Improvement of mixing technology of concrete mortar components in mixers

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Abstract. Methods of calculations and methods of modeling the mixing of components of construction mixtures are presented. Experimental studies were carried out using a prototype mixer. Compressive strength, workability, and concrete uniformity coefficient in strength were taken as the main defined characteristics of the concrete mixture. On the basis of the conducted researches the dependences for an estimation of design and layout decisions and parameters of work of mixers and technological cycles, and also their influence on quality and structural-rheological properties of ready products have been established. The obtained data confirm the hypothesis about the possibility of improving the quality of concrete mixtures by using a gravity-forced method. It has been established, that application of gravity-forced method of mixing allows to increase concrete strength by 5-10 %, and of mixture uniformity coefficient - by 1.4-2.5 %. At the same time, the duration of concrete mixtures preparation can be reduced by 1.5-2.0 times compared with the known methods.

1. Introduction
The development of the construction industry is associated with the improvement of constructions of technological equipment, new constructional materials and methods of their production.

The main challenges faced by developers and designers include the choice of design-layout scheme of the main unit (mixer) with the determination of its geometrical and kinematic parameters, the calculation of time parameters and power consumed during mixing [1-5]. The structural scheme choice is associated with the formulation of requirements for the operation mode (cyclic), mixed materials compositions. In this case, geometrical and kinematic parameters are mainly determined by the required capacity of the finished product output.

Due to the complexity of formalizing the kinetics of the mixing process and determining the power consumption [6-9], the experimental studies that allow obtaining experimental data, on the basis of which one can establish the real dependences of the design parameters, performance and quality of concrete mortar mixtures, are of great importance.

The mixing materials process is a mechanical process, as a result of which the constituent mixtures are evenly distributed in the mixed volume [3, 10, 11]. The mixing process is opposite to the separation process, i.e. separation of the mixture components from each other, which is predetermined by the imperfect action of the mixer (the influence of gravitational, inertial, centrifugal forces), the influence of the grain size difference of the mixing materials and other reasons. The actual mixing process usually consists of an overlap of mixing and separation.

The mixing quality is characterized by the degree of approximation of the mixture to the material with some ideal order of distribution of individual components [12-14]. For example, under
production conditions, the quality of concrete mixture preparation is checked by periodic sampling of the prepared mixture directly at its unloading from the mixer. In this case, the main indicators of the quality of concrete mixture are: workability, density, porosity, and delaminatability (uniformity).

2. Materials and methods
To solve the problem of obtaining concrete mixtures of high qualities, it is necessary to study the process of mixture formation during the interaction of the mixers working bodies with the particles of mixed materials. During the initial period of the mixer operation, the quality of mixing, estimated by the mixing degree (Fig. 1), is increased mainly due to convective mixing of components – moving groups of particles from one position to another, transfer, embedding, sliding layers, deformation and abrasion of the layer portion as a result of mechanical movement of the mixer working bodies (section I of the curve). At this time the mixing process takes place at the macro-volume level (macro-mixing).

![Figure 1. Concrete mixing process: I – convective mixing; II – diffusion mixing; III – balancing the mixing and separation process.](image)

The interface between the components is not yet large, hence the proportion of diffusion mixing - gradual redistribution of particles of different components across the interface - will also be insignificant. After this, further mixing makes no sense since the mixture quality remains constant (section III of the curve). The redistribution rate of individual particles in sections II and III depends not only on the nature of material movement [15], but also on its structural and rheological properties (particle size, size of interfacial surface, adhesion forces, etc.).

The mixing ratio is determined by the structural and rheological properties of the mixture, the kinematic parameters and the design features of the mixer. The value of this coefficient averaged over the mixer volume and over a certain mixing time can be determined experimentally. Using similarity theory and dimensional analysis, then it is possible to calculate the value of the mixing ratio for a mixer with other parameters. Since a theoretical determination of the mixing ratio is not possible, it is proposed to obtain it from experimental data.

Experimental studies were carried out using a prototype mixer [16], the layout of which is shown in Figure 2. The mixer works as follows. Electric motor 7 through the reducer 8 transmits torque to the working body made in the form of a screw with blades 11, 12, 13 rigidly mounted on it. In the position (a) the construction mixtures are prepared (mixing). This process is accompanied by the auxiliary operations (dosing and loading of the components). Mixing is carried out with combined (gravity-forced) method: under the influence of an auger the mixtures components are transported to the top of
the installation body, after which under the influence of gravitational forces they are dropped down. The forced mixing is carried out by the rotating blades. In the position (b) the mechanized laying of prepared mixture is carried out. Since the installation is mounted on a movable platform, it has maneuverability and smaller dimensions compared with the known ones [2, 3, 17].

Concrete compressive strength, workability, and the uniformity coefficient of concrete strength (coefficient of variation) are accepted as the main characteristics of the concrete mixture which should be determined [18]. To analyze the mixing process, sampling was performed at various time periods during the process of the concrete mixture preparation. After a specified time, the mixer was stopped and sampling was performed into a special cast, while the workability of the mixture was determined by mobility (cone slump) and rigidity of concrete mixture in accordance with GOST 10181-2014, using for this purpose standard cone and technical viscosity analyzer. The resulting control samples were tested for strength in accordance with GOST 10180-2012 (table 1).

Table 1. Means of measurement used for samples testing.

| Designation of the product characteristic (parameter) to be determined | Designation of the measuring instruments                      |
|---------------------------------------------------------------------|----------------------------------------------------------------|
| Environmental parameters                                            | Multimeter Testo 622                                           |
| Mass measurement                                                    | Electronic balance GF-1200                                     |
| Geometrical dimensions                                              | Calipers, type SHC-I-0.1-2                                     |
| Rupture load determination                                          | Tensile machine 2054 P-5                                       |

3. Research results and analysis
On the basis of the performed studies we obtained approximating dependencies of the uniformity coefficient of the strength (coefficient of variation) from the mixing time, adequately describing a mathematical model of the mixing process in a gravity-pressure mixer (see figure 2).
Figure 2. Structural and technological features of the gravity-forced mixer in the preparation of various compositions and samples of concrete mortar mixtures: a - during the mixtures preparation; b - during unloading into the construction (surface); c – moving direction of the mixtures components during mixing; d – during unloading; 1 – body in the form of a tipping cylindrical container with a conical bottom; 2 – support bearing of the mixer shaft; 3 – moving platform; 4 – tank for water storage; 5 – water pump for water supply; 6 – nozzle of adjustable diameter at the outlet pipe of the mixer; 7 – electric motor; 8 – reducer; 9 – shaft; 10 – auger with screw winding; 11 – mixing blade; 12 – bottom blades; 13 – blades of the cone part of the mixer drum.

The obtained data confirm the hypothesis of improving the quality of concrete mixtures prepared by gravity-forced method. For numerical estimation of quality improvement, the graphical dependences of strength growth and change in the uniformity coefficient of concrete strength were built (table 2). Experimental points, approximating curves and equations describing them, as well as the value of approximation reliability $R^2$ are shown on the graphs. Based on these dependencies we can conclude about a greater increase in the quality of concrete in the early mixing time, which can be explained by the manifestation of diffusion mixing already at the initial stage.

It should also be noted that the maximum increase in the concrete strength corresponds to the early curing time (figure 3), which leads to a reduction in the curing time of construction mixes, which is especially important in the conditions of a high-speed construction.

As a result of analysis of the experimental results, it is obvious that the use of gravity-forced mixing leads to the reduction in the mixing time of concrete mixtures until they reach their design strength (figure 4).

Based on the mathematical model of the mixing process for gravity-forced mixer, numerical equations of mixing process kinetics were obtained. It will allow to determine the mixing time more accurately, depending on the required coefficient of strength uniformity $V_R$. So, for example, for qualitative mixing of concrete mixture, i.e. achievement of variation coefficient $V_R = 10\%$, it is required not less than 100 s (figure 5).

From the obtained numerical equations of the mixing process kinetics it is clear that the uniformity coefficient of concrete strength (coefficient of variation) $V_R$ depends mainly on the used mixer.

The considered approaches of mathematical modeling make it possible to analyze the mixing process and to control it at the design stage, and also allow solving the problems of rationalization of the working process of mixers. The experimental studies results have confirmed the correctness and adequacy of theoretical studies to improve the quality of concrete due to combined mixing in gravity-forced mixer.
Table 2. Dependencies of the coefficient of variation and the strength of the concrete mortar mixtures CMM on the mixing time.

| Sample number | Curing time, day | Parameters and properties of CMM | The variation coefficient change, % | Strength growth, MPa |
|---------------|-----------------|---------------------------------|-------------------------------------|----------------------|
| 1             | 28              |                                 | $y = 32.431e^{-0.0046}$ $R^2 = 0.9435$ | $y = 0.722e^{0.1241}$ $R^2 = 0.9077$ |
| 2             | 7               |                                 | $y = 28.114e^{0.0077}$ $R^2 = 0.9046$ | $y = 0.607e^{0.276}$ $R^2 = 0.8716$ |
|               | 28              |                                 | $y = 32.351e^{0.0096}$ $R^2 = 0.8929$ | $y = 2.9127e^{0.0105}$ $R^2 = 0.9533$ |
| 3             | 7               |                                 | $y = 28.374e^{0.0273}$ $R^2 = 0.8664$ | $y = 4.0257e^{0.013}$ $R^2 = 0.6557$ |

Note: mixture composition №1 – M200; W/C = 0.6; C:S:G = 1:2.5:3.9; №2 – M300; W/C = 0.47; C:S:G = 1:1.8:2.8; №3 – M200; W/C = 0.28; C:S:G = 1:2.6:6.4; ● – gravity-forced mixer; ○ – standard mixture.
Figure 3. Dependence of concrete strength growth on curing time at mixing time 180 s.

Figure 4. Mixing time until the design strength is reached.

Figure 5. Mixing time of concrete mixtures until the coefficient of variation is reached $V_R = 10\%$ (equations of mixing kinetics are given on the right).

4. Conclusion
The use of gravity-forced method improves the quality of mixing, characterized by the strength and coefficient of uniformity of the hardened concrete. In this case, the strength of the fast hardening concrete increases by 5-10\%, and the coefficient of the mixture uniformity – by 1.4-2.5\%. The use of this mixing method leads to increased productivity, as the time of concrete mixtures preparation can be reduced by 1.5-2 times compared with serial gravity mixers.
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