

**REGULATION OF THE WATER DEMAND OF MORTAR MIXES FOR CELLULAR CONCRETES BY PLASTICIZERS AND MECHANO-CHEMICAL ACTIVATION**

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**Abstract.** The study investigates the influence of plasticizing admixtures of different chemical nature and the mechanical-chemical activation of components on the water demand and rheological properties of the mortar mixture for non-autoclaved cellular concrete. It is established that increasing the dosage of the plasticizer reduces water demand and enhances the mixture's mobility, ensuring stable gas formation and the development of a uniform pore structure, which is critically important for thermal-insulating materials. It has been demonstrated that polycarboxylate super plasticizers exhibit a more pronounced dispersing effect compared to naphthalene-formaldehyde admixtures, as they create combined steric and electrostatic barriers on the surface of cement particles, preventing their aggregation. The application of mechanical-chemical activation of the cement–ash system increases its fineness, activates particle surfaces, and accelerates early hydration processes, which leads to an increase in the spread diameter of the mixture without additional water demand, even at minimal admixture dosages. Optimal activation duration has been identified, at which the maximum rheological effect is achieved. Excessive activation time, in contrast, results in over-grinding, an increase in specific surface area, higher water demand, and potential deterioration of structural stability. Iso-surface analysis of the system "plasticizer dosage – activation duration – flow spread" confirmed the synergistic interaction of these parameters: the greatest increase in mobility occurs when a moderate amount of plasticizer is combined with a rational activation duration, ensuring an optimal balance between workability and mixture stability. The obtained results enable a more precise optimization of the mix design and technological regime for producing cellular concrete, improving mixture workability, structural uniformity, and the operational performance of the final material.

**Keywords:** cellular concrete, plasticizing admixtures, polycarboxylate super plasticizers, mechanical-chemical activation, water demand, mixture workability, iso-surfaces, composition optimization.

**Introduction.** One of the most significant directions in contemporary construction materials science is the improvement of thermal insulation cellular concretes. A decisive stage in the production of cellular concrete is the formation of its porous structure and the geometric parameters of inter-pore partitions, which largely determine the physical, mechanical, and thermal performance of the final material.

At the stage of primary structure formation, the system exhibits an inherent contradiction between two opposing phases: on the one hand, the air bubble forming the future pores, and on the other hand, the cementitious mortar matrix. The mortar phase represents a highly concentrated suspension consisting of liquid and solid particles. Within such a medium, the air bubble, due to its low density and mass, exists under mechanically unstable conditions. The degree of this instability is primarily governed by the rheological characteristics of the mortar phase.

In modern cellular concrete technology, particular attention is therefore devoted to the controlled regulation of the rheological properties of mortar mixtures, which ensure structural stability during pore formation, shaping, and early hardening. The rheological behavior of the mixture is determined by a complex combination of factors, including binder composition, type and dosage

of plasticizing admixtures, water-to-cement ratio (W/C), mixing intensity, and physicochemical activation of the components.

The rheological properties of mortar mixtures can be effectively regulated through control of water demand. Water demand is a key technological parameter that determines not only mixture workability but also density, porosity, structural uniformity, and ultimately the physical and mechanical properties of the hardened material. Excessive water content leads to reduced strength, segregation, and instability of the pore structure, whereas insufficient water complicates foaming processes and hinders uniform distribution of gas-forming components.

**Analysis of Recent Research and Publications.** The rheological characteristics of cement and cellular systems play a critical role in ensuring structural uniformity, optimal porosity, and stability during pore formation. Numerous studies [1–3] emphasize that the ability of a mixture to maintain plasticity, stability, and controlled gas formation without segregation constitutes a fundamental prerequisite for obtaining high-quality cellular concrete.

The workability and water demand of cement-based systems depend on interactions between binder particles, the surface properties of water, and the presence of organic and inorganic admixtures. According to previous studies [4, 5], an increase in binder dispersity or the introduction of active mineral additives modifies the specific surface area of the system, directly affecting the amount of adsorbed water and the kinetics of hydration processes.

Several researchers [5–7] have demonstrated that increased cement fineness or the incorporation of finely ground mineral additives (silica fume, fly ash, metakaolin) reduces water demand due to densification of the granular structure. The use of plasticizing and super plasticizing admixtures of various chemical types (naphthalene sulfonates, lignosulfonates, polycarboxylates) enables a reduction in the water-to-cement ratio by 10–25% without compromising mixture workability [8, 9].

The influence of plasticizing admixtures on the rheology of cement pastes has been extensively investigated. As reported by Ramachandran [6] and Rixom & Mailvaganam [7], lignosulfonate and naphthalene sulfonate admixtures reduce water demand by approximately 10–15%, whereas modern polycarboxylate-based super-plasticizers provide a more pronounced effect due to the steric repulsion mechanism between cement particles.

Experimental evidence indicates that optimal plasticizer dosage improves particle wettability, reduces the amount of bound water, and enhances the homogeneity of the cellular concrete structure. Excessive dosages, however, may result in excessive dilution of the mixture and loss of foam stability [8–10].

A significant approach to improving the technological properties of cement systems is mechanical-chemical activation. According to previous investigations, preliminary grinding of cement in high-energy mills alters particle morphology and creates active defects within the crystal lattice. This promotes intensified hydration, improved adsorption capacity, and, consequently, reduced water demand [11, 12]. It has been emphasized that the combination of mechanical activation with super plasticizer application produces a synergistic effect, enabling a reduction of the water-to-cement ratio to 0.25–0.30 while maintaining high workability. This is particularly important for cellular concretes, as excessive water content leads to reduced stability of the gas-foam structure and the formation of macropores [13, 14].

The rheological behavior of cellular systems differs fundamentally from that of conventional cement pastes due to the presence of pore-forming agents and stabilizers. Even minor variations in component ratios, viscosity, or surface activity of the liquid phase can significantly affect pore distribution, density, and strength of the final material [13–15].

Moreover, cellular cement systems exhibit complex nonlinear rheological behavior. Cement-foam mixtures demonstrate pseudoplastic characteristics, in which viscosity decreases with increasing shear rate. This implies that even slight changes in mixture composition or mixing energy may result in substantial variations in structure formation [15].

Recent studies also indicate that water demand and rheological properties are influenced by:

- content and fineness of quartz sand;
- type and concentration of surfactants;
- duration and intensity of mixing;

- temperature conditions during mixture preparation.

In particular, an increase in temperature above 30 °C accelerates hydration reactions and leads to structural thickening, necessitating additional water to maintain the required level of workability [16].

The analysis of the available literature indicates that a complex set of interrelated compositional and technological factors simultaneously affects the water demand of cellular concrete mortar mixtures. However, the interactions between these factors and their quantitative evaluation remain insufficiently studied, which determines the relevance and scientific significance of the present research.

**Research Objective.** The objective of this study is to determine the influence of plasticizing admixtures and mechanical-chemical activation on the water demand of mortar mixtures for cellular concrete.

**Research Tasks.** 1. To substantiate the selection of an appropriate type of plasticizer for the production of thermal insulation cellular concrete. 2. To conduct an experimental study using methods of mathematical statistics to evaluate the influence of various factors on the water demand of cellular concrete mortar mixtures.

**Materials and Methods.** The research was based on a systems approach, combining experimental investigations with statistical processing of results to determine the effects of individual and combined factors. Portland cement M-500 with a specific surface area of 320–340 m<sup>2</sup>/kg was used. The cement was characterized by stable hardening behavior and a low impurity content, which minimized result variability. Fly ash from thermal power plants was used as an active mineral additive, providing pozzolanic reactivity and reducing water demand through micro-filling of the intergranular space.

Chemical modification of the system was achieved using plasticizing admixtures: a naphthalene sulfonate plasticizer at dosages of 0.5–2.0% by cement mass and a polycarboxylate-based super plasticizer at dosages of 0.25–1.5%. Mortar mixtures were prepared by first dissolving the admixtures in mixing water, followed by the introduction of solid components and subsequent mixing. The flow spread diameter was determined using a Suttard viscometer. After the initial measurement, the mixture was subjected to mechanical-chemical activation for 30, 60, and 90 s in a laboratory rotor mixer providing intensive mixing and enhanced system homogeneity. After activation, the flow spread diameter was measured again.

The experimental program was conducted in two stages. During the first stage, the influence of two plasticizing admixtures of different chemical nature on the rheological properties and flow spread of cellular concrete mortar mixtures was evaluated. A second-generation naphthalene sulfonate super plasticizer acting via electrostatic dispersion of cement particles was selected for comparison. This admixture improves material density and strength, particularly at early stages of hardening, but may cause mixture segregation and structural non-uniformity when overdosed. A third-generation polycarboxylate super plasticizer acts through steric hindrance created by branched polymer chains, promoting uniform dispersion, structural stability, and improved physical and mechanical properties at relatively low dosages.

To address the second research task, a mathematical experiment design method was applied using a three-factor Box–Behnken design (type B-3). The selected variable factors were:

- X<sub>1</sub> – filler content (ground quartz sand): 0, 0.2, 0.4;
- X<sub>2</sub> – plasticizer dosage (naphthalene sulfonate): 0.5%, 1.0%, 1.5%;
- X<sub>3</sub> – duration of mechanical-chemical activation, s: 30, 60, 90.

Each factor was varied at three levels (minimum, central, and maximum), enabling the construction of a response surface model and assessment of factor interactions. The mixture preparation involved preliminary dry mixing of cement and ground quartz sand, followed by the addition of the plasticizer solution prepared in a portion of the mixing water. Subsequent mechanical-chemical activation was performed in a laboratory mixer for a duration corresponding to factor X<sub>3</sub>. The flow spread diameter was measured before and after activation, and the increment in flow spread was calculated as a quantitative indicator of the effect of mechanical-chemical activation.

**Research results.** Figure 1 illustrates the influence of plasticizer dosage at different water-to-cement ratios (W/C = 0.30–0.45) on the flow spread of the mixture. Based on the experimental data, clear regularities in the effect of plasticizing admixtures on mixture mobility were established.

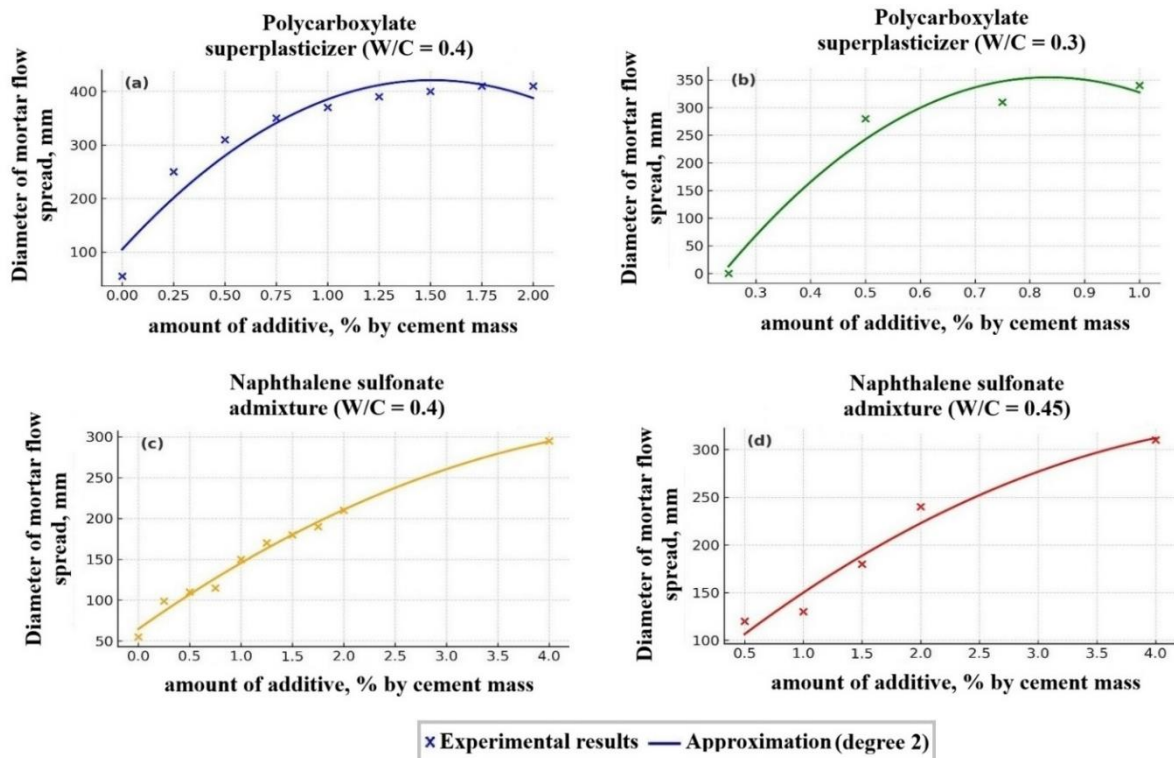


Fig. 1. Dependence relationship between the flow spread diameter and plasticizer dosage at different water-to-cement ratios obtained by polynomial approximation

Table 2 presents the results of the influence of variable factors on the flow spread diameter of the mortar mixture before and after activation, as well as the calculated increment in flow spread diameter, which characterizes the change in mixture workability induced by activation. The increment in flow spread diameter was adopted as a quantitative criterion for evaluating the effectiveness of the combined action of the plasticizer, mineral filler, and mechanical-chemical activation.

Table 2 – Planning matrix experiment and results

Run No.	Factors			Results		
	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	Flow spread diameter of the mortar mixture before activation, mm	Flow spread diameter of the mortar mixture after activation, mm	Increment in flow spread diameter, mm (absolute)
N	D	T				
1	-	-	-	50	160	110.0
2	+	-	-	90	215	125.0
3	-	+	-	70	225	155.0
4	+	+	-	255	300	45.0
5	-	-	+	120	220	100.0
6	+	-	+	195	340	145.0
7	-	+	+	155	250	95.0
8	+	+	+	245	380	135.0
9	-	0	0	165	230	65.0
10	+	0	0	220	320	100.0
11	0	-	0	155	285	130.0
12	0	+	0	185	340	155.0
13	0	0	-	165	270	105.0
14	0	0	+	185	320	130.0
15	0	0	0	210	270	60.0

Based on the experimental results, regression coefficients were determined and mathematical models describing the flow spread diameter of the mortar mixture before activation, after activation, and its variation induced by activation were developed. Due to the complex nonlinear nature of the observed relationships, logarithmic transformation was applied to obtain mathematical models that adequately describe the experimental data. The resulting logarithmic models of the response variables are expressed as follows:

1. Before activation  $LnD = 5.347 + 0.311x_1 + 0.204x_2 + 0.252x_3 + 0.085x_1x_2 - 0.117x_1x_3 - 0.112x_2x_3 - 0.097x_1^2 - 0.215x_2^2 - 0.184x_3^2$

2. After activation  $LnD = 5.705 + 0.177x_1 + 0.109x_2 + 0.129x_3 - 0.003x_1x_2 - 0.117x_1x_3 - 0.054x_2x_3 - 0.128x_1^2 - 0.009x_2^2 - 0.048x_3^2$

3. Increment  $LnD = 4.535 + 0.004x_1 - 0.063x_2 + 0.088x_3 - 0.173x_1x_2 + 0.229x_1x_3 - 0.069x_2x_3 - 0.256x_1^2 + 0.310x_2^2 + 0.115x_3^2$

All developed models were found to be adequate within a 5% experimental error. This made it possible to construct various graphical representations illustrating the influence of the variable factors on the water demand of the mortar mixture. Figure 2 presents a graphical interpretation of the experimental results. The combined three-dimensional plot illustrates the variation in the flow spread diameter of the mortar mixture before and after mechanical-chemical activation, as well as the increment of this parameter. This visualization enables a direct comparison of changes in mixture workability induced by mechanical-chemical activation under different combinations of filler content and plasticizer dosage.

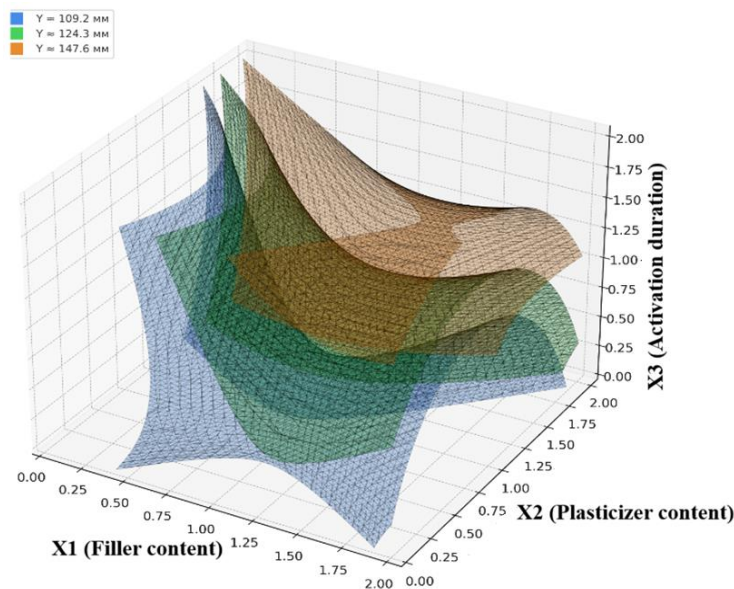


Fig. 2. Iso-surfaces of the flow spread increment resulting from mechanical-chemical activation

**Results and Discussion.** The obtained experimental results confirm a significant influence of both plasticizing admixtures and mechanical-chemical activation on the rheological properties of the mortar mixture. It was established that changes in mixture workability exhibit a pronounced nonlinear dependence on plasticizer dosage and activation duration.

**Effect of the Type of Plasticizing Admixture.** Figure 1 illustrates the dependence of the flow spread diameter of the mortar mixture on the dosage of plasticizing admixtures of different chemical nature at various water-to-cement ratios ( $W/C = 0.30-0.45$ ). As can be observed from the experimental data, an increase in plasticizer dosage in all cases leads to an increase in mixture workability, which is associated with enhanced dispersion of cement particles and a reduction in inter-particle coagulation. At the same time, the shape of the curves differs substantially depending on the chemical nature of the admixture.

For polycarboxylate-based super plasticizers (Fig. 1a, b), a pronounced parabolic relationship is observed. As the admixture dosage increases to 1.0–1.5% by cement mass, the flow spread diameter

increases rapidly, followed by a saturation effect. This behavior corresponds to the mechanism of action of polycarboxylates, which provide both electrostatic repulsion and steric stabilization of cement particles due to the presence of polymer side chains. The efficiency of the plasticizing effect increases with decreasing W/C, which is attributed to the higher particle concentration in the system and more intensive polymer adsorption on particle surfaces.

In contrast, naphthalene-formaldehyde-based admixtures (Fig. 1c, d) are characterized by an almost linear or sub-linear increase in flow spread without a clearly expressed saturation effect. Maximum workability values are achieved at dosages of 2.5–3.5%, which is mainly explained by the predominantly electrostatic mechanism of action of these admixtures. With increasing water-to-cement ratio, the efficiency of naphthalene-formaldehyde plasticizers decreases, since a higher amount of free water reduces the density of inter-particle contacts.

Thus, the experimental results confirm that polycarboxylate super plasticizers are more effective at low W/C ratios and provide a greater increase in mixture flow spread at lower dosages, whereas conventional naphthalene sulfonates exhibit a more linear but less pronounced effect. Polynomial approximation of different orders adequately describes the obtained experimental relationships and can be used for further quantitative assessment of the influence of plasticizers on the water demand of cement systems.

Analysis of the obtained dependencies indicates that the effectiveness of plasticizing admixtures strongly depends on both their chemical nature and the water-to-cement ratio of the system. Polycarboxylate super plasticizers ensure a significantly higher increase in workability due to the combined electrostatic and steric mechanisms, while naphthalene-formaldehyde admixtures demonstrate a gradual but less intensive effect. As the W/C ratio decreases, the sensitivity of the system to the action of plasticizers increases, opening opportunities for optimizing mortar compositions in order to reduce water demand while maintaining high technological performance.

**Effect of Mechanical-Chemical Activation.** Figure 2 presents iso-surfaces illustrating the influence of the main factors—filler content ( $X_1$ ), plasticizer dosage ( $X_2$ ), and duration of mechanical-chemical activation ( $X_3$ )—on the increment in the flow spread diameter of the mortar mixture. The iso-surfaces represent the spatial distribution of the response variable  $Y$ , which characterizes changes in mixture workability resulting from the combined action of these factors. As shown in the figure, the distribution exhibits a pronounced nonlinear character, indicating a complex interaction between the components of the system.

The most significant influence on flow spread is exerted by plasticizer dosage. As its content increases, the flow spread increases; however, beyond a certain level, a saturation effect is observed, where further increases in dosage do not lead to a substantial improvement. This behavior is explained by the attainment of a limiting surface adsorption of polymer molecules on cement particles, after which the system reaches a stabilized state.

The duration of mechanical-chemical activation ( $X_3$ ) exhibits a dual effect. At relatively short activation times (up to 60 s), the surface of cement grains is activated and the degree of system dispersion increases, which has a positive effect on flow spread. With increasing activation duration, however, the effect becomes adverse: excessive grinding of particles occurs, leading to an increase in specific surface area and water demand, which reduces the overall workability of the mixture. Thus, this factor is characterized by the presence of a clearly defined optimum.

The influence of mineral filler content ( $X_1$ ) is manifested through changes in system viscosity. At low and moderate concentrations, a slight increase in flow spread may occur due to a reduction in inter-particle friction. However, when the filler content exceeds a certain threshold, mixture workability decreases markedly as a result of plasticizer adsorption on the filler particle surfaces and mechanical densification of the structure.

The shape of the iso-surfaces indicates the presence of significant interactions between the investigated factors. The most pronounced synergistic effect is observed between plasticizer dosage and activation duration, where moderate mechanical-chemical treatment enhances the plasticizing effect and ensures the maximum increment in flow spread diameter. At the same time, excessive combinations of high values of both factors may lead to an opposite effect. Partial compensation of the negative influence

of filler content is also possible through activation, but only within optimal processing regimes.

Overall, the results confirm that mechanical-chemical activation in combination with plasticizing admixtures makes it possible to significantly enhance the workability of cement systems, provided that activation duration and mixture composition are appropriately selected. Polynomial approximation adequately reproduces the nonlinear nature of the observed dependencies and can be applied for predicting optimal technological parameters.

Further analysis of the obtained relationships shows that the effectiveness of mechanical-chemical activation is determined by the combined influence of activation duration, plasticizer dosage, and filler content. The maximum increment in flow spread is achieved at intermediate activation durations and increased plasticizer dosages, where a synergistic interaction between the factors is observed. Excessive activation or excessive filler content reduces mixture workability due to increased water demand and adsorption of plasticizer molecules by solid particles. Thus, an optimal combination of mechanical-chemical activation regime and mixture composition ensures maximum technological efficiency.

### Conclusions:

1. The study investigated the regularities governing the influence of plasticizing admixtures of different chemical nature and mechanical-chemical activation on the water demand and workability of mortar mixtures for cellular concrete. It was established that increasing plasticizer dosage within optimal concentration ranges reduces system water demand and increases the flow spread diameter.

2. Polycarboxylate super plasticizers provide a significantly greater effect compared to naphthalene-formaldehyde-based admixtures, which is explained by the combined electrostatic and steric mechanisms of action. Their efficiency increases with decreasing water-to-cement ratio.

3. Mechanical-chemical activation of the cement system positively affects mixture workability by increasing particle dispersity and surface activity. At the same time, excessive activation duration leads to an adverse effect due to increased specific surface area and water demand.

4. A synergistic interaction between plasticizer dosage and mechanical-chemical activation duration was identified. Optimal values of these factors ensure the maximum increment in flow spread diameter without compromising mixture stability.

5. The obtained results make it possible to determine rational component proportions and activation parameters for reducing water demand and improving the technological properties of cellular concretes, which is of practical significance for advancing thermal insulation material technologies.

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## РЕГУЛЮВАННЯ ВОДОПОТРЕБИ РОЗЧИНОВОЇ СУМІШІ ДЛЯ НІЗДРЮВАТИХ БЕТОНІВ ПЛАСТИФІКАТОРАМИ ТА МЕХАНО-ХІМІЧНОЮ АКТИВАЦІЄЮ

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**Анотація.** У роботі досліджено вплив пластифікуючих добавок різної хімічної природи та механо-хімічної активації компонентів на водопотребу та реологічні властивості розчинової суміші для ніздрюватого бетону. Встановлено, що збільшення дозування пластифікатора сприяє зменшенню водопотреби та підвищенню рухливості суміші, забезпечуючи стабільність газоутворення та формування рівномірної порової структури матеріалу, що є критично важливим для теплоізоляційних виробів. Доведено, що полікарбоксилатні суперпластифікатори проявляють більш виражений диспергувальний ефект порівняно з нафталінформальдегідними добавками, оскільки створюють на поверхні частинок цементу комбіновані стеричні та електростатичні бар'єри, які перешкоджають агрегації. Застосування механо-хімічної активації цементно-зольної системи підвищує її дисперсність, активує поверхню частинок і прискорює ранні стадії гідратації, що забезпечує зростання діаметра розтікання суміші без додаткового приросту водопотреби навіть за мінімальних дозувань добавок. Встановлено оптимальну тривалість активації, за якої досягається максимальний реологічний ефект. Надмірне подовження часу обробки, навпаки, призводить до надмірного подрібнення, збільшення питомої поверхні, підвищення водопотреби й можливого погіршення стабільності структури. Ізоповірхневий аналіз системи «дозування пластифікатора – тривалість активації – розтікання» підтвердив синергічний характер взаємодії цих параметрів: найбільший приріст рухливості спостерігається за поєднання помірної кількості пластифікатора з раціональною тривалістю механо-хімічної обробки, що забезпечує оптимальний баланс між текучістю та стійкістю суміші. Отримані результати дозволяють більш точно оптимізувати рецептуру та технологічний режим приготування ніздрюватих бетонів, підвищуючи технологічність, однорідність структури й експлуатаційні властивості готового матеріалу.

**Ключові слова:** ніздрюватий бетон, пластифікуючі добавки, полікарбоксилатні суперпластифікатори, механо-хімічна активація, водопотреба, рухливість розчинової суміші, ізоповірхні, оптимізація складу.

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