Modeling of a Stressstate of a Material of a Variable Working Chamber of the Mixer Depending on the Technological Eccentricity

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Abstract: Production of new and basic recipes of modified construction mixes entails creation of modern equipment, where the main process of the technological one is mixing. A number of rheological components is in quantity from 0.05 to 0.5%, while the powders from source components differ on the size of particles (from fractions of a micron to 5 mm) and density (from 0.1 g/cm³ up to 4.0 g/cm³). In order to produce qualitative multicomponent mixtures with specified characteristics can be implemented by designing of mixers using the mechanism of deformation of thin-walled elements, which organize motion control of components of the mixture and relevant to them, running processes of mixing materials. Installed, identified and analyzed the theoretical expression of the inertia load, inner strength, functional parameters and their extremes, which occur in arbitrary sections of a variable working chamber as a result of its deformation depending on the size of the technological eccentricity.

Key words: Adhesion • Agglomerating • segregation • Modified • Rheological additives • Dispersed phase • Thixotropic properties • Vertical mixing device • Deformation of thin-walled elements • Stress state of a material • Trunnion • Technological eccentricity • Affine • Oblique • A polar coordinate system • Inertial load • Inner power • Tangential stress • Shifting efforts • Function parameters.

INTRODUCTION

Mixing of granular materials is widely used in various branches of chemical technology, power industry, agro-industrial, construction and many others. The task of preparation of uniform composition of mixtures is used in preparing the granular mixtures inclined to connected with a number of difficulties, such as wide range of changing of physic-mechanical properties of the processed material, the requirements to the quality and composition of product, capacity, power and metal consumption, etc.

The use of means and methods of intensive mixing allows to reconsider seriously the basic formulations modified mixes and technology of their manufacturing, while intensify of a degree of influence of the modifying additives on physical-mechanical and technological parameters of prepared mixes leads to significant reduction of expensive components [1].

The tasks of increasing the efficiency of the systems used in preparing the granular mixtures inclined to adhesion and agglomerating, segregation on the physic-mechanical properties of particles (size, density and other), which differ in significant ratio of volumes of components (1:10 and above) determine the need for continuous improvement of known types of mixing equipment and creation of new ones. Most often in the production of construction materials gravity, centrifugal, drum, vibrating, worm-lobed and other mixers are used.
Their design is generally based on the characteristics of production, characteristics of mixed materials, the productivity of the required quality ready-mix and economic capabilities of the enterprise.

Today the receipt of several types of materials for construction purposes is not possible without the use of the mixing equipment, capable to provide the necessary level of homogeneity of the mixture. In dry mixes for regulation of their technological properties adopt «rheological» additives, a number of the components is introduced in small quantities (0.05-0.5%), however, their influence on the formation of properties of mortar mixtures and solutions is extremely large. They form in the aqueous phase own structural grid or interact with the dispersed phase and maintain system stability, intensify non-settling effect, increases the plasticity of the system, provide the necessary level of thixotropic properties [1, 2].

So, the objective is the development of the mathematical apparatus and theoretical models for the use of the mechanism of deformation of thin-walled elements in amalgamators of periodic action with changing working chamber, in order to produce qualitative multicomponent mixes with specified characteristics.

In accordance to the set objective it is necessary to install the analytical expressions for determination of a stress state of the material the changing of the working chamber.

The Main Part: The deformable body is made of elastic material (rubber or corded rubber). When the body workoccur tensions from deformation effects which arise from the displacement of the axis of a given trunnion of technological eccentricity and the weight of the blend components [3-8].

For the analysis and definition of the functions of inertial load and internal forces arising in the working chamber of a given trunnion of technological eccentricity makes the following assumptions and hypotheses:

- The material of the shell is uniform, continuous and linearly elastic, i.e. obeys Hooke law [9].
- In this design just working chamber isdeformed (hereinafter - shell), stiffness which is less than of other steel parts (hundreds of times).
- Chamber height \((L)\) and function of the radius of curvature \(\rho(x)\), forming the middle surface of the shell will remain constant in the process of the work of loading the design and saved the vertical position of the trunnion.
- Due to the small volume weight of the material chamber \((\rho)\)not taken into account tare weight of the chamber when calculating the effect of external concentrated static load on the trunnion to create the specified technological eccentricity and in determining the centrifugal inertial load of \(P_i\) from the rotation of the trunnion with a constant angular velocity \(W\).
Mode of operation of the mixer steady (steady-state), at a certain angular velocity \([\omega]=\text{const} (c-1)\) and the number of revolutions per minute \(n\).

The tilt angle \([\beta]\) of the geometrical axis of the deformed chamber is constant, i.e. coordinate axis \(X\) is a straight line.

For solving the task, use two of the moving reference frame (Fig. 1):

Affine or oblique coordinate system \([\rho, \alpha]\) at \(OCa\);

The polar coordinates \([\rho, \alpha]\), where defined using conditions

\[0 \leq x_a \leq L, \quad 0 \leq a \leq \rho\]  \hspace{1cm} (1)

Working chamber of the mixer is a thin-walled shell (Fig. 1) where \(h\)

\[h \leq d_a / 20\]  \hspace{1cm} (2)

As an approximating dependence for the function \(r_c=rc(x)\) accept the second degree polynomial \([7, 8, 10]\) and obtain:

\[r_c = r_c(x_a) = c_1 x_a^2 + c_2 x_a + c_3 = -0.2 \frac{D}{L} x_a^2 - 0.2 \frac{D}{L} x_a + 0.5 D\]  \hspace{1cm} (3)

where \(c_1, c_2, c_3\) are constants,

\[c_1 = -0.2 \frac{D}{L} x_a^2, \quad c_2 = -0.2 \frac{D}{L} x_a, \quad c_3 = 0.5 D\]  \hspace{1cm} (4)

Substituting (3) \(D=L\), according to initial data, obtain

\[r_c = r_c(x_a) = c_1 x_a^2 + c_2 x_a + c_3 = 0.5L - 0.2 x_a - 0.2 \frac{x_a^2}{L}\]  \hspace{1cm} (6)

As an approximating dependence for the function \(rc=rc(x)\) accept the second degree polynomial \([7, 8, 10]\) and obtain:

- Observed the hypothesis of flat horizontal sections \(x_c\) and there are no folds (local buckling) on a deformable surface of the camera.
Fig. 2: Settlement scheme to calculate the inertial load, inner strength, shear stresses and shifting efforts

- The character of loading of the shell and the constructive-technological ratio $D=L$ with the prerequisites of section 3, 6, 10, allows to schematize its tensed and deformed (final) state of the simplified model of pure shear [9-10], when in any section parallel to the axis $\rho$, will act only tangential stress $\tau$ and distributed power $S$.

\[ S = \pi h \]

and the longitudinal efforts

\[ N_i = N_4 = 0, \]

Find the infinitely small mass [9,10]

\[ dm_{np} = \frac{dG_k}{g} = \frac{pdV}{g} = \frac{\rho 2\pi r \sigma dx}{g} \]

and the linear inertial load $q_i$:

\[ dp_i = dm_{np} = \frac{\rho 2\pi r \sigma k \omega^2 R}{g} dx_a \]

\[ \frac{q_i}{dx_a} = dp_i \]

\[ q_i = \frac{2\pi r \sigma k \omega^2 R}{g} \rho_\omega = 0.4082 \frac{\pi \rho h \omega^2}{g} \left(0.5L - 0.2x_a - 0.2 \frac{x_a^2}{L}\right)x_a \]  

(11)

where the expressions for the functions $R=R(x_a)$, fixing the position of the rotating axis $X_0$ (Fig. 2) and the angular velocity of the trunnion $\omega$ are [9-10]:

\[ R = R(x_a) = x_a \tan \beta_c = x_a \frac{\sin \beta_c}{\sqrt{1 - \sin^2 \beta_c}} = x_a \frac{R_m}{L} \left(\frac{R_m}{L}\right)^2 \]

\[ = x_a \frac{0.2}{\sqrt{1 - 0.2^2}} = 0.2041x_a; \]

\[ \omega = \frac{\pi n_u}{30} \]

(13)

Upon receipt of the formula use the expression (11) to construct a dimensionless inertial load diagram of changes occurring in the material of the chamber from its own weight:

\[ q_i = q_i \frac{g}{\pi \rho h \omega^2 L^2} \]

(14)

get maximum value:

\[ q_{im} = q_i (x_{ai}) = 0.07579 \]

(15)

which is calculated from the expressions (4, 7)

\[ \left[ \frac{dq_i}{dx_a} \right]_{x_0 = x_{ai}} = 0.5 - 0.4 \frac{x_{ai}}{L} - 0.6 \frac{x_{ai}^2}{L^2} = 0 \]

(16)

where

\[ x_{ai} = 0.6385L \]

(17)

To determine the function of the internal forces $Q_i(x_a)$ pre find the support reactions $u_o, u_i$ from the load $q_i$ (formula (11), Fig. 2) from the equations in the form of the sum of the moments of all external forces regarding the points $O$ and $O$ accordingly:

\[ \sum m_o = 0 \Rightarrow u_o L \cos \beta_c - \int_0^L q_i (\cos \beta_c) x_a dx_a = 0, \]

whence

\[ u_o = \frac{0.98}{L} \int_0^L q_i x_a dx_a = \]

\[ = 0.98 \cdot 0.4082 \frac{\pi \rho h \omega^2}{Lg} \left(0.5L \frac{x_a^3}{3} - 0.2 \frac{x_a^4}{4} - 0.2 \frac{x_a^5}{5}\right)_{x_0 = x_{ai}} = \]

\[ = 0.03068 \frac{\pi \rho h \omega^2 L^3}{g}. \]

(18)
where 0.98 - coefficient, using the formula 12, [10] is

\[
\cos \beta_e = \frac{1}{\sqrt{1 + \alpha g^2 \beta_e}} = \frac{1}{\sqrt{1 + 0.204^2}} = 0.98;
\]  

(19)

\[
\sum m_a = 0 \Rightarrow u_a \cos \beta_e - \int_0^L q_i (\cos \beta_e) \left( L - x_i \right) dx_i = 0,
\]

whence

\[
u = \frac{0.98 L \int_0^L q_i dx_i - 0.98 \int_0^L q_i x_i dx_i}{L} = 0.98 \int_0^L q_i dx_i - u_a = \]

\[= 0.98 \cdot 0.4082 \frac{\rho \omega^2}{g} \left( 0.5 L x_i^2 - 0.2 \frac{x_i^3}{3} - 0.2 \frac{x_i^4}{4} \right) \bigg|_0^L - u_a = \]

\[= (0.05337 - 0.03068) \frac{\rho \omega^2 L^3}{g} = 0.0227 \frac{\rho \omega^2 L^3}{g}.
\]  

(20)

Next, on the basis of the obtained analytical expressions (11) and (20) for \( q_i(x) \) and supporting reaction \( u_a \), according to the circuit of the Figure 2, find:

\[
Q_i = Q(x_i) = u_a - 0.98 \int_0^L q_i dx_i =
\]

\[= u_a - 0.98 \cdot 0.4082 \frac{\rho \omega^2}{g} \left( 0.25 L x_i^2 - 0.0667 x_i^3 - 0.05 \frac{x_i^4}{L} \right) \bigg|_0^L =
\]

\[= \frac{\rho \omega^2}{g} \left( 0.0227 - 0.4 \frac{x_i^2}{L^2} \left( 0.25 - 0.0667 \frac{x_i}{L} - 0.05 \frac{x_i^2}{L^2} \right) \right).
\]  

(21)

Figure 3 shows the character of change of the inertial load on the material of the changeable working chamber depending on the design (thickness of the walls of the chamber, its height) and technological (rotation frequency of a trunnion, density of a material) parameters in flat horizontal sections of the chamber height.

Fig. 2. Settlement scheme to calculate the inertial load, inner strength, shear stresses and shifting efforts.

The greatest value of this function is at a distance necessary to understand that the functional parameters are from the base region of chamber \( x = 0.22 \) m \( (x = 0.6385 L) \) (Fig. 3.). As the maximum value of the coefficient of filling the chamber material is 0.75, the majority of the material acts on the base and part of it that is above the median height value of the chamber determines the increase of the values of inertial load due to the reduction of its diameter and centrifugal forces arising at rotation of the trunnion. Decreasing the thickness of the walls of the chamber fivefold, the value of the inertial load increases fivefold.

The graphs in Figure 4 show that the maximum value of inner strength is at the base of the chamber, which is rigidly fixed semirings and by increasing thickness of the chamber fivefold, the value of the internal forces increases fivefold.

For the determination of analytic expressions of distribution functional parameters and their extremes in arbitrary sections of the working chamber of mixer, it is necessary to understand that the functional parameters are tangential stress \( (\tau_{\text{tau}}, \tau_{\text{tau}}) \), where \( \tau = \pi (x, a) \) and the shifting efforts \( (S, S_{\text{tau}}) \), where \( S = S(x, a) \) in the section \( x \) of the chamber body.

The general nature of the distribution of tangential stresses \( (\tau_{\text{tau}}) \) in an arbitrary section of the \( x \) of the body while \( \varphi = 0 \) is presented in Figure 5. Due to the symmetry
The scheme of distribution of tangential stresses $\tau$ in an arbitrary section of the body at $\phi_0=0$ of the scheme concerning an axis $\rho$, diagram $\tau(x)$ for any moment of time $t$ will be the same as in the case when the rotation angle $\phi_0=0$.

Calculation of the diagram in an arbitrary section is produced using the following expressions [9-10]:

$$\tau(x, \alpha) = \tau_A \sin \alpha = \frac{Q}{\pi r_c h} \sin \alpha,$$

(22)

where $0 \leq x \leq L$, $0 \leq \alpha \leq \pi$,

$$\tau_A = \tau_A(x, \frac{\pi}{2}) = \frac{Q}{\pi r_c h},$$

(23)

where $A$ is the most tense point on the longitudinal section of the deformed body, in which

$$\tau_A = \tau_A(x, \frac{\pi}{2}) = \text{max};$$

(24)

Where $Q$ is the algebraic sum of the algebraic expressions of efforts $Q$ and $Q= P\psi$ according to the formula (21) we have

$$Q = Q(x) = Q_i + P_u$$

(25)

Multiplying the left and the right parts of relation (22) and (23) to the wall thickness $h$ get.

$$S = S(x, \alpha) = \tau h = \tau_A \sin \alpha = \frac{Q}{\pi r_c} \sin \alpha,$$

(26)

where $0 \leq x \leq L$, $0 \leq \alpha \leq \pi$,

$$S_A = S_A(x, \frac{\pi}{2}) = \tau_A h = \tau_A \sin \alpha = \frac{Q}{\pi r_c} = \text{max},$$

(27)

$$\tau_A = \tau_A(x, \frac{\pi}{2}) =\frac{\pi h \rho \omega^2}{g} \left[0.0227 - 0.4 \frac{x_h^2}{L}, 0.25 - 0.0676 \frac{x_h}{L} - 0.05 \frac{x_h^2}{L^2}\right] + P_u$$

(28)

The value is 20 times more than the shifting efforts. It should be noted that the maximum values of tangential stresses occur in chambers with minimum wall thickness and the highest values of shifting efforts occur in the chambers with maximum wall thickness.

According to the results of numerical studies shown in Figures 4-7, made the diagrams and the dependences of main functions and functional parameters of the chamber with thickness $h = 0.003 m$, as the most expedient from the point of view of ensuring the stability of deformable
working chamber for dimensions $D=L=0.35 \text{ m}$, $d=0.08 \text{ m}$. And defined the most loaded (dangerous) section $x_{\text{max}}$ of the working chamber and found the corresponding stationary coordinates $x_{\text{max}}$, absolute maxima $q_{\text{max}}$ (300.92), $Q_{\text{max}}$ (31.557 H m m), $\tau_{\text{max}}$ (3856.3 PA) and $S_{\text{max}}$ (347.06 PA) which help to assess the strength of the chamber in the loaded condition for the selected its thickness.

**CONCLUSION**

In order to produce qualitative multicomponent mixtures with desired characteristics can be implemented designs mixers using the mechanism of deformation of thin-walled elements, which organize control of components motion of the mixture and relevant for them, flow the processes of mixing materials. Defined, identified and analyzed the theoretical expressions of inertial load, inner strength, functional parameters and their extremes occurring in arbitrary sections of a variable working chamber because ofits deformation, depending on the magnitude of technological eccentricity.

Recap. Obtained the analytical expressions to define the functions of inertial load and internal forces, which arise in the changing chamber because of the given trunnion of the technological eccentricity. The greatest value of inertial load is achieved at a distance from the base of the chamber $x_{\text{max}}=0.6385L \text{ m}$ as the maximum value of the coefficient of filling material of the chamber is 0.75. The main mass of the material acts to the base and the part of it that is above the median height value of the chamber determines the increase of the values of inertial load due to the reduction of its diameter and centrifugal forces arising at rotation of the trunnion. The values of the inertial load increase fivefold and the values of the internal forces decrease 20 times with decreasing thickness of the walls of the chamber fivefold.

The analysis of analytical expressions of tangential stresses and shifting efforts showed that they accept the maximum values in the field of attach the chamber to the trunnion and by increasing height of the chamber from the base to the trunnion, their values are increased 6 times, but the values for the tangential stresses are 20 times more than the shifting efforts, the maximum values of tangential stresses occur in chambers with minimum wall thickness and the highest values of shifting efforts occur in the chambers with maximum wall thickness.

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