Influence of design and technological parameters of a high-speed paddle mixer on the quality of dry building mixes

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Abstract. Today, one of the most promising building materials is dry building mixes. Their production is not only a large segment of the construction market, but also a kind of testing ground for promising developments of modern technological equipment. The paper discusses the design of a high-speed fixed drum paddle mixer for producing modified dry building mixes with a complex recipe. The question is raised about the complexity of the uniform distribution of components in the total volume of the mix. A number of existing factors affecting the distribution of components of the prepared mix are determined. Criteria for evaluating the quality of the finished mix are given. The method for determining the influence of design and technological parameters on the quality indicators of the finished product is described. The method of experimental research that allows evaluating the influence of the design and technological parameters of the mixer on the inhomogeneity coefficient of the resulting dry construction mix is presented. The obtained results confirm the effectiveness of the proposed design of a high-speed paddle mixer to obtain high-quality modified dry building mixes at a minimum rate of heterogeneity of the mixture, as well as other indicators to measure the quality of the final product, diagrams of dependence of inhomogeneity coefficient of structural and technological parameters of the mixer are given. Rational values of the main design and technological parameters of the mixer for the production of dry building mixes are given.

1. Introduction

The use of dry building mixes in the world and national experience has shown their effectiveness and great advantage over classical methods of construction work: increased labor productivity from 1.5 to 5 times, reduced material consumption in comparison with traditional technologies by 3-10 times, uniformity of compositions and, as a result, improved quality of construction work, long shelf life without changing properties and the ability to transport and store at a negative temperature \cite{1,3,5}.

It is known that the quality of the resulting construction mix directly depends, first of all, on the mixing process in production. Therefore, in order to obtain high-quality mixes with a complex recipe, it is necessary to equip enterprises that produce construction mixes with modern mixing equipment that allows them to produce mixtures with the declared characteristics \cite{1,4,6}. 
2. Materials and methods

2.1. Materials

To date, there is a wide variety of design versions of the working bodies of mixers for the production of building mixes. As practice shows, the most effective among them are considered to be high-speed forced mixers.

In order to increase the efficiency of the mixing process of dry components and, first of all, to improve the quality of uniformity of the resulting mixture, the design of a fixed drum paddle mixer with a vertical arrangement of the blade shaft operating in a high-speed mixing mode is proposed [2,9,10].

The mixer design change was based on the following:

- firstly, the organization (creation) of the “fluidized layer”, i.e. the pseudo-fluidized state of the powdery material;
- secondly, creating additional circulation flows of the mixture components in the vertical direction (along the mixer body);
- thirdly, removing material from the stagnant areas of the mixer.

Paddle mixer (Fig. 1) consists of the following main components: a frame on which the drive and mixing drum are installed, a vertical paddle shaft (Fig. 2) mounted cantilevered inside a cylindrical mixing drum (Fig. 3). Several rows of blades are installed on the shaft, and in each row there are 3 blades that are turned to 120° relative to each other. A three-way helical spiral with breaks in the planes of rotation of the vertical shaft blades is fixed on the inner surface of the drum walls. It has a perforated surface. The size of the holes in this spiral exceeds 5-7 times the size of the part of the mixed components, and the value of the “live section” of the helical surface is at least 30-50% of its entire area.

Figure 1. Experimental installation of a paddle mixer.

Figure 2. Blade shaft.

Figure 3. Mixing drum.
A distinctive feature of this mixer is that when the blades of each row of the vertical shaft rotate, the mixed components are thrown onto the perforated helical spiral of the drum, which, in turn, intensifies the mixing process by moving the components of the mixture not only in the horizontal direction, but also in the vertical direction. This, in turn, leads to the destruction of stagnant zones in the drum and the creation of additional circulation flows of the mixture components in their total volume, which helps to improve the quality and reduce the inhomogeneity coefficient of the mixture.

2.2. Methods

As a result of the mixing process in the mixing drum, there is a mutual redistribution of particles of various materials that are separately or in a combined chaotic state before mixing. Ideally, you should get a mixture that preserves the ratio of the components to be mixed at any point in its volume. In fact, this ideal ratio is not observed due to a number of existing factors that affect the distribution of components in the mixture. These factors are divided into three groups [4,5,6,8]:

- mixing methods (pouring, shoveling, layering components, mixing components in a “fluidized” layer, etc.);
- design and technological features of mixers and their operating modes (the degree of filling of the mixing drum, the speed and nature of material circulation inside the mixing chamber, the design, speed and frequency of rotation of the mixing body);
- physical and mechanical properties of the mixture components (ratio of components, their granulometric composition, bulk mass and bulk density, coefficient of internal friction, etc.).

In the mixed volume of the material, an infinite variety of relative positions of the components of the mixed materials is possible, and under these conditions, the ratio of components at arbitrary points in the volume of the mixture is a random variable, so most modern methods of quality assessment are based on statistical analysis methods.

The most common criterion for evaluating the quality of the finished mixture is the value of the average square deviation $S$ of the content of the key component in the mixture samples [1,4,7], but the most common criterion for evaluating the quality of mixing dry mixtures is the coefficient of heterogeneity (variation) $V_c$.

For obtaining high-quality dry mixes in a mixer of this type is necessary to ensure the pseudo-fluidization of the mixture components, which is typical for high-speed blending mode (frequency of rotation of the blade shaft more than 5 s$^{-1}$). It is necessary to consider the influence of the quality of the obtained mixtures (the heterogeneity coefficient of the mixture, $V_c\%$) on the physical and mechanical properties of the mixture (tensile strength $\sigma_m$, MPa) and specific energy consumptions ($q$, kW $\cdot$ h/t) in the mixing process. Therefore, it is advisable to choose the named indicators ($V_c$, $\sigma_m$, $q$) as the response functions of the regression equations obtained when studying the influence of the main geometric and technological parameters on the mixing process of dry components.

The cycle of the mixing process, when using the laboratory setup consists of:

- the loading time of the drum with the components of the mixture, which depends on the volume of the body (near 8-10 s);
- the time required to get a high-quality finished product (16-20 s);
- the time of unloading the mixture (near 10 s).

The following geometric and technological factors influence the indicators of the response functions of the regression equations in this case:

$$V_c, \sigma_m, q = f(D, H, d, i, j, b, l, q, h, \beta, C, k, p, n_m, t),$$

where $D$ – diameter of the mixer drum, $m$; $H$ – the height of the drum mixer, $m$; $d$ – the diameter of blade shaft, $m$; $i$ – number of rows of blades on the shaft, Pcs; $j$ – number of blades in a row on the shaft, Pcs; $b$ – the width of the paddle vertical shaft, $m$; $l$ – vertical shaft blade length, $m$; $\alpha$ – angle of attack of the vertical shaft blade, deg.; $h$ – width of the helical surface of the drum blades, $m$; $L_\phi$ – length of the forming helical surface of the drum blade $m$; $\beta$ – angle of lift of the helical surface of the drum blades, deg.; $C$ – the value of the live cross section of the helical surface of the drum blades, %;
k – number of turns of the helical surface of the drum blades, PCs; φ – material loading ratio of the drum; np – speed of rotation of the blade shaft, min⁻¹; t – mixing time, s.

To conduct research to determine the influence of design and technological parameters on the degree of heterogeneity of the mixture, a mixer with the following geometric parameters was studied [1]:

- the parameters of the drum of the laboratory installation are accepted D = 300 mm, H = 310 mm;
- the angle of lift of the helical surface of the drum blades is not more than 30° and not less than 15°;
- the number of rows of blades is determined by the ratio: i = H/(h₀+b);
- geometric parameters of the mixer shaft blades: blade length l=(D-d)/2, blade width b and blade angle of attack α (varies in the range of 19°÷51°);
- the number of blades in one row on the shaft is assumed to be 3 and are positioned relative to each other after 120°;
- the width of the helical surface of the drum blades is 40 mm, and the value of the “live section” C changes in the range from 14 to 46%.

The capacity of the mixer directly depends on the load factor (φ), so we assume its maximum value is 0.7. The mixing time (t) was chosen based on additional experiments, which determined that the mixing time is 16-20 s, and the full cycle time is 40÷50 s.

The interval for varying the speed of the blade shaft was adopted 470÷630 min⁻¹ based on the fact that when the speed decreases, the load is not pseudo-fluidized, and with a further increase, the energy consumption increases significantly.

3. Results

As a result of the study, we obtained graphs of the dependence of the inhomogeneity coefficient $V_C$ on the angle of attack of the blades α for fixed values of the “live section” values $C = 14\%, 20\%, 30\%, 40\%, 46\%$ and the speed of the blade shaft $n_p=470, 500, 550, 600, 630$ min⁻¹. Analysis of these graphs showed that the minimum values of the inhomogeneity coefficient of the mixture equal to 2.7% and 2% are observed at the angle of attack in 35°, the speed of rotation of the blade shaft 550 min⁻¹, and the values of the live section equal to 14% and 46%, respectively (Fig. 4) [1].

![Figure 4](image_url)

**Figure 4.** Graphs of the dependence of the inhomogeneity coefficient of the mixture $V_C$ on the angle of attack α of the shaft blades at fixed values of the values of the live section $C$ from the screw surfaces and the shaft rotation frequency.

4. Discussion

The results obtained are explained by the fact that with a minimum value of the “live section” equal to 14% due to the larger area of the helical surface, the bulk of the material, supported by its throwing blades, rises along the helical surface and at the end of it, passes from layer to layer under the influence of gravity, which contributes to mixing the components of the mixture. When the value of the
“live section” is equal to 46%, when the blades of the shaft throw the components of the mixture on the helical surface of the drum blades, the material almost immediately wakes up on the layer below, which intensifies the mixing process.

5. Summary
As a result of the study, rational values of the main design and technological parameters of the mixer for the production of dry building mixes were determined, namely: the frequency of rotation of the vertical shaft \( n_p \), the angle of attack of the blade \( \alpha \), and the value of the “live section” of the helical surface of the drum blades \( C \) of the mixer, taking into account that \( q \rightarrow \min \), \( V_C \rightarrow \min \) and \( \sigma_0 \rightarrow \max \). So, \( \alpha=35^\circ \), \( n_p = 470 \text{ min}^{-1} \) and \( C=46\% \).

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