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Efficient mixing of bulk building materials for building structures

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ABSTRACT:
The study presents an analysis of the efficiency of mixing bulk building materials used in binder-based composites. The research focused on evaluating the impact of mixer blade geometry on the homogeneity of the resulting mixture. Comparative experiments were conducted using traditional straight-blade and newly patented spiral-type mixers operating at 366 rpm. The degree of homogenization was assessed through the mass heterogeneity coefficient (V_c) for the lightest composite component. Results showed that the innovative mixer design significantly reduced mixing time by approximately 40 seconds and improved the uniformity of the mixture (V_c < 12 %) compared to conventional mixers. The findings demonstrate that blade geometry plays a critical role in optimizing the mixing process, enhancing material consistency, and reducing air entrainment, which contributes to improved mechanical properties of construction composites.

KEYWORDS:
bulk materials; mixer design; homogenization; mixing efficiency; construction composites

1. Introduction

The mixing processes of bulk materials in binder-based boards are suitable for the quality of construction work. Mixing mortars using machinery is an important and responsible step in the operation, and can be properly classified as a component. Construction mortars consist of various ingredients, such as quartz sand, cement, water, and additional chemicals, which must be thoroughly mixed to achieve optimal properties of the mixed composite. Accuracy in proportions and mixing quality are crucial for the durability, strength, and aesthetics of the finished product.

Mechanical mixing of mortars is characterized by the following parameters:

- Component diversity; mortar components may have different physical properties and variable particle sizes, which can make them difficult to distribute evenly throughout the mass;
- Accuracy of proportions; multiple mixers require precise dosing of ingredients to ensure a properly homogenized mixture;
- Effectiveness over time; the mixing process must be fast and efficient. Furthermore, the mixing time is related to the phenomenon of air entrainment in the mixed composition, which affects the regulation of its physical and mechanical properties.

Working elements, blades – mixers are distinguished by the following types: paddle blades, ribbon blades, propeller blades, turbine blades, anchor blades, frame blades, spring blades, and other names derived from the geometry of the mixing element's blade. The constant search for new design solutions for mixers is driven by the need to increase efficiency and mixing quality, shorten the mixing cycle, reduce or increase composite aeration while ensuring maximum

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homogenization of the mixing product, thereby achieving the specified durability and quality of the mixing product [1-5].

2. Selecting the design solution for a construction mixer's working element

Mixing is a physical process that changes the heterogeneity of the composition. This has been demonstrated to be an important element of the technological process in the processing of various materials, changing their physical and mechanical properties and the external aesthetics of the product, which depends on the homogeneity of the mixed mass. The mixing process requires:
– uniform distribution of the starting materials among themselves,
– preventing the formation of voids in the mixture.

The mixing process depends on the following factors:
– the coefficient of friction between particles resulting from the physical properties of the materials and their quantitative proportions,
– the rotational speed of the shaft and the peripheral speed of the working elements of the mixer blade,
– the direction and impact of the working elements (mixer),
– the geometry of the structure, including the active surface of the working elements,
– the degree to which the drum capacity is filled with the mixed ingredients,
– the mixing time,
– the method of unidirectional or bidirectional mixing.

As a result of the interaction of these factors, the mass undergoes a change and homogenization, which changes over time. Its quality determines the probability of decomposition of one of the components. This process progresses from an initial disordered decomposition to an ordered state.

A construction mixer is used to produce homogeneous solutions or homogeneous masses from various components. Its efficiency and quality depend on the correct selection of the tip – the working element. The mixer has a clutch element for attaching the mixing tool on one side, and a working blade of various shapes for mixing the components on the other. When selecting a mixer for a specific technological task, it is necessary to select the shape of the working blades and the design of the clutch attached to the mixer's shaft.

The given composition of the solution or mass, its volume, and consistency require the use of a mixer with a specific mixing blade shape. Therefore, it is important to select the appropriate mixer design for the selected technological task. For example, a spiral mixer is shown in Figure 1.

Fig. 1. Spiral mixer [3]

The spiral mixer is the most popular design, consisting of a long rod (shaft) with several spiral coils attached to its end and a protective ring at the bottom. These mixers are available in right-hand and left-hand versions. In the former, the coil is twisted clockwise, in the latter, counterclockwise. Right-hand mixers are designed for preparing thick cement-plaster mixtures. In such mixtures, heavy particles settle to the bottom, while the clockwise rotating spiral lifts them upward, giving the mixture a uniform consistency.

For mixing low-viscosity materials, such as liquids and those with air fillers, a left-hand mixing element is necessary, where it is recommended to direct the particles downward. The counterclockwise rotating spiral pushes some of the ingredients downward, preventing the material from splashing. Another type is a straight-blade mixer, which is used for mixing ready-mixed facade plasters. The design is shown in Figure 2.

Fig. 2. Stirrer with straight blades [3]

This type of mixer only horizontally mixes the mixtures, effectively removing air bubbles and preventing the formation of new air voids. These mixers are used to produce mixtures based on gypsum, polymer resins, sealants, and adhesives. Excess air in such materials causes a loss of functional properties. Selecting the correct consistency is therefore an important factor in the planned processing technology for plastic building materials.

The screw-type mixer, shown in Figure 3, with counter-rotating blades, is used to mix very light liquid solutions, most commonly varnishes and paints. Models with two screws are available. The lower screw lifts the ingredients and mixes them, while the upper screw presses the solution down, preventing splashing.

Fig. 3. Mixer with a screw-type working element tip [3]

Specialized working elements, distinguished by their exceptional durability, are used to prepare concrete, sand-gravel, bituminous, and other high-density materials. The diameter of the mixer ranges from 80 mm to 160 mm. Standard working element lengths are 40 cm and 60 cm. If this is not sufficient, additional extensions are used. The total length of the mixer can reach up to 1 m. The mixer can mix solutions in tanks with a capacity of up to 200 liters.

To improve the efficiency of the mixing process of dry mixtures, authors from the Faculty of Civil Engineering of the Częstochowa University of Technology have developed new working element designs – mixers. These new designs have been described and published in patent descriptions [6, 7]. An example of a new innovative mixer design is shown in Figure 4, where the new design, approved by the Polish Patent Office [8], allows for shorter processing times and eliminates air entrainment in plastic masses such as adhesives and facade plasters. The new mixer was designed with blades as shown in Figure 4.

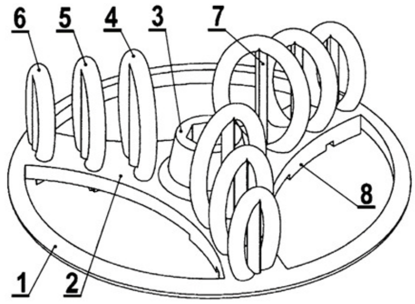

Fig. 4. New innovative design solution for the agitator [7]

The agitator comprises a circular ring and a hub for rotary shaft connection and is characterized in that it has a three-armed base element (2) integrated within a circular ring (1) and located within it, with edges formed by circular arcs with centers located at a distance L from the center of the agitator that is from 0.65 to 0.75 times the outer diameter of the ring (1) and with a diameter of each element from 0.9 to 1.1 times the outer diameter of the ring (1). The axes of symmetry of the element (2) coincide with the heights of the equilateral triangle around which the ring (1) is circumscribed. On each arm of the element (2), the agitator has, preferably, three mixing elements (4, 5 and 6) integrated within it in the form of circular rings, each with a thickness equal to the thickness of the ring (1) and whose diameter decreases radially from the center of the agitator. Each of the elements (4, 5 and 6) is positioned perpendicular to element (2) and parallel to the axis of symmetry of the next, counterclockwise arm of element (2).

3. A method for testing the quality of the homogeneous mixing process of the mass components depends on the mixing time

The quality control of the mixing process can be performed on a composite basis, where the uniformity of the distribution of one of the components in the mass is determined in the adopted two-composite system. One method of assessment is the method described in [5], which determines the mass heterogeneity coefficient (V_c) for one of the components, where its value is determined according to expression (1).

$$V_c = \frac{100}{C_0}\sqrt{\frac{\sum_{i-1}^{n}(C_i - C_0)^2}{n-1}} \tag{1}$$

where:

C_0 – output coefficient for the composite mass with ideal mass volume distribution,
C_i – coefficient of variation, varying the significance of the coefficient based on the mass volume of one of the composites during the tests,
n – number of tests.

Non-uniformity coefficient in the tests, where V_c is determined for the components with the lowest specific gravity. A large number of tests ensures accurate results, with a favorable mixing process of V_c < 10 %, and with an ideal V_c = 0 %.

Comparative tests were conducted for a mixer with the design as shown in Figure 2 and for a mixer with the design as shown in Figure 4, mounted in a mixer drive for mixing construction adhesive rotating at 366 rpm clockwise for a time period from 0 to 180 seconds. The test was performed for a mixture composed of water, filler +0.063 mm, and a dispersion phase with a fraction of –0.063 mm.

To check the quality of the mixing degree, defined by the mass heterogeneity coefficient (V_c), samples for evaluation were collected from the mix drum along the entire drum height using a special sampling tool (volume shears) with a repeatable sample volume. After hydration, the samples were weighed and subjected to dispersion-mass analysis with a precision of 0.5 mg. The composition of the composites was determined based on the mass change, indicating the distribution heterogeneity coefficient, determined according to formula (1). Figure 5 shows the distribution of the composite components depending on the mixing time. As can be seen from the dependencies, the distribution stabilizes after a processing time of 160 s - 180 s for a mixer with the consistency shown in Figure 2.

For a mixer design as shown in Figure 4, the components are mixed in a shorter time (see the graph in Fig. 6), where stabilization of the distribution (V_c) is achieved within a time interval of 90 s - 120 s. This proves the beneficial effect of the new geometry of the blades of the working element – the mixer.

4. Conclusions

The mixing process of multicomponent compositions made of bulk materials in a liquid environment using a straight-blade mixer (Fig. 2) and a spring-type mixer (Fig. 4), evaluated by mixing time and the mass inhomogeneity coefficient (V_c) parameter for the lightest component of the mixed composite, at a drive shaft speed of 366 rpm, showed that increasing the rotational speed of the working element above 366 rpm leads to an increase in the mass inhomogeneity coefficient (V_c) of >24 %. In tests using the mixer design shown in Figure 2 rotating at 366 rpm, stabilization occurred within 160 s - 180 s, and the mass inhomogeneity coefficient (V_c) was <12 % for the fraction – 0.063.

A research comparison of the spiral-type mixer design shown in Figure 4 showed that the new design stabilizes the degree of homogenization within a time interval of 40 s. Lower when evaluating (V_c) < 12 % for the component mass fraction – 0.063.

It is advisable to continue research, taking into account the influence of different rotational speeds and other blade variants that affect the heterogeneity coefficient (V_c) of the mixed components of the composition. Graphical results of the research results are presented in Figures 5 and 6.

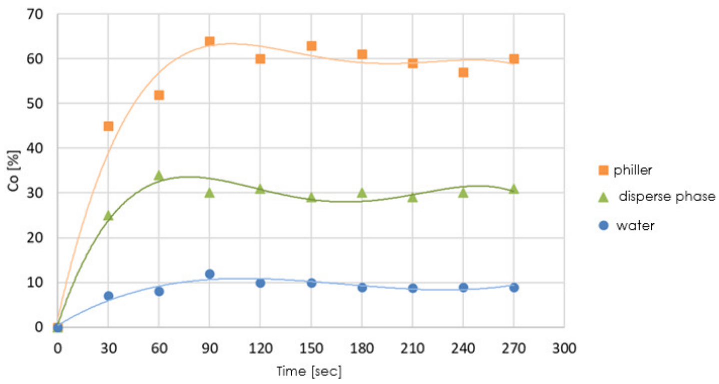

Fig. 5. Dependence of the homogeneity of the component distribution on the mixing time at a speed of 366 rpm for the mixer design shown in Figure 1, where the stabilization of the distribution heterogeneity occurs in the time interval of 160 s - 180 s

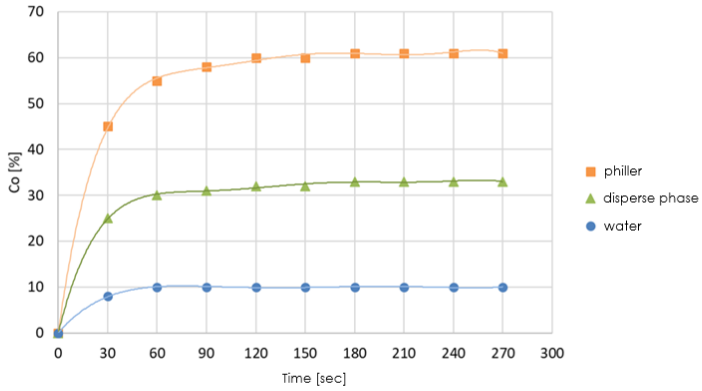

Fig. 6. Dependence of the distribution of the composite components in the mass on the mixing time for the mixer design shown in Figure 4, rotating at a speed of 366 rpm, where the stabilization of the distribution heterogeneity occurs in the time interval of 90 s - 120 s

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Efektywne mieszanie sypkich materiałów budowlanych do konstrukcji budowlanych

STRESZCZENIE:
W pracy przedstawiono analizę efektywności mieszania sypkich materiałów budowlanych stosowanych w kompozytach na bazie spoiw. Badania koncentrowały się na ocenie wpływu geometrii łopatek mieszadła na jednorodność uzyskanej mieszanki. Przeprowadzono eksperymenty porównawcze z użyciem tradycyjnych mieszadeł o prostych łopatkach oraz nowo opatentowanych mieszadeł spiralnych, pracujących z prędkością 366 obr./min. Stopień homogenizacji oceniano za pomocą współczynnika niejednorodności masy (V_c) dla najlżejszego składnika kompozytu. Wyniki wykazały, że innowacyjna konstrukcja mieszadła istotnie skróciła czas mieszania o około 40 s oraz poprawiła jednorodność mieszanki ($V_c < 12\,\%$) w porównaniu z mieszadłami konwencjonalnymi. Uzyskane rezultaty dowodzą, że geometria łopatek odgrywa kluczową rolę w optymalizacji procesu mieszania, poprawie jednorodności materiału oraz ograniczeniu napowietrzania, co przekłada się na lepsze właściwości mechaniczne kompozytów budowlanych.

SŁOWA KLUCZOWE:
materiały sypkie; konstrukcja mieszadła; homogenizacja; efektywność mieszania; kompozyty budowlane