Simulation model for the collision of the individual components of dry mixes with the inner surface housing during their preparation in high-speed twin-rotor turbulent mixer

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Abstract. To mix the components of dry construction mixtures, various mixer designs are used. Forced mixers are considered the most effective. The mixing of the components in the working space of the forced action mixers is carried out due to the repeated action of the working body on them. In the process of multiple interaction of the working body and the particles of the mixture, they are repeatedly moved in the working space of the mixer. The nature of the movement of the particles of the mixture in the working space is chaotic in nature, which makes it impossible to determine the necessary time for preparing a homogeneous mixture. To ensure high uniformity of the prepared mixtures, it is proposed to use the design of a new mixer with a cascade principle of mixing the components of the mixture. To determine the trajectories of the mixture components in the working space of the mixer of a new design, it is proposed to use the results of the presented analytical studies.

1. Introduction

As it was already revealed earlier [1-4], a two-rotor turbulent mixer, operating in cascade mode and referred to the machines of a new generation [6-8], can be successfully used for the preparation of dry mixes. Such a mixer is shown in figure 1.

Technical characteristics of the mixer with two rotors are shown in table 1.

Table 1. Technical characteristics of the mixer with two rotors.

| Characteristic                              | Value          |
|--------------------------------------------|----------------|
| Productivity, m³ / h                       | 0.4            |
| Rotor speed, min⁻¹                         | 200…300        |
| The angle of installation of the blades on the rotors, hail | 60            |
| Motor power, kW                            | 0.9            |
| Dimensions, mm: length, width, height     | 755, 552, 710  |
2. Theoretical part

According to the technical characteristics of the machine, the working process of preparing building mixtures is carried out at high speeds of the working body rotation.

This is fraught with the fact that the filler fraction of 3 ... 5 mm in the process of mixing components when meeting with the machine body or when rebounding from the blades of rapidly rotating rotors can be destroyed. This phenomenon contributes to the presence, in this case, of freshly formed surfaces, which will activate the process of interaction subsequently with the mortar component. Thus, the activation that takes place in the process of preparing dry building mixes is a positive aspect of the operating conditions of the new mixer.

To build the model, the following conditions are accepted:
- particles of the mixture have the shape of a ball;
- the impact of particles is considered as a solid ones on the surface;
- particles on impact do not change the shape of the ball;
- there is no rotational movement of particles.

The test is based on the criterion of destruction, which makes it possible to assume that a spherical particle splits into two equal parts when it encounters a surface [9-12]. Cleavage occurs if the kinetic energy of the moving part exceeds the surface energy of the two newly formed surfaces [13-15]:

$$2\pi(1-S_0)R^2\sigma \leq \frac{4}{6} \pi \rho R^3 V_r,$$

(1)

where $S_0$ - the proportion of the cross-sectional area of the particle resulting from splitting;

$R$ - particle radius (scope); $\rho$ - aggregate particle density; $\sigma$ - surface tension; $V_r$ - particle velocity before impact with the surface (body or blade).

If the fracture plane is not diametrical during destruction figure 2, then its position relative to the center of gravity is characterized by the distance $h$.

Figure 1. Double rotor mixer: a - schematic diagram; b - general form.

Figure 2. Design diagram of the split aggregate particle $m_1$, $m_2$ - masses of a split particle.
If, according to figure 2, the area of the formed crack in a particle before splitting equals, then the value is defined as

\[ S_0 = \frac{S}{\pi(R^2 - h^2)}. \]

In this case, the condition for the development of a crack is:

\[ 2\pi(R^2 - h^2)(1 - S_0)\sigma \leq \frac{4}{6} \pi \rho R^3 \nu, \]

(2)

For further research, the ratio of the broken parts of the particle is taken as \( \kappa = \frac{m_2}{m_1} \), and the ratio of sizes \( h \) and \( R \) is as \( q = \frac{h}{R} \). In this case, \( k(q) = \frac{(1 - q^2)(2 + q)}{4 - (1 - q)^3(2 + q)} \).

In graphical form, this dependence is shown in figure 3.

![Figure 3](image)

**Figure 3.** Graphical version of dependency.

Figure 4 shows the design of the process of collision of a particle with a surface.

![Figure 4](image)

**Figure 4.** Calculation schemes for the collision of a filler particle with a fixed surface: a - normal to the surface, b - tangent to the surface.

The point of contact of a particle with a surface is point E. At the same time, according to the coordinates along the normal, this contact is represented as En (figure 4, a) and tangentially to this surface Et (figure 4, b).

To consider the interaction of a particle with a surface, the following notation is introduced: \( \alpha_0 \) - is the angle of incidence of the particle; \( \gamma \) is the angle between the normal to the plane of the split and the axis \( E_n \); \( m_1, m_2 \) are the masses of the divided particle; \( \beta_1, \beta_2 \) are the reflection angles of the divided masses; \( V_1, V_2 \) are the velocities of the split masses, respectively, after the impact with the surface; \( S_n, S_t \) are the projections of the shock pulse acting on the particle in the process of splitting; \( S'_{\gamma}, S''_{\gamma} \) are the components of the shock pulse acting on the split parts of their separation.
All the above parameters determine the behavior of the particle after its splitting.
To clarify the behavior of the newly formed two particles after splitting, one should use the pulse theorem:

\[ m_1\vec{V}_1 - m_1\vec{V}_R = S + S_{\gamma(1)} , \]
\[ m_2\vec{V}_2 - m_2\vec{V}_R = S + S_{\gamma(2)} . \]

As a result of projecting onto the \( E_n \) and \( E_z \) axes, the following equations were obtained:

\[ m_1V_1 \cos \beta_1 + m_1\nu_R \cos \alpha_0 = S_n - S', \gamma \cos \gamma - S''_\gamma \sin \gamma , \]
\[ m_1V_1 \sin \beta_1 + m_1\nu_R \sin \alpha_0 = S_z - S', \gamma \sin \gamma - S''_\gamma \cos \gamma , \]
\[ m_2V_2 \cos \beta_2 + m_2\nu_R \cos \alpha_0 = S'_\gamma \cos \gamma + S''_\gamma \sin \gamma , \]
\[ m_2V_2 \sin \beta_2 - m_2\nu_R \sin \alpha_0 = S'_\gamma \sin \gamma - S''_\gamma \cos \gamma . \]

According to Newton's theory of impact \( V_1 \cos \beta_1 = \varepsilon \nu_R \cos \alpha \) with entered recovery factor \( \varepsilon \).

The ratio between \( S_n \) and \( S_z \) is determined by the dynamic coefficient of friction, which is assumed to be equal to the static coefficient of friction \( f_0 \): \( S_n = f_0 S_z \) [16, 17]. The angle of the shock pulse \( \vec{S}_\gamma \) to the split plane is determined by the coefficient \( f_1 \) similar to friction coefficient: \( S''_\gamma = fS' \gamma \).

Due to the fact that the blow is not absolutely elastic \( (\varepsilon(1)) \) kinetic energy is lost as a result of particle collisions with the surface:

\[ E_{1e} + E_{2e} = \kappa_0 E_0 . \]

where \( E_{1e} \), \( E_{2e} \) - kinetic energies of the newly formed particles after the impact and split of the original; \( E_0 \) - kinetic energy of a particle before impact ; \( \kappa_0 \) - loss factor.

Then equation (9) can be represented as follows:

\[ \kappa_0 (m_1 + m_2)\nu_R^2 = m_1V_1^2 + m_2V_2^2 , \]

The equations obtained above are reduced to a dimensionless form.

To clarify the behavior of the newly formed two particles after splitting, the following dependencies are introduced:

\[ V_{1n} = V_1 \cos \beta_1 ; \ V_{1r} = V_1 \sin \beta_1 , \ V_{2n} = V_2 \cos \beta_2 , \ V_{2r} = V_2 \sin \beta_2 . \]

Post speed \( V_1 \) and \( V_2 \) can be represented by their relation to the pre-impact speed, when the splitting of a particle has not yet occurred: \( \vec{V}_1 = \vec{V}_R / \nu_R \); \( \vec{V}_2 = \vec{V}_R / \nu_R \), and shock pulses \( S_n \), \( S_z \), \( S_\gamma \) are relation to size \( m_1 \) and \( \nu_R \): \( \vec{S}_n = S_n / m_\nu_R ; \vec{S}_z = S_z / m_\nu_R ; \vec{S}_\gamma = S_\gamma / m_\nu_R . \)

Ultimately, after the transformations carried out, the system of dimensionless equations is as follows:

\[ \vec{V}_{1n} + \cos \alpha_0 = \vec{S}_n - S'_\gamma C_1 , \]
\[ \vec{V}_{1r} - \sin \alpha_0 = -f_0 S_n + S'_\gamma C_2 , \]
\[ \tilde{V}_{2n} + \cos \alpha_0 = \frac{1}{k} \tilde{S}/C_1, \]  
(13)

\[ \tilde{V}_{2\tau} - \sin \alpha_0 = -\frac{1}{k} \tilde{S}/C_1, \]  
(14)

\[ \tilde{V}_{1n} = \varepsilon_0 \cos \alpha_0, \]  
(15)

\[ k_0 (1 + k) = \tilde{V}_{1n}^2 + \tilde{V}_{1\tau}^2 (\tilde{V}_{2n}^2 + \tilde{V}_{2\tau}^2) k. \]  
(16)

The following notation is used in the system of equations presented: \( k = k_{(q)}; \)
\[ C_1 = \cos \gamma + f_1 \sin \gamma; \]  
\[ C_2 = f \cos \gamma - \sin \gamma. \]

The system of equations is solved using the appropriate program (Mathcad).

Influence parameters \( k, f, \gamma, k_0 \) at dimensionless speeds \( \tilde{V}_1 \) and \( \tilde{V}_2 \) shown in the graphical dependencies (figure 5, 6, 7, 8).

These graphical dependences make it possible to determine the magnitudes of the post-impact speeds of the ruptured parts of the aggregate in the prepared dry construction mixtures with various combinations of the effect of the technological parameters under study.

**Figure 5.** Dependence of post-impact speeds on the ratio particle masses \( k \).

**Figure 6.** The dependence of post-impact speeds on the angle of inclination rupture planes \( \gamma \).

**Figure 7.** Dependence of post-impact speeds from coefficient \( k_0 \).
Figure 8. Dependence of post-impact speeds on the mass ratio of particles $f_1$ at various $k$: a - particle size 0.5 mm, b - particle size 1 mm.

Thus, using numerical data of graphical dependencies, when preparing dry building mixtures in two-rotor turbulent mixers, their activation can take place simultaneously with the mixing of the mixture components.

3. Conclusions

1. A simulation model of the collision process of a dry building mixture aggregate particle with the inner surface of the mixer housing (blade) has been built, which leads to its splitting into two parts.

2. Dependencies for determining the post-impact velocities of the split parts of the aggregate particle are found.

3. Graphic dependences of the post-impact speeds of movement of the split particles in the mixture on the technological parameters of the working process were constructed, which make it possible to predict the conditions for the appearance of activation of building mixtures when they are prepared in two-rotor turbulent mixers.

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