High-quality poly-dispersed mixtures applied in additive 3D technologies.

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High-quality poly-dispersed mixtures applied in additive 3D technologies.

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Abstract. The paper describes the new mixer design to obtain high-quality poly-dispersed powders applied in additive 3D technologies. It also considers a new mixing principle of dry powder particles ensuring the distribution of such particles in the total volume, which is close to ideal. The paper presents the mathematical model of mixer operation providing for the quality assessment of the ready mixtures. Besides, it demonstrates experimental results and obtained rational values of mixer process parameters.

1. Introduction

At present, the technologies aimed to obtain dry poly-dispersed powder mixtures are of vital importance in the development of the global market of construction materials. Such mixtures are essential with regard to not only the aesthetic finishing and renovation, but also due to opportunities that they provide to receive a ready construction project with prescribed properties using additive 3D technologies. In recent years, such mixtures have firmly established themselves in the construction market and are still developing. New and advanced developments, able to solve specific objectives of construction industry, appear all over the world, including China and Brazil, which are currently characterized by the highest production growth rates of construction mixtures.

Rapid development of innovative technologies, study of materials at nanolevel and a comprehensive approach open up great opportunities for this industry. The main motive of its development is, undoubtedly, high growth in demand for modified construction mixtures. With constantly developing residential construction, the use of dry mixtures is viewed as the best option not only in terms of its quality, nomenclature and time in construction, but also in terms of finishing or renovation. The use of dry mixtures following the principle of “cover with water and use” made them popular in the modern market [6, 7, 8].

The properties of construction mixtures depend on physical-chemical and physical-mechanical characteristics of their components, while the energy cost depends on the nature of their processing. Hence, the production of construction mixtures shall be considered as a separate chemical and technological system integrated into a multipurpose production of various construction materials and consisting of various subsystems consuming significant amounts of different types of raw materials, fuel and energy resources, etc.

The following represent the main processes included into the technological chain of construction mixtures production exercising a significant influence on their performance characteristics: preparation of raw components, their proportioning and mixing, distribution of small chemical additives and bulk molding compounds. Material homogeneity forms the basis for the required quality of modern construction mixtures. Performance characteristics of obtained product directly depend on how evenly the separate components will be distributed in the bulk mixture. Even minor deviation in the composition of small additives caused by their poor distribution can negatively affect both physical-mechanical and technical-operational properties of a mixture.

For these very reasons, the mixing unit is rightfully considered the key sector of industrial plants producing dry construction mixtures. Therefore, the performance of mixing equipment is a major step towards high-quality production.

Along with the developed methods of complex reduction in energy cost [1] for construction mixtures, including rational mechanical mixing, it is necessary to study variations in concentration of construction mixture components during high-speed mixing.

For this reason the development of mixers as major equipment in a technological chain, advanced design with minimization of consumed resources and an increase in the product range per unit equipment remains the most relevant task in the production of dry construction mixtures.

2. Design solution.

According to performed analysis of technical solutions [3, 4] with regard to mixers used to obtain dry construction mixtures, the study suggests the design of a blade mixer implying circulation of material along its casing throughout the height of a mixture layer.

The design was focused on the creation of counterflow convective currents of a mixed material both in horizontal and vertical directions. The creation of such currents is ensured due to installed spirals on the internal surface of a mixing drum.

Fig. 1 shows the general view of the designed facility. It consists of a frame (1), on which a cylindrical drum (11) with screw augers is installed. The drum is activated by a drive (5) installed on centering supports (6). The drum drive consists of an electric motor and a reducer. For the initial belt tension and its regulation in operation, the facility implies a drive belt tensioner (7). On top, the drum is tightly closed with a cap (8), which holds a vertical shaft and prevents the mixed components getting out of a drum. The cap is equipped with a feed opening (10). The shaft with blades is rotated by the electric motor (3) installed on slides (2). Rotation from the motor to a blade shaft pulley (9) firmly fixed on a drum pin is ensured through a V-belt drive. A drive belt tensioner (4) is also implied for the blade shaft drive. The internal cavity of a drum pin (12) serves the discharger of finished materials.

The frame of experimental facility is welded from equal angles and rectangular cross-section. The rectangular cross-section of 40×25 mm in size with wall thickness of 2 mm is used to make base supports (1). Struts from the same rectangular cross-section are welded to make the facility more rigid.

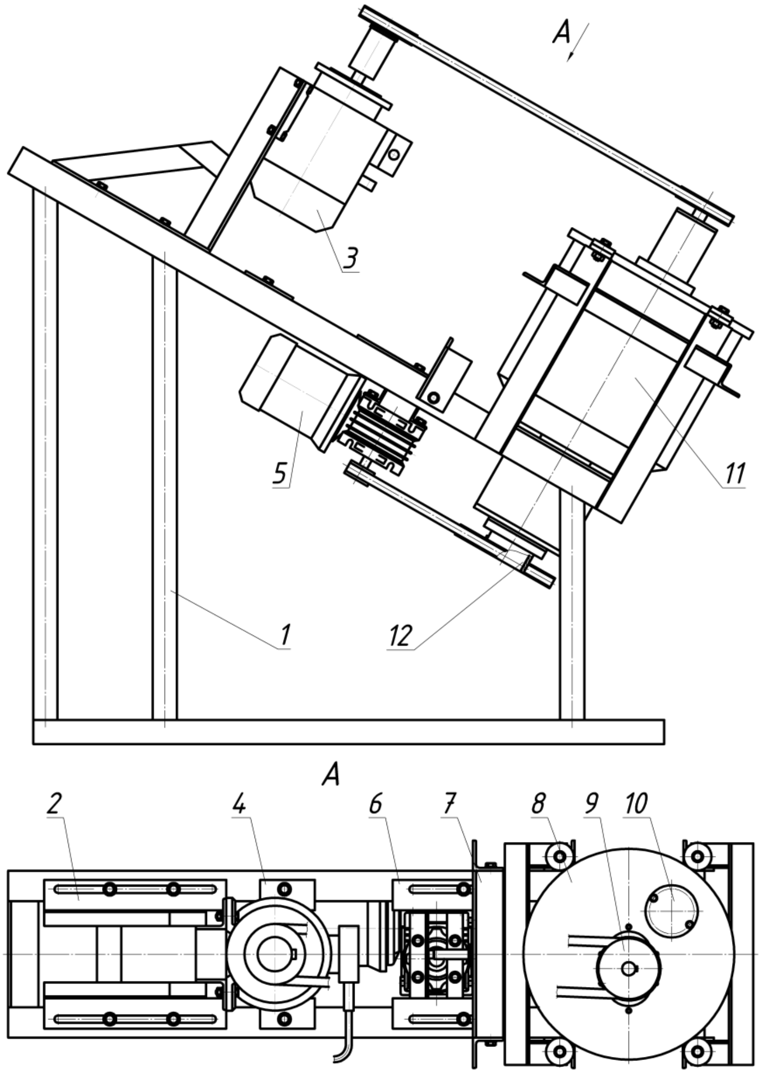

Figure 1. A general view of a blade mixer: 1 - frame; 2 - motor slides; 3 - electric motor rotating a blade shaft; 4 - drive belt tensioner rotating a blade shaft; 5 - drum drive; 6 - slides of the motor rotating a drum; 7 - drive belt tensioner rotating a drum; 8 – drum cap; 9 - blade shaft pulley; 10 – feed opening; 11 - drum; 12 - discharge opening.

In order to install all parts and nodes of a mixer, the rectangular cross-section structure (2) is welded, which is connected through welding with supports. An equal angle with a leg width of 50 mm was used. The thickness of an angle made 5 mm. To fix a cap (8) (Figure 1), the frame (3) was welded from an equal angle with a leg width of 50 and 40 mm. To fix a cap, cylindrical nuts were welded to a frame. Along their central axis, open bolt holes with a diameter of 10 mm were drilled.

The frame of a mixer is designed and made so that the plane of a mixing drum and all nodes are located at an angle of 29° to the horizon.

A drum assembly is fixed with four M10 screws to the frame (Fig. 2). The mixing drum has cylindrical casing (1). The bottom part of a drum (2) is conical. The wall thickness makes 6 mm. The outer diameter of a drum equals 320 mm. Screw augers (3) are welded to the internal surface of a drum, which have gaps to ensure passing of shaft blades. The pin (5) is connected by welding to the casing. The outer surface of a pin has two roller bearings (4). External bearing rings are fastened to the internal surface of the bearing block (9), which in turn is fastened with screws to the frame of a mixer and keeps the drum assembly fixed. The bearing block is closed with caps (11) and (10) from two sides. To hold the internal ring of the lower bearing in place there are two counter nuts (6), which do not allow the internal ring to be displaced axially. The pulley (8) is installed with a key (7) to initiate a torque effect via belt driving from the drive to a mixing drum. The pulley is fixed to a shaft via the interference fit. There is a groove on a drum pin to install a key, which keeps a pulley from turning.

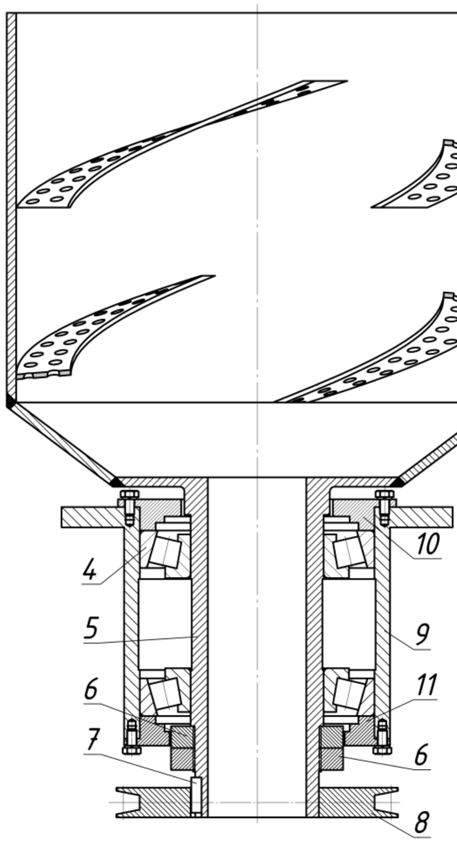

Figure 2. Drum assembly: 1 – drum casing; 2 - bottom conical part; 3 - screw auger; 4 - bearings; 5 - pin; 6 - counter nuts; 7 - key; 8 - pulley; 9 - bearing block; 11, 10 - caps.

Fig. 3 presents a shaft with bladed bushings. There are three bushings on a shaft: two end bushings (1) and a middle bushing (2). There are three blades (3) on each bushing, which are turned relative to each other by 120°. Blades of the upper row are turned relative to two rows by 180°. Some blades with bushings are set aside from each other at 124 mm and 112 mm. The shaft is installed on two bearings (4). Outer bearing rings are placed in a bearing block (5). The bearing block is closed with caps (6,7) with set sealing from two sides. The lower bearing is an enclosed bearing. The bearing block is installed in cantilever fashion on a fixed cap (8) of a drum. The casing housing is cut on a cap. Holes and a thread are made on a cap around the housing. The housing of a shaft assembly has three positions: central (on a cap axis), extreme (at a distance of 48 mm from the central position), intermediate. The bearing block is fastened by screws to a cap. There is a ring groove in the lower part of a cap to prevent outflow of material and dusting. A sealing is installed into a groove.

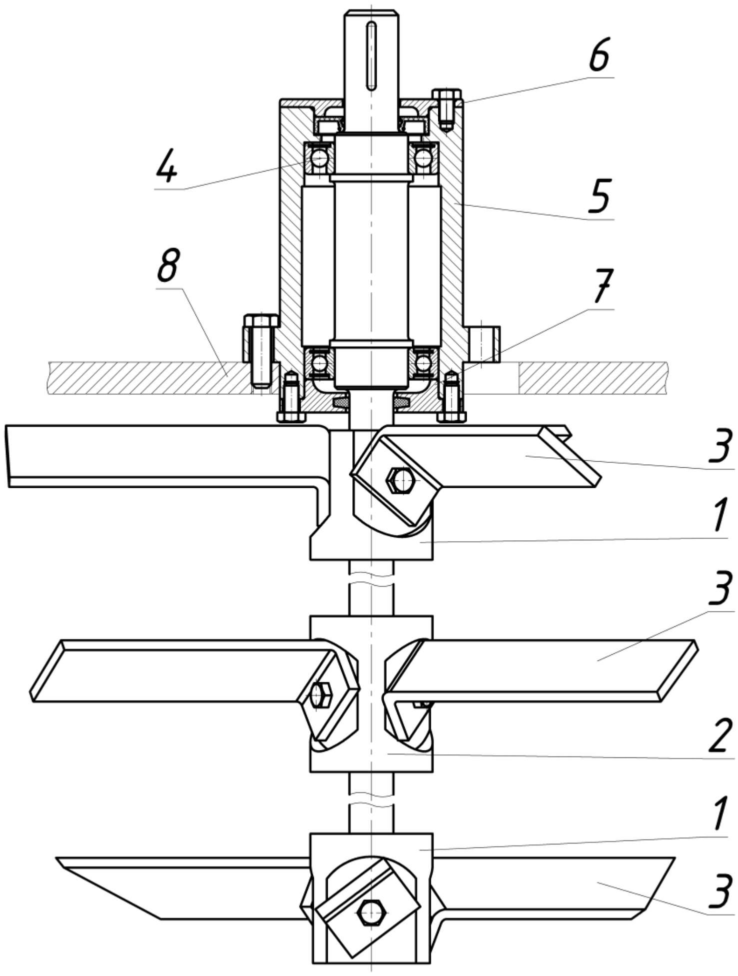

Figure 3. Shaft assembly: 1 - end bushing; 2 - middle bushing; 3 - blade; 4 - bearing; 5 - bearing block; 6,7 - bearing caps; 8 – drum cap.

Operating principle

The bulk mixer operates as follows: mixed components are loaded through a feed opening (10) (Fig. 1) and get inside a drum (11). Simultaneously, the electric motor (3) that ensures rotation of a vertical shaft through V-belt driving is switched on. The rotation of blades leads to the formation of a funnel inside a drum, which sucks the material from above to the drum bottom. The material starts circulating. After a certain time (2-5 seconds), the electric drive (5) of a drum turns on. The electric drive consists of an electric motor, a worm reducer and a V-belt drive. The drum starts rotating. The drum shall rotate against the rotation of blades, while the direction of drum rotation is chosen according to the direction of auger flights. The material is charged via blades on screws. The screw augers lift the mixed components in vertical and horizontal directions. While moving along the surface of a screw, the mixture gets to the second row of blades, having shifted both in vertical and horizontal directions, gets on a middle part of a screw and moves upwards. Then, the mixture reaches the top of a mixer drum where reverse blades cut off the moving mixture from the screw and push it down towards the main stream of a mixture. After mixing the mixture is discharged through a discharge opening (12). After the mixer is fully discharged, the process is repeated.

Thus, the suggested design of a mixer allows increasing the degree of homogeneity of a ready-made product and reducing the mixing time due to circulation of primary components both in horizontal and vertical directions inside a drum of a mixer [9].

3. Quality of a blade mixer.

To assess the operating quality of a mixer, it is suggested to use such indicator as the concentration of a key component and its change throughout mixing. The change in concentration of a key component of a mixture in the blade mixer will be considered within the diffusion model [2]. The diffusion model corresponds to a flow with piston-like movement of material, complicated with cross-sectional mixing of bulk particles and governed by the diffusion law [10].

According to the above-mentioned facts, the main equation describing the change in concentration of a key component of a mixture may be as follows:

$$\frac{\partial C}{\partial t} = -\bar{v}_z \cdot \frac{\partial C}{\partial z} + \frac{\bar{D}_r}{r} \cdot \frac{\partial}{\partial r} \cdot \left(r \cdot \frac{\partial C}{\partial r} \right), \tag{1}$$

where C - concentration of a key component of a mixture;

$\bar{v}_z$ - average speed of material circulation along the Oz axis;

$\bar{D}_r$ - average radial diffusion coefficient of a mixture.

Based on expression (1) and considering that the radial diffusion coefficient of a bulk material is defined as the product of material movement speed along the radial direction by the path along this direction [5], it is possible to find the necessary expression defining the change in concentration of a key component throughout the mixing of powder materials:

$$C(t,r) = \frac{C_н}{J_0\left(\psi_1 \cdot \frac{d}{2 \cdot R}\right)} \cdot \exp\left(-\frac{\psi_1^2 \cdot l^2 \cdot A \cdot \left(1 + \frac{3 \cdot d}{2 \cdot l}\right)}{18 \cdot R^2} \cdot \omega \cdot t \right) \cdot J_0\left(\psi_1 \cdot \frac{r}{R}\right), \tag{2}$$

where d - diameter of a rotor shaft, m;

ω - rotor angular speed, c^{-1};

R - inside radius of a mixer casing, m;

$C_н$ - initial concentration of a key component of a mixture;

J_0 - the Bessel function of the first kind;

ψ_1 - the first root of the Bessel function of the first kind;

l - length of a mixing blade, m;

The obtained expression (2) allows describing the change in concentration of a key component of bulk material in the blade mixer depending on design (l, d, R) and process parameters (ω, t).

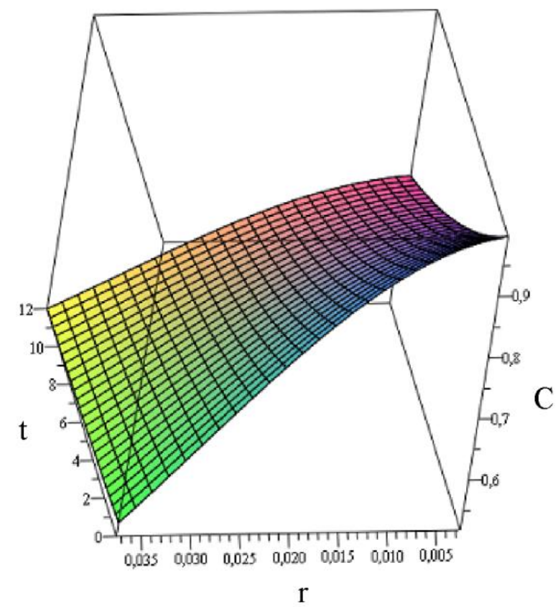

Figure 4. The dependence of change in concentration of a bulk material in a blade mixer upon change in time and distance from rotation axis for the following values: ω=0.4; ψ=2.404; l=0.035; λ=0.84; d=0.005; R=0.04; C_k=0.5; C_0=1.

The graphical interpretation of obtained dependence (2) presented in Fig. 4 allows concluding that the change in concentration of a key component is mainly ensured by an exponential factor.

4. Definition of rational parameters.

The study of operational parameters of the suggested mixer was performed in two stages [1]. The first stage implied visual observation of poly-dispersed mixing in a full-scale model, which is fully identical to the design of experimental facility in a smaller scale. The casing of a full-scale model was made from transparent polyvinyl chloride. Sony HXR-NX5M video shooting was made to register movements of mixture components.

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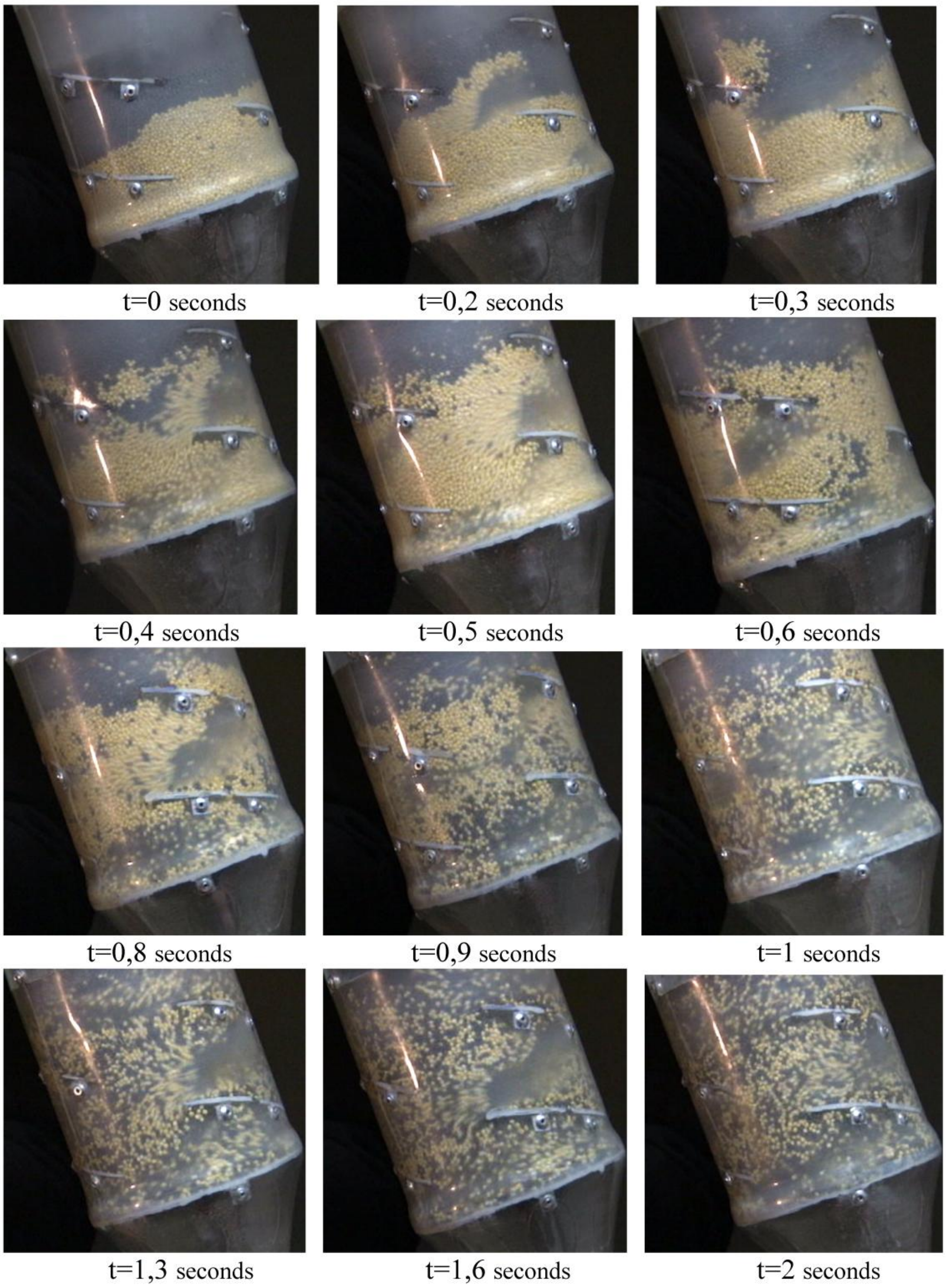

Figure 5. Movement of mixture components in a full-scale model through different time intervals.

The analysis of high speed video shooting showed that the movement of material being on a helix surface is pulsating. Such movement is caused by the fact that the material displaced by a blade gets to a certain height and, in the condition of ideal incompressible granular medium, transfers a pulse of kinetic energy to the layer of material being on a helix surface. In this case, the time, during which the material is lifted, is directly proportional to the frequency of blades passing over a certain screw auger.

After passing the kneading blade a trace is formed in a zone of its action where mixture components are almost completely absent. The material descending from lower rounds of a screw auger gets into this released volume, which serves an initial condition for the formation of new pulse of material movement. It was also defined that with the increase in a rotor speed, and hence the frequency of a kneading blade passing over the screw auger, the material begins to partially fill the formed trace, due to which the material volume pushed out by the blade decreases thus leading to a smaller value of pulse transmission. With a further increase in speed, the trace formed by the blade completely ceases to be filled and cancels energy transmission to the material lying on the surface of the screw auger. This is explained by the fact that there is not enough time for a blade to pass over a spiral for filling the volume formed by a trace.

The second phase of mixer operation study was accompanied by laboratory tests [1]. Upon the results of such tests (Fig. 6), rational parameters of the suggested mixer design were obtained.

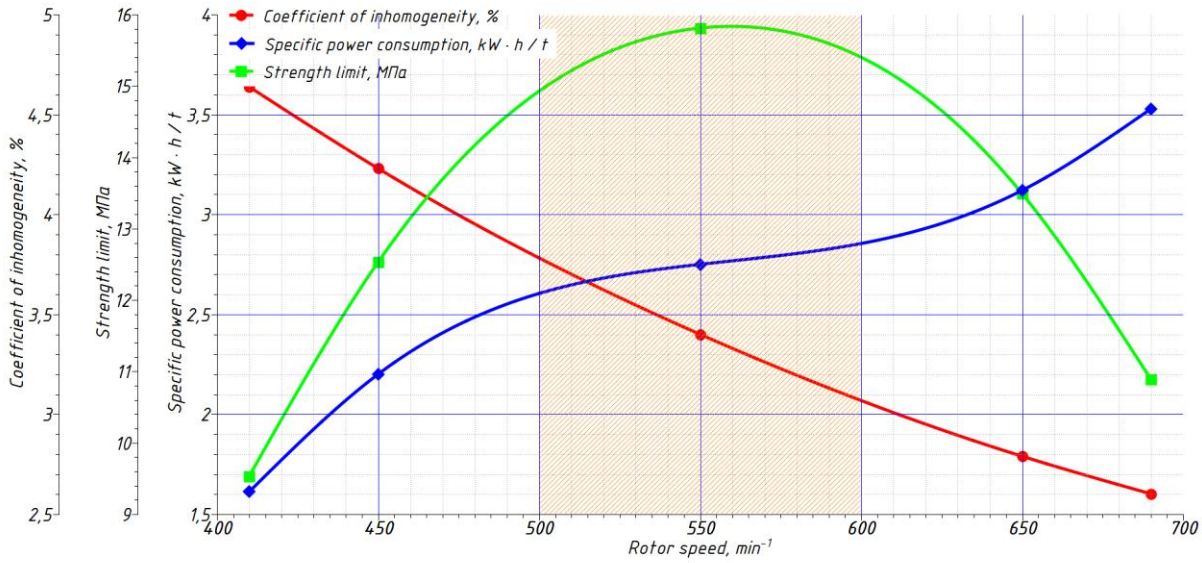

Figure 6. Diagrams of mixer operation parameters dependence on rotor speed.

Fig. 6 shows that with the change of a rotor speed from 410 to 690 min^{-1}, the coefficient of key component concentration has the minimum value of 2.6% at the rotor speed of 690 min^{-1}, the tensile strength has the maximum value of 15.9 MPa at the rotor speed of 550 min^{-1} and power consumption has the minimum value of 1.6 kWh/t at the rotor speed of 410 min^{-1}.

The analysis of obtained dependences makes it possible to conclude that the most rational number of rotor turns will make from 500 to 600 min^{-1} (shaded area in Fig. 6). Such values were chosen proceeding from the fact that the minimum permissible compression strength of mortar dry mixture on the 28th day has to be not less than 15 MPa, coefficient of inhomogeneity for high-quality mixtures shall not exceed 4%, and power consumption shall be minimum.

5. Conclusions

The development and design of highly efficient mixing equipment allowing producing high-quality powders for additive application in construction are an important and perspective task for researchers and designers of industrial equipment.

The development of 3D construction printing technology imposes advanced requirements on the quality of used components and the process of their production. Mixing as one of key stages of this process fosters the quality of finished products and makes designers to constantly improve the mixing equipment.

The suggested design of a blade mixer allows increasing the degree of homogeneity of a ready-made product and reducing the mixing time due to circulation of initial components both in horizontal and vertical directions inside a drum of a mixer, which will further enhance the quality of poly-dispersed powders.

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