential exposure. The third part is mainly used to define the material properties of the particles. These parameters will be used when calculating the interparticle interaction forces.

The fourth part is used to import the CAD model into the calculation area. Specifically, in this paper, two geometric shapes need to be introduced, namely the agitator shaft and the outer barrel wall of the wet granulator. The fifth part defines the contact model between particles. In this paper, the Hertz contact model and the adhesive force model are used to select the SJKR model. This section defines the geometric wall that is in contact with the particle, which includes four planes and two planes where CAD graphics are imported. Defines the cuboid grain area for inserting particles.

3.3 DEM simulation parameter setting

In order to simulate the granulation process of the granulator, a physical model as shown in Fig. 5 was established through SolidWorks. The left end of the agitator shaft was the feed port, and the particles were moved to the right under the agitation axis transport operation. The physical parameters involved in the simulation were simulated. See Table 1.

Table 1.DEM simulation parameters

parameter name	parameter
Total number of particles	50000
Particle radius	0.001m
Particle density	18000kg/m^3
Elastic Modulus	5000000pa
Poisson's ratio	0.45
Recovery factor	0.3
Coefficient of friction	0.02
Stirring shaft speed	333r/min

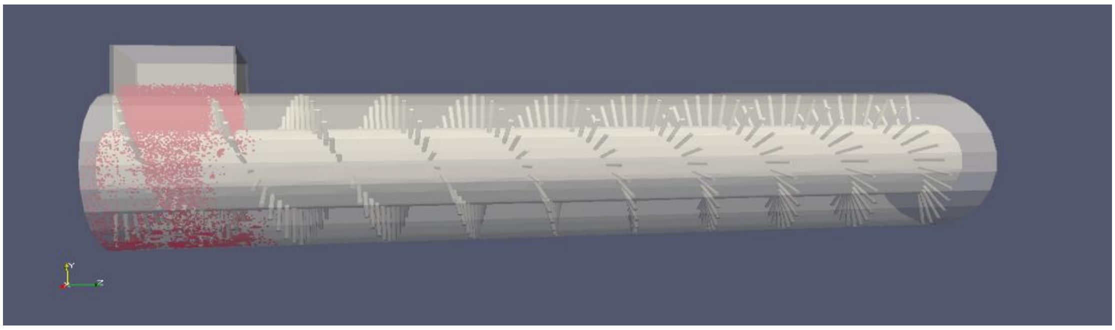

Fig 5. Pelletizer simulation physical model

4. ANALYSIS OF SIMULATION RESULTS

4.1 Simulation calculation results and analysis of mixing density

First of all, this project will study the effect of mixing density on the mixing effect and material transport capacity of the granulator. In order to rule out the interference of other factors, the control variable method is used to consider 5 different stirring axes. The ring gaps of the stirring axes are the same and the only The difference is the difference in mixing density. The mixing density and the total number of teeth of the 5 sets of stirring shafts are shown in Table 2.

Table 2. Stir density distribution

No.	Mixing density	Total teeth
1	18	91
2	24	121
3	30	151
4	36	181
5	42	211

Fig. 6 shows the schematic diagram of the stirring shafts with different mixing densities used for DEM simulation. It can be seen that the ring gaps of these stirring shafts are the same, and the mixing densities are different respectively 18, 24, 30, 36, 42. The simulation has a total step size of 500,000 steps and an intermediate result is output every 10,000 steps.

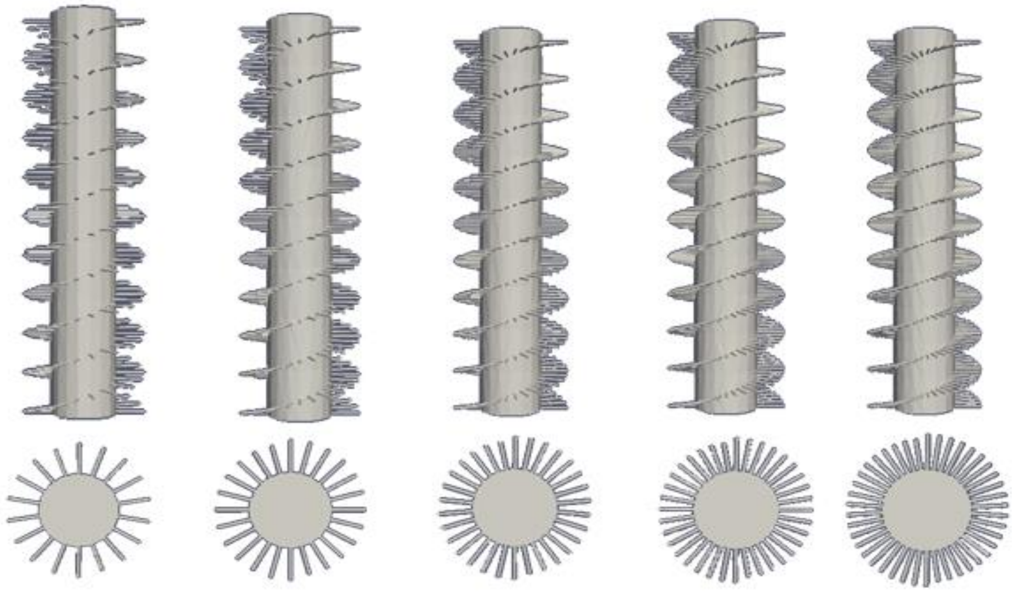

Fig 6. Different tooth density models

In order to obtain the best mixing density, the center of gravity of the system during the simulation was averaged to obtain the average barycentric coordinates as a function of the mixing density, as shown in Fig 7. It can be seen that when the mixing density is small, increasing the number of teeth helps to increase the material transport capability of the agitator shaft. However, as the mixing density increases, the material conveying capacity of the agitator shaft gradually decreases. See Table 3 for specific values.

From Table 3, it can be seen that when the density of teeth was increased from 18 to 24, the particle transport capacity increased by 12.7%, while from 36 to 42 the transport capacity increased by only 2.57%, and the remaining two growth rates were respectively for 4.49% and 5.12%, comprehensive consideration of a suitable mixing tooth density is 30-36. Once the mixing tooth density exceeds 36 particles, the transportation capacity will remain basically unchanged.

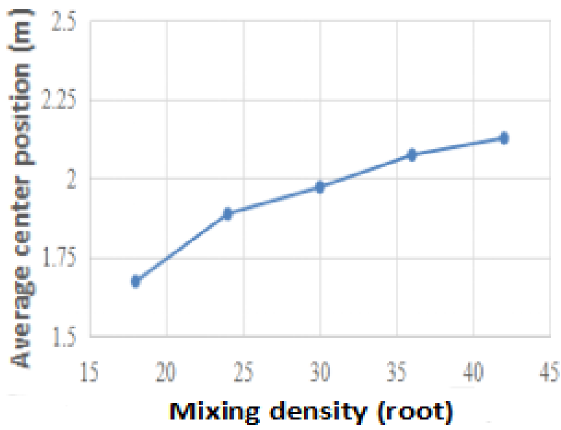

Fig 7. The average center of gravity of the system varies with the tooth density

Table 3. The average position of the center of gravity of the granular system varies with the tooth density

Mixer density Average	center of gravity	Increase percentage
18	1.673532	-----
24	1.886999	12.7555%
30	1.971747	4.4912%
36	2.073541	5.1626%
42	2.126877	2.5722%

4.2 Simulation calculation results and analysis of rib ring gap

In order to simulate the impact of ring gap on the granulation effect, this paper considers five kinds of agitator shafts with different ring gaps. The schematic diagram is shown in Fig 8. They all have the same mixing tooth density of 30. The only difference is the pitch of the mixing teeth. Different (see Table 4), the larger the pitch, the larger the ring gap and the larger the granulation space. In the same way, this section will study the effect of annulus on pelletizing effect and material transport capacity, using the axial component of the particle system's center-of-gravity coordinate and the kinetic energy of the particle system as two indicators.

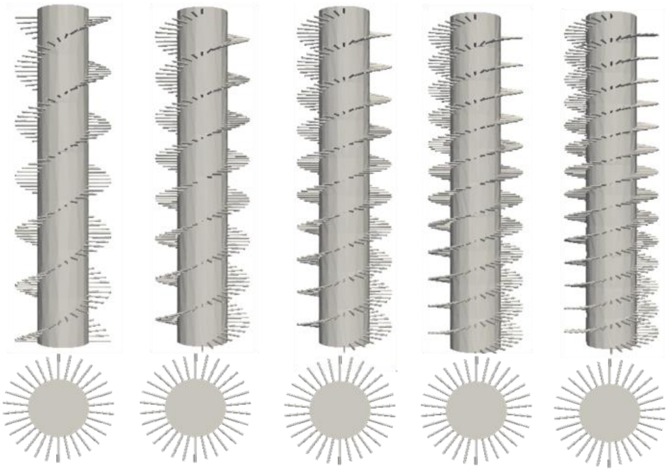

Fig 8. Schematic diagram of the impact of the ring in the simulation

Table 4. Pitch values for 5 sets of data

No	Pitch	Total number of teeth
1	1075	91
2	806.26	121
3	645	151
4	537.5	181
5	460.7	211

Fig 9 shows the effect of annulus on the material transport capacity of the agitator shaft. It can be found that when the annulus is too wide or too narrow, it is not conducive to the transport of the material. When the annulus is too wide, there is not enough stirrer to transport the particles. However, when the annular gap is too narrow, the granulation space is too small and it is not conducive to the transport of particles. The current calculation results show that when the screw pitch is between 645 mm and 806.25 mm, the agitator shaft has the best transport effect.

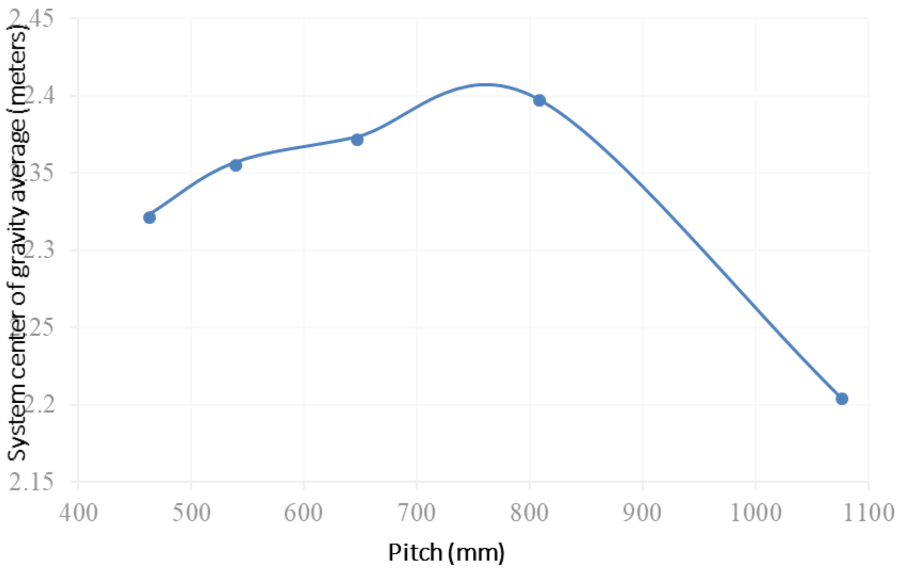

Fig 9. The average center of gravity of the system varies with the tooth density

5. SUMMARY

In this chapter, according to the change of the kinetic energy of carbon black particle system and the change of center of gravity of carbon black particles with time in the actual granulation process of carbon black, the influence of different mixing densities and different mixing ring gaps on the mixing effect and material transport capacity of the granulator is obtained. , can be summarized as the following four conclusions:

(1) When the mixing ring gap is the same, the greater the mixing density, the stronger the material conveying capacity of the agitator shaft; but when the mixing density reaches 36, the mixing density is increased, and the degree of material transport capacity is increased to a limited extent. For the consideration of material transport capacity and production cost, it is recommended to mix the tooth density between 30~36.

(2) When the mixing ring gap is the same, the granulation effect of the stirring shaft and the mixing density are not monotonically related. When the mixing density is between 24 and 30, the stirring axis has the best granulation effect.
(3) When the mixing densities are the same, the annulus and the material transport capacity are not monotonically related. When the pitch is between 645 and 800 mm, the agitation shaft has the best material transport capability.
(4)When the mixing tooth density is the same, there is a monotonous relationship between the granulation effect of the agitator shaft and the annulus. When the thread pitch is less than 800 mm, the annulus is larger and the agitation shaft granulation effect is better. When the thread pitch is greater than 800, the agitation shaft is pelletized. The effect is almost unchanged.

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