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Simulation analysis of the significance and interaction of influencing factors on mixing uniformity of double drum recycling mixing plant

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ABSTRACT: The mixing uniformity of the double drum recycling mixing plant has an important effect on the quality of recycled asphalt mixture. The mixing uniformity of the double drum recycling mixing plant not only depends on the axial installation angle of the blade, the radial installation angle of the blade, the phase angle of the stirring arm, the inclination angle of the drum, and the rotation speed of the drum, but also on the interaction between these factors. In order to further clarify the relationship between the mixing uniformity and the above factors, the significance and interaction of influencing factors of mixing uniformity were studied based on EDEM and response surface methodology (RSM). The result shows that the factors affecting the mixing uniformity of the aggregates are significantly different when the aggregate size is different. Therefore, when studying the mixing uniformity of a mixing plant, it is not comprehensive to conduct research on a certain factor in a single-sided manner. Instead, the main factors and the interaction between the factors should be considered comprehensively.

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23 **Keywords:** Double drum recycling mixing plant, EDEM, mixing uniformity, Response Surface
24 Methodology, structural design.

25 1. Introduction

26 The mixing uniformity of double drum recycling mixing plant largely determines the quality of the recycled asphalt
27 mixture, and its structural parameters and working parameters have an important influence on the mixing uniformity
28 of the asphalt mixture. Therefore, many scholars have conducted a lot of research. Ma *et al* [1] analyzed the
29 influence of the single factor of structure parameter and working parameter on the uniformity of mixing. Liu *et al*
30 [2] analyzed the stress of the recycled asphalt mixture in the double-drum recycling mixing plant, and qualitatively
31 analyzed the accumulation of the mixture on the mixing blades, and determined the installation range of the blade
32 inclination. Zhao *et al* [3] optimized the structure of the drying drum of the asphalt mixing equipment, and analyzed
33 the parameter matching of the asphalt mixing machine blades based on the discrete element method (EDEM).
34 SIMONS T A H *et al* [4] studied on the characterization of granular mixing in a helical ribbon blade blender.
35 SAKAI M *et al* [5] evaluated the uniformity of solid mixing in an industrial blender based on the discrete element
36 simulation. John Milstead *et al* [6] proposed an improvement to the shape of the mixing blade on the outer wall of
37 the inner cylinder, which can extend the residence time of the mixture on the blade, increase the amount and height
38 of the blade, and enhance the spraying and uniformity of the mixture. Larry W. Hudman *et al* [7] proposed a mixing
39 chain device that can reduce the adhesion of the asphalt mixture on the outer surface of the inner cylinder to prevent
40 the adhered aging materials from cracking and falling into the mixing chamber to contaminate the mixture. Based on
41 the analysis of the structure and working principle of the double drum, I. Choustere [8] pointed out the advantages of
42 the equipment in terms of exhaust emission. Ivica Androjić *et al* [9] analyzed the energy consumption in the
43 production of hot-mix asphalt (batch mixing equipment). D. Peinado *et al* [10] analyzed the energy and exergy in an
44 asphalt plant's rotary dryer.

45 Jon Elvar Wallevik *et al* [11] analyzed the shear rate inside a concrete truck mixer. Justas BRAŽIŪNAS [12]
46 proposed parameters of technological processes for mixing of bitumen with mineral aggregates that occur in a
47 bitumen batching system (BBS) are stochastic and impact on the composition of bitumen binder as well as physical
48 and mechanical properties of the produced HMA mixture, namely, air void content, stability, flow and Marshall

49 quotient. Henrikas Sivilevičius [13] simulated the composition of recycled hot-mix asphalt mixture produced in
50 asphalt mixing plant

51 Other aspects include: M. Mohajeri, Molenaar *et al* [14] performed elastic modulus, indirect tensile strength, and
52 fatigue strength tests on compacted cylindrical samples considering different RAP content and humidity. It shows
53 that when RAP has low humidity, the recycled mixture produced by double drum mixing equipment has better
54 mechanical properties than the recycled mixture produced by batch mixing equipment. Yu [15] analyzed the main
55 reasons for the deviation of the asphalt content caused by the ASTEC double-drum continuous recycling mixing
56 equipment, and proposed an improvement plan. Cao [16] pointed out that in actual production of double-drum
57 continuous recycling mixing plant, the moisture content of aggregate, the temperature of asphalt, and the addition of
58 recycled materials will all have a certain degree of influence on continuous metering and grading. Gao Xin [17]
59 designed a set of two-stage dust removal system based on the structural characteristics of the double-drum
60 continuous regeneration mixing equipment, and used Fluent software to simulate and optimize the structure of the
61 flow field in the cyclone dust collector. Zhong [18] studied the continuous drum-type asphalt mixing plant metering
62 system, process flow and metering method.

63 Chi [19] used continuous tracking to detect the production quality of the mixture and found that the double-drum
64 continuous regenerative mixing equipment has better mixing effect than the forced batch mixing equipment. Other
65 studies on the structural parameters of mixing equipment using the discrete element method are also mentioned
66 [20][21][22][23][24].

67 Above research focuses on the optimization and improvement of the performance of the double-drum mixing
68 plant, and the mixing uniformity of the double-drum recycling mixing plant is its most important performance index.
69 The limited literature on the effect of structural parameters and working parameters on the uniformity of mixing is
70 only in the influence of a single parameter. In the actual mixing process, the uniformity of mixing is affected by the
71 interaction of the drum speed, drum inclination angle, blade axial installation angle, blade radial installation angle,
72 and phase angle of the mixing arm.

73 In the actual mixing process, the mixing uniformity of the mixing drum is affected by the interaction of its
74 structural parameters and working parameters.

75 For this reason, this paper establishes a simulation model based on the discrete element method (DEM) that meets
76 the actual working conditions. Based on the analysis of the influence of each single factor on the uniformity of

aggregate mixing, a mathematical model between the discrete coefficient of aggregate and each factor is established by using the response surface methodology (RSM), and the significant relationship between each factor and its interaction on the uniformity of aggregate were analyzed. Furthermore, the influences of the rotating speed of the drum, the inclination angle of the drum, the axial installation angle of the blade, the radial installation angle of the blade, the phase angle of the mixing arm and other factors on the mixing uniformity are studied, which provides a reference for further understanding of the mixing mechanism and reveals the movement law of particles on the mixing blade.

2. Analysis of main influencing parameters

The double drum is the core component of the double drum recycling mixing plant. The outer cylinder is fixed to the frame and installed at a certain angle with the ground. The inner cylinder is coaxial with the outer cylinder to form a mixing zone with the outer cylinder.

A discharge port is opened at the end of the inner cylinder near the burner, and a stirring blade is installed on the outside. The cold aggregate enters the inner cylinder from the feed port after proportioning, and moves toward the burner under the action of gravity. With the rotation of the inner cylinder, the super-heated aggregate continuously falls into the mixing chamber from the discharge port at the end of the inner cylinder. Recycled materials, new asphalt, recycled materials and powder are added to the mixing chamber from different cross-sections of the outer cylinder. The aggregate is heated and stirred in the outer cylinder to form a recycled mixture, which realizes the recycling of old recycled materials.

2.1 Blade installation angle

The installation angle of the blade affects the mixing uniformity and efficiency through affecting the axial, radial, and circumferential movement of the mixture[1Error! Reference source not found.]. Its radial angle and axial angle have an important influence on the performance of double drum recycling mixing plant, as shown in Fig.1. Where α is blade radial angle and β is axial angle. Therefore, it is necessary to analyze the range of blade installation angle.

(a) Blade installation angle

(b) Mixture movement

FIGURE 1. blade mixing mixture 3D view.

When blade radial angle $\alpha = 0^\circ$ and axial angle is β , The force analysis of the mixing unit on the blade is shown in Fig.2(a). When $\beta = \gamma$, and blade radial angle is α , the force analysis of the mixing unit on the blade is shown in Fig.2(b). Where F is the force on the asphalt mixture, f is friction between blade and aggregate, F_1 is axial force, it mainly causes the axial movement of the mixture. F_2 is tangential force, it mainly causes the circumferential movement of the mixture. F_3 is radial force, it mainly causes radial movement of the mixture. F_4 is tangential force, it mainly causes circumferential motion of the mixture. As shown in Fig.3, in order to realize the axial movement of the mixture, it will meet the requirements: $F_1 - f \geq 0$, $\beta \geq \arctan \mu$. Where μ is friction coefficient. For the same reason,

112 the condition for the mixture to achieve radial movement shall be: $\alpha \geq \arctan \mu$.

(a) Axial direction

(b) Radial direction

FIGURE 2. The force analysis of the mixing unit.

118 Material pile formed on the face of blade during mixing as shown in Fig.3, where AB and BC are the side edges of
 119 the pile, the mixture moves along the side edges. β is the axial installation angle of the blade, γ is the angle of the
 120 drum; W is the width of the blade; b is blade height; and θ is the angle between the side edges of the pile and the
 121 horizontal plane, that is, the mixture accumulation angle.

(a) Axial direction

(b) Radial direction

FIGURE 3. Schematic diagram of material pile in front of blade.

The mixing speed coefficient is used to describe the axial and circumferential movement of the mixture, as shown in (1) [10]. Where K is Mixing speed coefficient, K_a is axial velocity coefficient, K_c is circumferential velocity coefficient, W_0 is the projection length of the blade on the horizontal line; W_1 , W_2 are the projection length of the two edges of the blade on the horizontal line;

$$\begin{cases} K_a = (W_1 - W_2) / W_0 = \tan(\beta - \gamma) / \tan \theta \\ K_c = S_1 / S_2 = \cos^2(\beta - \gamma) - \cot^2 \theta \sin^2(\beta - \gamma) \\ K = K_a K_c = [\tan(\beta - \gamma) / \tan \theta] [\cos^2(\beta - \gamma) - \cot^2 \theta \sin^2(\beta - \gamma)] \end{cases} \quad (1)$$

In order to maximize the axial and circumferential velocity of the mixture, if $K'(\beta) = 0$, we can get:

$$K'(\beta) = \tan^2 \theta - 2 \sec^2 \theta \sin^2(\beta - \gamma) - \tan^2(\beta - \gamma) = 0.$$

From $\theta = 55^\circ \sim 70^\circ$, $\gamma = 2^\circ \sim 6^\circ$, $\beta = 33.54^\circ \sim 45.36^\circ$.

According to the calculation method of axial installation angle, the range of blade radial installation angle is:

$$\alpha = 31.54^\circ \sim 39.36^\circ.$$

2.2 Rotation speed of inner cylinder

The rotation speed of the inner cylinder is controlled within a certain range, and the mixture will fall from the blade when it reaches a certain height. The force analysis of the mixing unit on the blade is shown in Fig.4. If the mixture is in the self falling state, the sliding force of material unit should overcome the centrifugal force and friction force.

As shown in Fig. 4, Centrifugal force F_c can be divided into component force F_a and component force F_b ,

F_a is parallel to the blade and F_b is perpendicular to the blade; Similarly, gravity G can be divided into

component force G_1 and component force G_2 , G_1 is parallel to the blade and G_2 is perpendicular to the blade.

Before the inner cylinder speed reaches the critical speed, the conditions for the mixture to meet the self falling are as follows:

$$F_a + f \leq G_1 \quad (2)$$

$$\begin{cases} F_a = F_c \cos \alpha \\ F_c = m \omega^2 R = \frac{m \pi^2 n^2 R}{30^2} \\ G_1 = mg \sin(\alpha + \delta) \\ f = \mu [G_2 + F_b] \\ G_2 = mg \cos(\beta - \gamma) \cos(\alpha + \delta) \\ F_b = F_c \sin \alpha \end{cases} \quad (3)$$

Where δ is Material glide angle, R is blade end rotation radius, g is gravitational acceleration. $\gamma = 2^\circ \sim 6^\circ$,

$\beta = 30^\circ \sim 46^\circ$, $\alpha = 0^\circ \sim 45^\circ$, $\delta = 42^\circ \sim 75^\circ$ [11].

Take (3) into (2) to calculate:

$$n \leq \frac{30}{\pi} \sqrt{\frac{g \sin(\alpha + \delta) - \mu g \cos(\beta - \gamma) \cos(\alpha + \delta)}{R (\cos \alpha + \mu \sin \alpha)}} \quad (4)$$

Substituting the above parameters into (4), the critical speed of the drum is 13.4 r/min. According to the speed requirements, the primary drum speed is 6-10 r/min.

FIGURE 4. Force analysis of material unit.

2.3 Phase angle of mixing arm

Under the action of gravity, the particles of the mixture do parabolic motion at a certain initial speed. The initial velocity V_0 is composed of the relative velocity V_r and the implicated velocity V_ω , that is $V_0 = V_r + V_\omega$. V_ω is the linear speed of rotation of the inner cylinder, V_r is the sliding speed of particles on the stacking surface of the blade.

Because $V_r = V_\omega$, therefore, V_ω is taken as the initial velocity of scattering[12][13].

FIGURE 5. Schematic diagram of material throwing.

Established the coordinate system as shown in Figure 5. The X axis is parallel to the ground, and the Z axis coincides with the mixing axis. The particle is thrown out at the initial speed from point P_0 (corresponding position angle δ_0) and falls to point P_1 (corresponding position angle δ_1) on the cylinder wall, its movement equation in the mixing drum is shown in (3).

$$\begin{cases} md^2x / dt^2 = 0 \\ md^2y / dt^2 = -mg \cos \gamma \\ md^2z / dt^2 = -mg \sin \gamma \end{cases} \quad (3)$$

Where X, y and Z are the projections of material particles on the X, y and Z axes; t is the time the particle moving from point P_0 to point P_1 . According to the initial boundary condition, when $t = 0$, take the approximate values for X_0 , Y_0 and Z_0 , Differential equation of motion is shown in (4).

$$\begin{cases} x = -R\omega t \sin(\alpha + \delta_0) + R \cos \delta_0 \\ y = -(1/2)gt^2 \cos \gamma + R\omega t \cos \beta \cos(\alpha + \delta_0) + R \sin \delta_0 \\ z = -(1/2)gt^2 \sin \gamma + R\omega t \sin \beta \cos(\alpha + \delta_0) \end{cases} \quad (4)$$

The falling point of particles is the intersection of the curve described in (4) and the inner wall of the outer cylinder, corresponding to the coordinate system shown in Figure 7, the cylinder equation is $x^2 + y^2 = R^2$. Thus, the time t_p is particle movement from P_0 to P_1 is obtained. The positions x_1 and y_1 of particles along the x and y directions can be expressed as:

$$\begin{cases} x_1 = -R\omega t_p \sin(\alpha + \delta_0) + R \cos \delta_0 \\ y_1 = -(1/2)gt_p^2 \cos \gamma + R\omega t_p \cos \beta \cos(\alpha + \delta_0) + R \sin \delta_0 \end{cases}$$

(a) Below the X axis

(b) Above the X axis

FIGURE 6. Projection diagram of materials thrown on XOY plane.

After the particles fall to point a, they roll down along the inner wall of the outer cylinder, In order to reduce the segregation of the mixture, the phase angle between adjacent blades shall meet the following relationship: the spray position is above the X-axis, $\varphi \leq \delta_1 + \delta_0$; the spray position is under the X-axis, $\varphi \leq \delta_1 - \delta_0$, where $\tan \delta_1 = |y_1| / |x_1|$, $\varphi \leq 67.3^\circ$.

3. Simulation analysis

3.1 Discrete element method (DEM) Contact model

189 The simulation model is established based on DEM, the contact relationship of DEM generally includes particle to
 190 particle and particle to geometry, as shown in Figure 7. The displacement change of particles in contact is shown in
 191 Figure 8, Particle i is in contact with particle j at point C, dotted line is the initial contact position, a is the tangent
 192 overlap, δ is the normal overlap.

FIGURE 7. Particle contact diagram.

FIGURE 8. Schematic diagram of particle contact displacement.

197 The vibration equation can be used to express the contact problem of particle model in DEM. The contact
 198 relationship of particles is represented by vibration model as shown in Fig.9. Where a) is normal vibration model, b) is
 199 tangent vibration model and c) is sliding model.

FIGURE 9. Vibration model.

203 The vibration motions of particles are disintegrated into the normal and tangential directions in the process of
 204 contact. The vibration equation is shown in (5), the first is normal vibration motional equation, the second is tangential

slide equation, the third is tangential rolling equation.

$$\begin{cases} m_{1,2}d^2u_n/dt^2 + c_n du_n/dt + K_n u_n = F_n \\ m_{1,2}d^2u_s/dt^2 + c_s du_s/dt + K_s u_s = F_s \\ I_{1,2}d^2\theta/dt^2 + (c_s du_s/dt + K_s u_s)s = M \end{cases} \quad (5)$$

Where $m_{1,2}$ is the equivalent mass of particles; $I_{1,2}$ is the equivalent moment of inertia; r is the revolving radius; u_n is the relative displacement normally, and u_s is the tangential one; θ denotes rotational angle for itself, F_n is the normal components of particles acted on by outside force, F_s is the tangential one; M is the external moment of particles, K_n is the normal elastic coefficient in contact model, K_s is the tangential one; c_n is the normal damping coefficient; c_s is the tangential one.

The friction force between contacting particles has an effect on the tangential sliding and rolling of particles. Through the sliding model, the limiting conditions of tangential sliding and rolling can be obtained as shown in equation (6):

$$F_s = \mu K_n u_n \operatorname{sgn}[K_s(u_s + d\theta/2)]$$

Where μ is the friction coefficient, $\operatorname{sgn}(x) = \begin{cases} 1, & x \geq 0 \\ -1, & x < 0 \end{cases}$.

2.2 Simulation model of double drum regenerative mixing plant

Simulation model of double drum regeneration mixing equipment is established by EDEM software, as shown in Fig.10. In order to improve the simulation speed, the aggregate in the mixture is simplified as a single spherical particle model. Three kinds of aggregate with different particle size range are used to simulate the mixture. The particle size range is 2.36-4.75 mm, 4.75-9.5 mm, and 9.5-19 mm, respectively. Named aggregate 1, aggregate 2, and aggregate 3. According to the production efficiency and gradation, the production rate of each particle factory is 1.51, aggregate 14.73, and aggregate 20.21 kg / s.

FIGURE 10. Simulation model of double drum regeneration mixing equipment.

The contact forces between asphalt and mineral aggregate, between mineral aggregate and mineral aggregate covered with asphalt, and between mineral aggregate and mixing plant are complex, including inter molecular Van der Waals force, acid-base force based on chemical reaction, meshing friction force, etc. in order to simulate the adhesion of asphalt, Hertz Mindlin with JKR cohesion contact model in EDEM software was selected. The intrinsic parameters and contact parameters of mixing device and material particles are shown in Table 1 and Table 2. Where μ is Poisson's ratio; E is shear modulus; ρ is the density; e is the recovery coefficient; f_j is static friction coefficient, f_d is dynamic friction coefficient.

TABLE 1. Intrinsic parameters of mixing device and mixture.

material	μ	E (GPa)	$\rho(\text{kg}\cdot\text{m}^{-3})$
steel	0.30	70	7 850
aggregate	0.25	23	2 850

TABLE 2. Contact parameters of mixing device and material particles.

Contact relationship	e	f_j	f_d
Steel -aggregate	0.10	0.6	0.24
Aggregate-aggregate	0.06	0.8	0.32

3. Analysis of factors affecting mixing uniformity (Single factor)

3.1 Influence of drum speed on mixing uniformity

Let $\beta = 40^\circ$, $\alpha = 36^\circ$, $\varphi = 40^\circ$, $\gamma = 4^\circ$, n is 6r / min, 7r / min, 8r / min, 9r / min, and 10r / min respectively. After the material flow is stable, the particle distribution of the mixture at different speed is as shown in Fig.12.

(a) $n=6r/min$

(b) $n=7r/min$

(c) $n=8r/min$

(d) $n=9r/min$

(e) $n=10r/min$

FIGURE 11. Mixture distribution at different speeds.

In the mixture distribution diagram shown in Figure 11, the right side is the feed port and the left side is the discharge port. Due to the setting of the particle factory, small particles (green and pink particles in the figure) are

distributed in the bottom layer, that is, the mixture enters the mixing chamber in the state of segregation. It can be seen from Figure 11 that the segregation of the mixture is gradually improved along the axial direction of the mixing chamber, that is, the extension of the mixing time is conducive to the improvement of the mixture uniformity. As shown in Fig.11 (a) and (b), the aggregate segregation is serious and almost runs through the whole mixing chamber. With the increase of rotation speed, the mixture uniformity is improved to some extent as shown in Fig.11 (c) . When n is 9r/min and 10r/min , as shown in Fig.11(d) and (e), there is almost no obvious segregation in the middle of the mixing chamber and after.

The average velocity of the particles in the mixing chamber at different speeds is shown in Fig.13. It can be seen from Fig.12 that after the material flow is stable, the higher the drum speed is, the greater the average movement speed of the mixture particles is.

FIGURE 12. Average particle velocity at different speed.

According to the analysis of Fig.11 and Fig.12, when the feed rate of the feed port is constant, the slow speed of the drum is not conducive to the movement of the mixture particles, resulting in a relatively large filling ratio of the mixture in the mixing drum, as shown in Fig.11 (a) and (b). The wrapping of the thick material layer limits the large-scale cross movement of the material particles, and the slow rotation speed of the roller itself reduces the intensity of the mixture movement, and the segregation is serious when the final rotation speed is slow. The distribution data of three kinds of aggregate at the outlet are extracted respectively, the relationship between the dispersion coefficient of aggregate and drum speed is shown in Fig.13.

FIGURE 13. The relationship between the dispersion coefficient of aggregate and drum speed.

As shown in Figure 13, the drum speed has a great influence on the mixing uniformity of the mixture. When the rotating speed of drum increases from 6r/min to 9r/min, the dispersion coefficients of three kinds of aggregate decrease, and the dispersion coefficients of aggregate 1 and aggregate 3 decrease obviously. Because aggregate 1 and aggregate 3 are relatively fine and coarse particles, and the number of particles is relatively small, it is easy to produce segregation. When the rotating speed of the drum is low, the distribution of particles is less disturbed. With the increase of the rotating speed of the drum, the aggregate throwing increases correspondingly, the large-scale cross movement among particles becomes more intense, and the renewal frequency of particle position increases. Because the number of particles in aggregate 2 is relatively large and the particle size is moderate, its particle distribution has strong anti-interference ability and small fluctuation range of dispersion coefficient. When the drum speed changes from 9r/min to 10r/min, the decrease range of the dispersion coefficient of aggregate 1 and aggregate 3 becomes smaller, and the dispersion coefficient of aggregate 2 increases slightly, that is to say, the influence of drum speed on the uniformity of aggregate is nonlinear. When the rotating speed of the drum reaches a certain value, the mixture distribution tends to be stable, and further increasing the rotating speed will not have a great positive effect on the improvement of mixing uniformity.

3.2 Influence of drum inclination on mixing uniformity

Let $\beta = 40^\circ$, $\alpha = 36^\circ$, $\varphi = 40^\circ$, $n = 8\text{r/min}$, γ is $2^\circ, 3^\circ, 4^\circ, 5^\circ, 6^\circ$, respectively. The relationship between the dispersion coefficient of aggregate and the inclination of drum is shown in Fig.14.

FIGURE 14. The relationship between the dispersion coefficient of aggregate and the angle of inclination of drum.

As shown in Figure 14, with the change of drum inclination, the dispersion coefficient of aggregate 1 and aggregate 2 fluctuates less, and the dispersion coefficient of aggregate 3 fluctuates relatively more, but it is also controlled within the range of 0.07, indicating that the change of drum inclination has less influence on the uniformity of mixture. Theoretically, increasing the inclination of the drum can prolong the retention time of the mixture in the mixing drum and increase the mixing times. However, as shown in Fig.15, the greater the inclination of the drum is, the greater the segregation of the mixture is. Collect the number of mixture particles in the middle area of the mixing drum. The relationship between the number of mixture particles and the inclination of the drum is shown in Fig.15.

FIGURE 15. The number of particles in the middle of the mixing drum with different inclination.

As shown in Figure 15, the greater the inclination of the drum, the more particles of the mixture retained in the

302 drum. Due to the constant feed rate of the feed port, the increase of the number of particles in the mixing drum indicates
303 that the axial movement speed is weakened and the retention time of the mixture is prolonged.

304 The feed rate of particle factory is reduced by 30%, and other parameters remain unchanged. The uniformity of
305 mixture is analyzed when the inclination of roller is 6° .

306 The dispersion coefficients of aggregate 1, 2 and 3 are 0.427, 0.184 and 0.683 respectively, which are lower than
307 before the feed rate is reduced. It shows that the filling ratio of the mixing chamber is high when the inclination angle
308 of the drum is 6° without the decrease of the feeding rate. It can be concluded that increasing the inclination of the
309 drum can prolong the mixing time of the mixture. However, the retained mixture is easy to cause a large filling ratio in
310 the mixing drum, which is not conducive to mixing.

311 The dispersion coefficient of the three aggregates at the drum inclination angle is 4° and the rotation speed is 9r/min
312 is smaller than that of the three aggregates at the drum inclination angle is 2° and the rotation speed is 8r/min. Therefore,
313 in order to solve the problem of the increase of the filling ratio of the mixing drum caused by the increase of the
314 inclination angle of the drum, the speed of the drum can be properly increased without reducing the productivity.

315 3.3 Influence of blade axial installation angle on mixing uniformity

316 Let $\alpha = 36^\circ$, $\varphi = 40^\circ$, $\gamma = 4^\circ$, $n = 8\text{r/min}$, $\beta = 31^\circ, 34^\circ, 37^\circ, 40^\circ, 43^\circ, 46^\circ$, respectively. The relationship between the
317 dispersion coefficient of aggregate and blade axial installation angle is shown in Fig.16.

318

319 **FIGURE 16.** The relationship between the dispersion coefficient of aggregate and blade axial installation angle

320 As shown in Figure 16, the axial installation angle of blade has great influence on the mixing uniformity. When the

axial installation angle of the blade increases from 34 °to 46 °, the dispersion coefficients of the three aggregates all increase. When the axial installation angle of blade decreases from 34 °to 31 °, the dispersion coefficients of aggregate 1 and aggregate 3 increase slightly. In general, when $\beta = 34^\circ$, the uniformity of the mixture is better.

The axial installation angle affects the intensity of axial and circumferential movement of the mixture, and then affects the mixing uniformity. In order to analyze the influence of blade axial installation angle on aggregate movement speed. The average velocities of all particles moving along the axial and circumferential directions at different axial installation angles were collected, as shown in Fig.17.

FIGURE 17. The average velocity of particles in axial and circumferential directions with different axial installation angles.

As shown in Fig.17, the axial installation angle of blade increases from 31 ° to 46 °, the average axial velocity of the particles increases first and then decreases, and the maximum value is obtained at $\beta = 40^\circ$. The average circumferential velocity of the particles in the mixture reaches the maximum value when $\beta = 34^\circ$, and decreases with the increase of the axial installation angle of the blades. In combination with figure16 and figure 17, when $\beta = 34^\circ$,

the circumferential movement of the mixture is sufficient, which is conducive to the mixing of aggregates; the axial movement speed of the mixture is slow, which is conducive to the extension of mixing time.

The feed rate of particle plant is reduced by 30%, and other parameters are unchanged. The uniformity of mixture is analyzed when $\beta = 31^\circ$. The dispersion coefficients of aggregate 1, 2 and 3 are 0.363, 0.145 and 0.626 respectively, which are lower than before the feed rate is reduced. It shows that the filling ratio of the mixing drum is high when $\beta = 31^\circ$ without the decrease of the feeding rate. As shown in Fig.17, compared with $\beta = 34^\circ$, when $\beta = 31^\circ$, the axial movement speed of the mixture is slower, and the filling ratio of the mixing drum is higher, which is not conducive to the cross movement between particles. The circumferential velocity of the mixture is decreased, and the particle throwing is weakened. Therefore, the axial installation angle should take into account the axial and circumferential movement of the mixture.

3.4 Influence of phase angle of mixing arm on mixing uniformity

Let $\beta = 40^\circ$, $\alpha = 36^\circ$, $\gamma = 4^\circ$, $n = 8\text{r/min}$, φ is 20° , 30° , 40° , 50° and 60° , respectively. The relationship between the dispersion coefficient of aggregate and phase angle of mixing arm is shown in Fig.18. (The relationship between C_v and φ as shown in Fig.18)

FIGURE 18. The relationship between the dispersion coefficient of aggregate and phase angle of mixing arm (The relationship between C_v and φ).

As shown in Fig.18, the dispersion coefficient of aggregate 1 changes little, and the dispersion coefficients of aggregate 2 and aggregate 3 vary greatly. When the phase angle of the mixing arm is 30° , the dispersion coefficients of

355 aggregate 2 and aggregate 3 are the minimum;When the phase angle of mixing arm increases from 30°to 60°, the
 356 dispersion coefficient of aggregate 2 and aggregate 3 increases gradually, and the dispersion coefficient of aggregate 3
 357 increases exponentially. It shows that the phase angle of the mixing arm has a significant impact on the uniformity of
 358 large particles in the mixture, and the large phase angle is unfavorable to the mixing of coarse aggregate.The mixing
 359 effect diagram of different mixing arm phase angle is shown in Figure 19.

362 **FIGURE 19. The mixing effect diagram of different mixing arm phase angle.**

363 As shown in Fig.19, the phase angle of the mixing arm increases, and the feeding cycle of the mixing equipment also
 364 increases. The increase of picking period will increase the rolling stroke of mixture, and the segregation of large
 365 particle will be intensified. Therefore, the phase angle of the mixing arm has a great influence on the uniformity of
 366 large particles. As shown in Fig. 19 (a), the phase angle of the mixing arm is too small, and the distance between
 367 adjacent blades is small. The mixing process is similar to the spiral conveying process, and the spraying of the mixture
 368 is low, which is not conducive to the mixing of the mixture.

369 Collect the number of particles in the middle section of the mixing drum,the relationship between the number of
 370 particles retained in the mixing drum and the phase angle of the mixing arm is shown in Fig.20.

FIGURE 20. The relationship between the number of particles retained in the mixing drum and the phase angle of the mixing arm.

As shown in Fig.20, the larger the phase angle between the mixing arms is, the more the particles in the mixing drum are. It shows that with the increase of the phase angle, the velocity of the mixture slows down gradually. The increase of phase angle is easy to delay the mixing of the mixture, and increase the filling ratio of the mixing chamber.

The feed rate of particle plant is reduced by 30%, and other parameters are unchanged. The uniformity of mixture is analyzed when the phase angle of the mixing arm is 60° . The dispersion coefficients of aggregate 1, 2 and 3 are 0.451, 0.316 and 1.038, respectively, which are lower than before the feed rate is reduced. It shows that when the feed rate is constant and the phase angle of the mixing arm is 60° , the filling ratio of the mixing drum is on the high side. As shown in Fig.18 and Fig.20, when the phase angle of the mixing arm is 60° , the high filling ratio of the mixing drum is also the reason for the poor mixing uniformity of the mixture.

3.5 Influence of blade radial installation angle on mixing uniformity

Let $\beta = 40^\circ$, $\varphi = 40^\circ$, $\gamma = 4^\circ$, $n = 8\pi/\text{min}$, α is $32^\circ, 34^\circ, 36^\circ, 38^\circ$ and 40° respectively. The relationship between the dispersion coefficient of aggregate and blade radial installation angle is shown in Fig.21(The relationship between C_v and α as shown in Fig.21).

FIGURE 21. The relationship between the dispersion coefficient of aggregate and blade radial installation angle(The relationship between C_v and α).

As shown in Figure 21, the dispersion coefficient of aggregate 1 and aggregate 2 has little change. The dispersion coefficient of aggregate 3 is relatively large influenced by the radial installation angle of blade, but its fluctuation range is also less than 0.11. It shows that the radial installation angle of blade has little influence on the uniformity of mixture.

The radial installation angle of the blade can make the mixture separate from the inner wall of the outer cylinder, shorten the rolling distance and reduce the segregation of the coarse particles in the rolling process. Therefore, as

shown in Figure 21, the uniformity of aggregate 3 is greatly affected by the radial installation angle of blade. When the radial installation angle of blade is 36° and other parameters remain unchanged, the uniformity of aggregate is compared when the phase angle of mixing arm is 60° and 40° . The results show that the dispersion coefficients of aggregate 1, 2 and 3 are 0.464, 0.363 and 1.298 respectively when the phase angle is 60° , which are higher than that when the phase angle is 40° .

As shown in Figure 22, the cross section of the mixing drum when the phase angle of the mixing arm is 40° . After the mixture is thrown away from the previous blade and then lifted by the next blade, the distance of particles rolling down the inner wall of the outer cylinder is shortened. It can be concluded that the setting of phase angle in the simulation test of this section has the function of reducing the rolling segregation. Therefore, the dispersion coefficient of aggregate 3 has no obvious trend with the change of blade radial installation angle.

FIGURE 22. Sectional drawing of mixing drum.

In addition, the radial installation angle of the blade will also affect the movement speed of the mixture particles. In order to study the influence of blade radial installation angle on the mixture moving speed, collect the average speed of all particles, and get the average moving speed of particles under different radial installation angles as shown in Fig.23.

FIGURE 23. Change of particle average velocity with time under different radial installation angles.

As shown in Fig.24, the average velocity of particles has little change, that is, the radial installation angle of blade has little influence on the velocity of mixture. According to Fig. 21 and Fig. 23, when the radial installation angle of blade is 36°, the average velocity of particles in the mixture is relatively large, and the homogeneity of the mixture is relatively well. When the radial installation angle of blade is 40°, the average velocity of particles is slow, which is not conducive to the mixing of mixture.

4. Response surface methodology (RSM) analysis

The influence of each single factor on the mixing uniformity of the mixture was studied, in order to analyze the interaction between various factors and solve the best parameters match, the response surface method is used for further research.

4.1 Simulation scheme design

Referring to the design of the structural parameters and motion parameters of the double drum mixing equipment in the previous paper, the value ranges of five factors are set as follows: the axial installation angle of the blade (A), the radial installation angle of the blade (B), the phase angle of the mixing arm (C), the inclination angle of the drum (D) and the rotation speed of the drum (E), are respectively set as follows:

$$34^{\circ} \leq A \leq 46^{\circ}, 32^{\circ} \leq B \leq 40^{\circ}, 20^{\circ} \leq C \leq 60^{\circ}, 2^{\circ} \leq D \leq 6^{\circ}, \text{ and } 6r/\min \leq E \leq 10r/\min.$$

Taking A, B, C, D, E as the influencing factors and the discrete coefficient of aggregate as the response value, according to the design method of response surface experiment, the simulation scheme of five factors and three levels

427 is designed.As shown in table 3.

428

TABLE 3. Influencing factors and level value.

Influencing factors	level value		
	-1	0	1
axial installation angle (A) /°	34	40	46
radial installation angle (B) /°	32	36	40
phase angle of the mixing arm (C) /°	20	40	60
inclination angle of the drum (D) /°	2	4	6
rotation speed of the drum (E) /r·min ⁻¹	6	8	10

429 4.2 Simulation results and analysis

430 According to the range of influence factors in Table 3,the simulation scheme and results obtained by Box Behnken
431 design test method as shown in Table 4:

432

TABLE 4. Simulation scheme and results.

	simulation scheme					discrete coefficient		
	phase					agggreg	agggreg	agggreg
num	axial installatio n angle (A) /°	radial installatio n angle (B) /°	angle of the mixing arm (C) /°	inclinatio n angle of the drum (D) /°	rotation speed of the drum (E) /rpm	ate 1 (C _{v1}))	ate 2 (C _{v2}))	ate 3 (C _{v3}))
1	46	36	40	4	10	0.428	0.188	0.610
2	40	36	40	4	8	0.451	0.232	0.708
3	40	40	40	2	8	0.455	0.234	0.688
4	46	36	60	4	8	0.533	0.386	1.361
5	40	36	60	4	10	0.474	0.290	0.819
6	46	36	40	4	6	0.573	0.226	0.843
7	40	36	60	2	8	0.424	0.272	0.899
8	34	36	40	6	8	0.397	0.188	0.609
9	40	40	60	4	8	0.528	0.445	1.248

10	40	36	40	4	8	0.451	0.232	0.708
11	40	36	60	4	6	0.576	0.401	1.726
12	40	40	40	4	10	0.358	0.157	0.657
13	40	36	40	4	8	0.451	0.232	0.708
14	46	36	40	2	8	0.489	0.222	0.754
15	40	32	40	2	8	0.448	0.196	0.663
16	34	32	40	4	8	0.396	0.188	0.612
17	40	36	40	4	8	0.451	0.232	0.708
18	34	36	40	2	8	0.399	0.192	0.670
19	40	32	20	4	8	0.578	0.367	0.815
20	40	36	40	4	8	0.451	0.232	0.708
21	40	36	40	4	8	0.451	0.232	0.708
22	40	36	40	2	10	0.418	0.178	0.591
23	46	32	40	4	8	0.509	0.240	0.765
24	40	36	20	4	10	0.476	0.287	0.716
25	40	36	20	6	8	0.447	0.255	0.622
26	40	36	40	6	6	0.496	0.239	0.841
27	40	32	40	4	10	0.421	0.182	0.642
28	40	36	40	6	10	0.366	0.185	0.567
29	46	36	20	4	8	0.539	0.299	0.718
30	34	36	40	4	10	0.365	0.160	0.522
31	34	36	60	4	8	0.430	0.325	1.034
32	40	40	40	4	6	0.495	0.237	0.877
33	40	32	40	6	8	0.456	0.243	0.681
34	46	40	40	4	8	0.516	0.256	0.892
35	40	40	20	4	8	0.563	0.346	0.719
36	34	40	40	4	8	0.387	0.187	0.624
37	34	36	40	4	6	0.461	0.230	0.826
38	34	36	20	4	8	0.543	0.365	0.652
39	40	40	40	6	8	0.466	0.249	0.789
40	40	36	20	2	8	0.609	0.378	0.753

41	40	36	20	4	6	0.664	0.403	0.911
42	40	36	40	2	6	0.521	0.220	0.797
43	40	36	60	6	8	0.524	0.460	1.530
44	40	32	60	4	8	0.449	0.318	0.944
45	40	32	40	4	6	0.506	0.212	0.831
46	46	36	40	6	8	0.542	0.275	0.894

433 The simulation results are analyzed by response surface method, the mathematical model between the discrete
434 coefficient and each factor of aggregate 1 is shown in eq.(7). The mathematical model between the discrete
435 coefficient and each factor of aggregate 2 is shown in eq.(8). The mathematical model between the discrete
436 coefficient and each factor of aggregate 3 is shown in eq. (9). Table 5, table 6 and table 7 are the variance analysis
437 tables of each model.

438
$$Cv1 = 0.21769 + 0.00583A - 0.00579B - 0.00738C - 0.07563D + 0.10353E +$$

$$0.00017AB + 0.00001AC + 0.00114AD - 0.00102AE + 0.00297BC +$$
 (7)

$$0.00009BD - 0.00163BE + 0.00102CD - 0.00071CE - 0.00161DE$$

439
$$Cv2 = 1.16815 + 0.00052A - 0.00475B - 0.06012C - 0.0647D + 0.10344E +$$

$$0.00018AB + 0.00026AC + 0.0012AD + 0.00066AE + 0.00046BC -$$
 (8)

$$0.001BD - 0.00156BE + 0.00195CD + 0.00004CE - 0.00075DE$$

440
$$Cv3 = 6.2745 - 0.07282A - 0.10148B - 0.08952C - 0.38336D - 0.02615E +$$

$$0.00120AB + 0.00054AC + 0.00417AD + 0.00148AE + 0.00125BC +$$
 (9)

$$0.00264BD - 0.00094BE + 0.00477CD - 0.00445CE - 0.00422DE$$

441 TABLE 5. Aggregate 1 variance analysis.

Source of variance	Sum of squares	degree of freedom	Root mean square	F value	P value	Saliency
Model	0.19	20	0.00944	16.06	< 0.0001	significan
			1			t.
A	0.035	1	0.035	59.41	< 0.0001	
B	5.013E-07	1	5.013E-07	0.0008526	0.9769	

C	0.014	1	0.014	24.58	< 0.0001
D	0.000307	1	0.000307	0.52	0.4767
E	0.061	1	0.061	103.35	< 0.0001
AB	0.00006468	1	0.00006468	0.11	0.7429
AC	0.002842	1	0.002842	4.83	0.0374
AD	0.0007506	1	0.0007506	1.28	0.2693
AE	0.0005979	1	0.0005979	1.02	0.3229
BC	0.002252	1	0.002252	3.83	0.0616
BD	0.000001941	1	0.000001941	0.003301	0.9546
BE	0.000684	1	0.000684	1.16	0.2911
CD	0.017	1	0.017	29.29	< 0.0001
CE	0.00188	1	0.00188	3.2	0.0859
DE	0.0001651	1	0.0001651	0.28	0.6008

TABLE 6. Model analysis of variance table for aggregate 2.

Source of Variance	quadratic sum	degree of freedom	root-mean-square	F value	P value	Significance
Model	0.26	20	0.013	28.92	< 0.0001	significant.
A	0.004086	1	0.004086	9.19	0.0056	
B	0.00168	1	0.00168	3.78	0.0633	
C	0.002431	1	0.002431	5.47	0.0277	
D	0.002544	1	0.002544	5.72	0.0246	

E	0.018	1	0.018	41.01	< 0.0001
AB	0.00007152	1	0.000071 52	0.16	0.6918
AC	0.003979	1	0.003979	8.95	0.0062
AD	0.000824	1	0.000824	1.85	0.1856
AE	0.0002495	1	0.000249 5	0.56	0.4609
BC	0.005391	1	0.005391	12.12	0.0018
BD	0.0002611	1	0.000261 1	0.59	0.4508
BE	0.0006193	1	0.000619 3	1.39	0.2491
CD	0.024	1	0.024	54.77	< 0.0001
CE	0.000008702	1	0.000008 702	0.02	0.8899
DE	0.00003555	1	0.000035 55	0.08	0.7797

TABLE 7. Model analysis of variance table for aggregate 3.

Source of Variance	quadratic sum	degree of freedom	root mean square	F Value	P Value	Significa nce
Model	2.4	20	0.12	16.19	< 0.0001	significan t.
A	0.1	1	0.1	14.01	0.001	
B	0.018	1	0.018	2.47	0.1287	
C	0.83	1	0.83	112.64	< 0.0001	
D	0.032	1	0.032	4.34	0.0475	
E	0.4	1	0.4	53.92	< 0.0001	
AB	0.003326	1	0.00332 6	0.45	0.509	
AC	0.017	1	0.017	2.29	0.1429	
AD	0.01	1	0.01	1.35	0.2563	

			0.00125		
AE	0.001254	1	4	0.17	0.6843
BC	0.04	1	0.04	5.41	0.0284
BD	0.001782	1	2	0.24	0.6282
BE	0.0002274	1	74	0.031	0.8624
CD	0.15	1	0.15	19.65	0.0002
CE	0.13	1	0.13	17.13	0.0003
DE	0.001141	1	1	0.15	0.6981

444 According to table 5, table 6 ,and table 7, the P value of the fitting model is less than 0.0001, indicating that the
445 fitting effect is very significant. In response surface analysis, when P value is less than 0.05, it indicates that the
446 influence degree of this factor is more significant.The significance order of the influence of single factor on the
447 dispersion coefficient of aggregate 1 is as follows: $E > A > C > D > B$, Among them, factor A, factor C, and factor E
448 have significant influence. The significant order of the influence of each interaction factor on the dispersion coefficient
449 of aggregate 1 is as follows:

450 $CD > AC > BC > CE > AD > BE > AE > DE > AB > BD$. Among them, factors AC,and factors CD have
451 significant influence.The significance order of the influence of single factor on the dispersion coefficient of aggregate 2
452 is as follows: $E > A > D > C > B$. Among them, factor A, factor C, factor D and factor E have significant
453 influence.The significant order of the influence of each interaction factor on the dispersion coefficient of aggregate 2 is
454 as follows:

455 $CD > BC > AC > AD > BE > BD > AE > AB > DE > CE$.Among them, factors AC, factors BC and factors CD have
456 significant influence.The significance order of the influence of single factor on the dispersion coefficient of aggregate 3
457 is as follows: $C > E > A > D > B$, Among them, factor A, factor C, factor D and factor E have significant
458 influence.The significant order of the influence of each interaction factor on the dispersion coefficient of aggregate 3 is
459 as follows:

460 $CD > CE > BC > AC > AD > AB > BD > AE > DE > BE$.Among them, factors BC, factors CD, and factors CE
461 have significant influence.

4.3 Fitting model test

In order to test the rationality of the fitting model, the randomness and normality of the residual are analyzed. The relationship between residual and predicted value of aggregate fitting model is shown in Fig.24. The student residual is randomly distributed on both sides of the predicted value, it shows that there is no correlation between residual and predicted value, that is, residual is caused by random error. The residual normal probability distribution of aggregate fitting model is shown in Fig.25. The residuals of students are basically distributed on the straight line of normal distribution, that is, the residuals are subject to normal distribution. Therefore, the fitting model is reasonable, and the effect of various factors can be predicted by response surface method.

FIGURE 24. Relationship between student residual and predicted value.

(c)

FIGURE 25. Normal probability distribution of student residuals.

4.4 Interaction factor analysis

Among the interaction factors, the interactions of drum angle and phase angle of mixing arm, blade axial installation angle and phase angle of mixing arm have significant effect on the dispersion coefficient of aggregate 1. The response surface relationship between dispersion coefficient and significant interaction factor of aggregate 1 is shown in Fig. 26.

(a)

(b)

FIGURE 26. The response surface relationship between dispersion coefficient and significant interaction factor of aggregate 1.

As shown in Figure 26 (a), when the phase angle of the mixing arm is 20° , the dispersion coefficient of aggregate 1 decreases with the increase of the inclination of the drum; When the phase angle of the mixing arm is 60° , the dispersion coefficient of aggregate 1 increases with the increase of the inclination of the drum. As shown in Figure 27 (b), if the phase angle of the mixing arm is any value, the dispersion coefficient of aggregate 1 will decrease with the decrease of the axial installation angle. Among them, when the phase angle of the mixing arm is 60° , its dispersion

499 coefficient decreases faster.

500 Among the interaction factors, the interactions of Phase angle of mixing arm and axial installation angle of blade,
501 blade radial installation angle and mixing arm phase angle, drum inclination angle and phase angle of mixing arm have
502 significant effect on the dispersion coefficient of aggregate 2. The response surface relationship between dispersion
503 coefficient and significant interaction factor of aggregate 2 is shown in Fig. 27.

a)

b)

FIGURE 27. The response surface relationship between dispersion coefficient and significant interaction factor of aggregate 2.

As shown in Figure 28, the interaction between the phase angle of mixing arm and the installation angle of blade (axial and radial) has a similar effect on the uniformity of aggregate 2. When the phase angle of the mixing arm is constant, the change of the axial and radial installation angle of the blade has little influence on the dispersion coefficient of aggregate 2, among them, when the phase angle of the mixing arm is 60°, the effect is relatively obvious. When the phase angle of the mixing arm changes, the inclination of the drum has a great influence on the uniformity of aggregate 2. When the phase angle is 20°, the dispersion coefficient of aggregate 2 decreases with the increase of the inclination of the drum. When the phase angle is 60°, the dispersion coefficient of aggregate 2 increases with the increase of the inclination of the drum.

Among the interaction factors, the interactions of blade radial installation angle and phase angle of mixing arm, drum inclination angle and Phase angle of mixing arm, drum rotation speed and phase angle of mixing arm have significant effect on the dispersion coefficient of aggregate 3. The response surface relationship between dispersion coefficient and significant interaction factor of aggregate 3 is shown in Fig. 28.

a)

b)

FIGURE 28. The response surface relationship between dispersion coefficient and significant interaction factor of aggregate 3.

As shown in Fig.28, When the phase angle of the mixing arm is 20° , blade radial installation angle, drum inclination angle, and drum rotation speed have little influence on the dispersion coefficient of aggregate 3; When the phase angle of mixing arm is 60° , the dispersion coefficient of aggregate 3 increases with the increase of blade radial installation angle, decreases with the decrease of drum inclination angle, and increases with the decrease of drum rotation speed. Therefore, When the phase angle of the mixing arm is large, drum rotation speed, drum inclination angle and blade radial installation angle have obvious influence on the uniformity of aggregate 3. Therefore, when the phase angle of the mixing arm is large, the speed of the drum, the inclination of the drum and the radial installation angle of the blades have obvious influence on the uniformity of aggregate 3. As shown in Fig.28 (c), when the drum speed is 10 r/min, the dispersion coefficient of aggregate 3 decreases first and then increases with the increase of the phase angle of the mixing arm, and the change range is small. When the rotating speed of the drum is 6 r/min, the dispersion coefficient of aggregate 3 increases greatly with the increases of the phase angle of the mixing arm. The results show that when the phase angle of the mixing arm is large and the rotating speed of the drum is reduced, the segregation of aggregate 3 is easy to increase.

As shown in Fig.26 (a), Fig.27 (c), and Fig.28 (b), the interaction between the angle of drum and the phase angle of mixing arm has a significant effect on the dispersion coefficient of the three kinds of aggregate. In order to improve the mixing uniformity, the phase angle when the inclination of the drum is large should be smaller than that when the

inclination of the drum is small. When the inclination of the drum is constant, the phase angle corresponding to the low point of the response surface of the discrete coefficient of aggregate decreases in turn, that is, a smaller phase angle should be arranged for the mixing of large particles.

4.5 Response surface optimization results

Taking the minimum value of discrete coefficient as the optimization objective, the values of each parameter are obtained as follows:

The blade axial installation angle is 34.896° , the blade radial installation angle is 38.389° , the phase angle of the mixing arm is 31.676° , the drum inclination angle is 5.999° , and the drum rotational speed is 9.997r/min . After rounding, the blade axial installation angle is 35° , the blade radial installation angle is 38° , the phase angle of the mixing arm is 32° , the drum inclination angle is 6° , and the drum rotational speed is 10r/min .

5. Conclusions

(1) Increasing the rotation speed and reducing the axial installation angle of the blade can reduce the dispersion coefficient of the aggregate. When the feed rate is unchanged, only increasing the phase angle will cause the filling rate of the stirring chamber to increase and the stirring uniformity to decrease. Therefore, in order to obtain better stirring uniformity, the phase angle when the drum inclination angle is larger should be smaller than the phase angle when the drum inclination angle is small, and it is not appropriate to use a larger phase angle for the stirring of large-size particles.

(2) Through the response surface method, the significant relationship between the influence of each single factor and its interaction on the discrete coefficients of the three aggregates is obtained.

The significant factors affecting the dispersion coefficient of aggregate 1 and the significant relationship are: $n > \beta > \varphi$, In the interaction term, φ and γ , φ and β have significant influence. The significant factors and the significant relationship of the dispersion coefficient of aggregate 2 are: $n > \beta > \gamma > \varphi$, and among the interaction terms, φ and γ , φ and α , φ and β have significant influences; The significant factors and the significant relationship of the dispersion coefficient of aggregate 3 are: $\varphi > n > \beta > \gamma$, and among the interaction terms, φ and γ , φ and n , and φ and α have significant effects.

Taking the lowest dispersion coefficient as the goal, the best parameter matching is: $\alpha=38^\circ$, $\beta=35^\circ$, $\gamma=6^\circ$,

n=10r / min , $\varphi=32^{\circ}$.

Declarations:

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

Competing interests

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled “Simulation analysis of the significance and interaction of influencing factors on mixing uniformity of double drum recycling mixing plant ”.

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Authors' contributions

The overarching research goals were developed by MA Deng-cheng ,CHEN Chao and LIU Chenqi. MA Deng-cheng provided the concept and wrote the first draft of the manuscript. CHEN Chao established the models and LIU Chenqi performed simulation analysis. MA Deng-cheng analyzed the calculated results. All authors replied to reviewers’ comments and revised the final version.

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