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Study of mineral components influence on foam system properties

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Abstract. In the article, the properties of foams obtained by activating an aqueous solution of a synthetic foaming agent, produced in Russia, are considered. According to the results, the foaming agent has sufficient characteristics that meet the requirements for building foaming agents. However, to improve the quality of materials, it is necessary to increase the foam stability. For this purpose it is proposed to use a mineral modifier of silicate composition (NM) based on quartz sand, obtained by wet stage milling of raw materials in a ball mill. The results of experimental studies show the effectiveness of NM introduction as a foam stabilizer. The use of a modifier during the foam system preparation leads to an increase in its stability in time and volume: the foam stability rises to 120 min, which is sufficient for the cement-based binding system with NM, offered for the further production of non-autoclaved cellular composites.

1. Introduction

In Russia requirements documents that regulate the quality indicators of building foaming agents used for the production of cellular concrete are introduced in the form of practical instructions in production. Analysis of the technology of cellular materials allowed the enterprises to develop certain requirements for the properties of foaming agents, which allows them to be ranked by the degree of technical and economic efficiency. The number of basic characteristics of foaming agents include their expansion ratio, stability over time and stability of porous mortar. At the same time, a specific methodology for studying the above properties of the foam agent, as a rule, is described in detail in the technical conditions for trade marks of foaming agents.

In recent years, synthetic foam agents of native and foreign production have been particularly demanding. Despite their lower resistance compared to protein, the characteristics of synthetic foaming agents in total are higher [1-3]. It is worth noting that, as a rule, Russian foaming agents practically are equal to the quality of import analogues. In this regard, on the basis of preliminary analysis of properties, as well as economic practicability for the production of foam concrete, a synthetic Russian foaming agent produced by limited liability company Shchit - Penostrom was used in the work. The concentration of the foaming agent solution in water, for which all the required parameters were studied, was assumed to be 0,6% according to the recommendations of the manufacturer.

2. Research methods

Expansion ratio of foam is determined by the ratio of the volume of the foam to the volume of the foaming agent used to form this foam:

$$K = \frac{V_f}{V_{fs}} \tag{1}$$

where V_f – is the volume of the foam obtained, cm^3; V_{fs} – is the volume of the foaming agent solution taken for testing, cm^3.

The expansion ratio of the prepared foam should be in the range of 6–10 in the case of lightly porous concrete, 10-20 for heat-insulating constructural materials and 15–40 for heat-insulating concretes [4].

Together with the expansion ratio, it is necessary to control the stability of the foam, which is determined by the time during which there is no upsetting of the foam column. The foam stability should be at least 15 minutes. In cases of technological failure of production, this indicator increases to 30 minutes. In addition, a number of manufacturers also suggest evaluating the stability of the foam in time before the release of 50% of the liquid (SP) from the foam, as well as the stability of the foam in the porous mortar or the foam utilization factor [5]. The value of the last factor characterizes the compatibility of the foam and cement paste, as well as the proportion of the use of a foaming agent for the preparation of the solution.

The stability of the foam in porous mortar is calculated by the formula:

$$C_{cp}^{f} = \frac{V_{cp}^{porous}}{V_{cp} + V_f} \tag{2}$$

where V_{cp}^{porous} – volume of the received porous mortar, l; V_{cp} – volume of cement paste, l; V_f – volume of foam, l.

The study of this indicator is performed according to the following procedure. To form 1 liter of the porous mortar in equal amounts, a cement paste with W/C = 0,4 and foam is mixed. The system is mixed for 1 minute and the height of the cellular–concrete mix is measured. The resulting technical foam can be considered satisfactory if the value is 0,8-0,85, the qualitative foam is > 0,95.

In addition to the indicated parameters, foam resistance is characterized by the coefficients of stability by synaeresis (K_{syn}^{f}) and volume (K_V^f) [5], which is determined by the processes of water separation – synaeresis:

$$K_{syn}^{f} = 1 - \frac{M_{syn}}{\rho_f} \tag{3}$$

$$K_V^f = 1 - \frac{V_{in} - V_T}{V_{in}} \tag{4}$$

where M_{syn} – is the mass of synaeresis of 1 liter of foam (the amount of segregated water), g; ρ_f – foam density, g/l; V_T – variable in time volume of foam, l; V_{in} – initial volume of foam, l. The specific surface was measured by the air permeability method with the Khodakov system devise, granulometry - using the Analysette 22 NanoTec plus particle size analyzer.

3. Results and discussions

According to the data obtained (Figure 1), the synthetic foaming agent Penostrom possesses satisfactory characteristics for foam stability in time, determined by volume change and synaeresis. So, in the case of water separation, the most intensive phenomenon of synaeresis is observed in the period up to 40 minutes (Figure 1, curve 2). Further, there is a significant inhibition of processes, which leads to a complete destruction of the foam structure by 80 minutes.

Table 1. A slightly more complex table with a narrow caption.

Foam density, g/l	Expansion ratio	Stablity, min	Stability of the foam in porous mortar
76	15	60	0,80

The physical meaning of the phenomenon of synaeresis is as follows. The production of foam is always associated with the use of a significant amount of water, which leads to its separation already at the beating up stage of the foam or immediately after its formation. Excess liquid from the foam films "flows" to the parts of connection of the films (Plato-Gibbs channels) along which it moves to the nodes of the channels, and then flows from the upper layers of the foam to the lower ones under the action of gravitational force [6-9]. As a result, a "watering" of the foam is observed in the system, which leads to thinning of the films and coalescence ("collapse") of the foam bubbles. The result of this process is a decrease in the stability of the foam and a reduction of the of its "life" time. In this case, the synaeresis of the foam is characterized by its coefficient, the maximum value of which is 1 and is noted in the first minutes of life (usually up to 10–15 minutes). With time, the value of this coefficient tends to zero [8].Changes in the volume of the foam are characterized by a slightly different kinetics. There are no sharp changes in the values of the coefficient of stability by volume. There is a smooth reduction in the volume of foam (Figure 1, curve 2). In this case, the stability of the foam with the release of less than 50% of water is stored up to 70 minutes. Further, the foam is destroyed and its volume is reduced to almost zero. Thus, the synthetic foaming agent Penostrom is characterised by good indexes of the expansion ratio that are necessary for the production of cellular concrete of a given class. Nevertheless, the stability of the foam in time is not high enough and is 80 minutes. However, for a pure cement test, the beginning of setting, i.e. initial processes of system structure formation, begins in 150 minutes. Such a significant difference in time between the "lifetime" of the foam and the beginning of the hardening of the matrix will lead to deformation and shrinkage, a decrease in the quality of finished products: an increase in density, a decrease in thermal conductivity, etc. In connection with the foregoing, a preliminary stabilization of the foamed mass is required to improve the quality of the products on its basis.

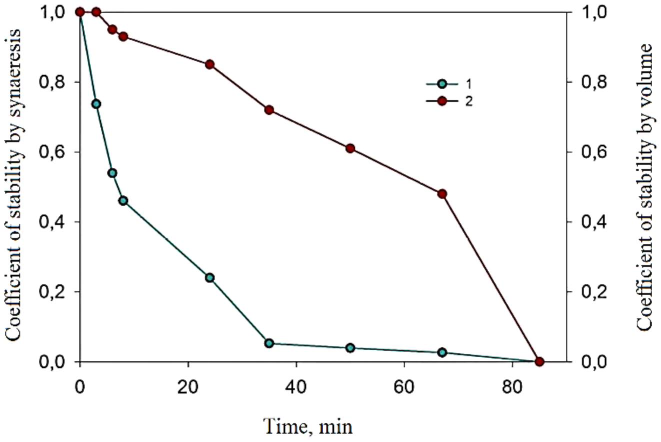


Figure 1. Stability of foams by synaeresis (1) and volume (2).

To increase the stability of the foam in time, a number of authors suggest the use of highly disperse mineral components, such as chalk, microsilica, etc. [10,11], as well as chemical stabilizers [12]. In this connection, the possibility of using a nanostructured modifier (NM) of a silicate composition based on quartz sand of the Korochansky deposit as a stabilizer of the foam system was studied. The features of obtaining and using the modifier are described in [13-26]. In this study NM was used primarily to improve the characteristics of Portland cement. The introduction of NM permits to increase the strength and reduce the setting time to 80 min [18-23]. However, the effect of NM on the properties of foam is also important in the case of using a modified binder in non-autoclaved hardening cellular concretes. The study of the impact of NM on foam was the task solved in the study of ways to increase foam stability and improve the quality of foam concrete. For comparison, chalk was used as the most widely applied mineral foam densifier in the production of heat-insulating foam concrete.

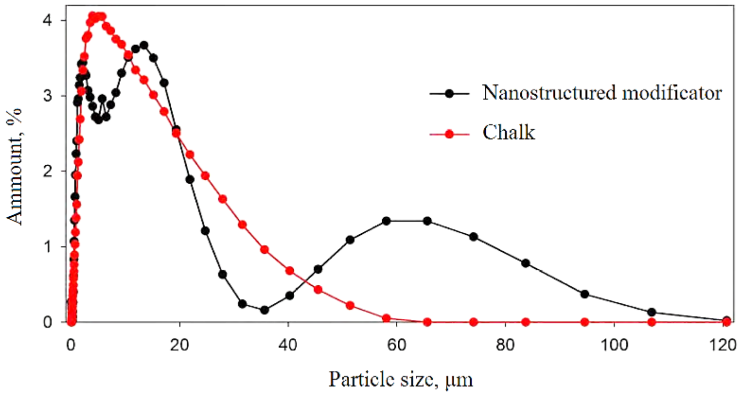


Figure 2. Granulometry of mineral components.

Thus, the dispersion of mineral components is comparable, therefore, a nanostructured modifier, when introduced into a foam system, will perform a function analogous to a chalk – acting as a densifier-stabilizer. To confirm this assumption, the stability of the foam in the presence of mineral components was studied.

The introduction of mineral stabilizers significantly reduces the synaeresis effect (Figure 3, a). In this case, the introduction of the chalk component almost completely eliminates the process of water separation from the foam while maintaining its volume. The use of a modifier in the formation of foam promotes an increase in its "life" by 1,5 times – stability in time increases from 80 to 120 minutes. In this case, the resistance, estimated by the separation of 50% of the liquid from the system, is maintained up to 80 minutes, while foam from the Penostrom without any additions by this time is completely destroyed.

An analysis of the kinetics of the change in the volume of the foam confirms the synaeresis data (Figure 3, b). The use of dispersed components to stabilize the foam leads to a significant increase in the stability of the foam. Thus, upsetting of the foam system does not practically occur regardless of the type of mineral additive.

It should be noted that despite the absence of volume changes in the case of mineral fillers application, the structure of the foam undergoes significant changes (Figure 4). So, as it was noted before, the absence of any stabilizers in foam, prepared on the basis of pure Penostrom, leads to its complete upsetting and water separation from its structure (Figure 4, d). The use of the chalk component helps to stabilize the foam at the entire stage of its life cycle. Nevertheless, the initial structure of the foam is characterized by small pores, uniformly distributed in the volume of the dispersion medium (Figure 4, b). With the passage of time (after 60 minutes), the pore size shifts toward larger dimensions, however, no synaeresis processes are observed (Figure 4, d).

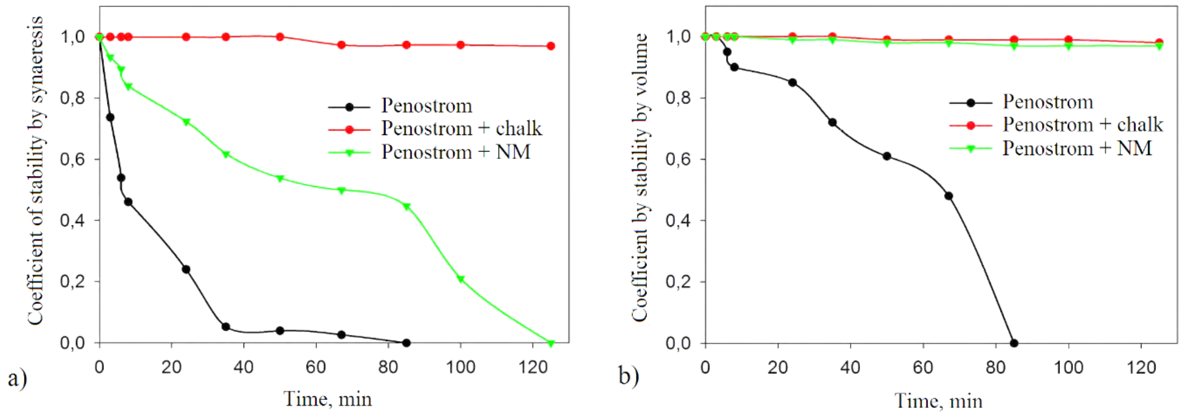
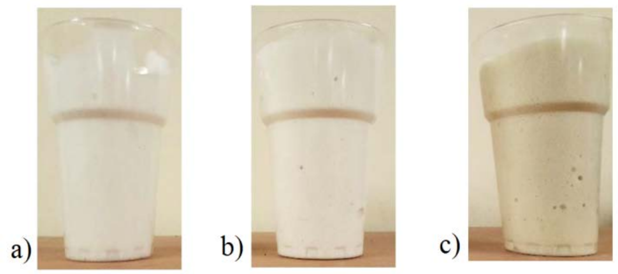


Figure 3. Kinetics of stability of foams in time by synaeresis (a) and volume (b) in the presence of mineral stabilizers.

The introduction of the nanostructured modifier into the foam mass has the same effect: the foam upsetting does not occur after the time has elapsed. However, the structure of the foam is characterized by the presence of large pores formed by confluence of smaller ones (Figure 4, f). In this case, the size of the fine pores considerably exceeds the size of the fine pores in the Penostrom + chalk system. The result of these processes is the essential water-separation of the mixture. However, the value of synaeresis is less than that for foam without mineral stabilizers (Figure 4, d).

After 5 minutes



After 60 minutes

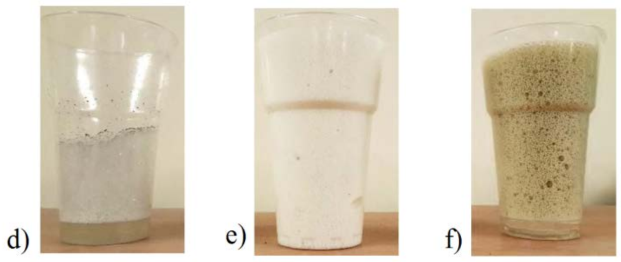


Figure 4. Visualization of synaeresis processes and changes in the volume of foam systems depending on the composition: a, d – Penostrom; b, e – Penostrom + chalk; c, f – Penostrom + nanostructured modifier.

Thus, the use of a nanostructured modifier in the obtaiment of a foam system makes it possible to achieve high stability indices in time with lower values of synaeresis (time of onset of synaeresis, amount of water). In this case, the effect of the influence of NM is less significant in comparison with chalk stabilizer. This is due to the features of the chalk structure, which is characterized by microporosity and, as a consequence, a high degree of hygroscopicity. Nevertheless, the mechanism of the modifier effect on the system is similar to the chalk and consists in the following.

When a nanostructured modifier is introduced into a foam system, adsorption ("adhesion") of solid particles on the surface of foam bubbles occurs, as well as the filling of the space between them. As a result, on one side there is an increase in the roughness of the walls of the bubbles, and on the other, the narrowing of the Plato-Gibbs canals and their blockage. A consequence of these phenomena is an increase in the dispersion of the foam (a decrease in the size of the bubbles and an increase in their number per unit area), which leads to an increase of its stability in time and volume.

An analysis of the microstructure of the foam systems confirms the proposed mechanism. Thus, foam without mineral dopants is characterized by an irregular geometry of cells with brightly expressed Plato-Gibbs channels of approximately the same size (Figure 5, a). The introduction of fillers in the foam system leads to a decrease in the size of the bubbles (Figure 5, b). At the same time, an accumulation of solid phase particles of mineral stabilizers is observed on their surfaces and in channels cross-points (Figure 5, b, c). It is worth noting that in the case of using chalk filling of channels (joints between the bubbles) is not complete. Nevertheless, dispersed components in the foam contribute to an increase in the viscosity of the system, which leads to an increase in its stability.

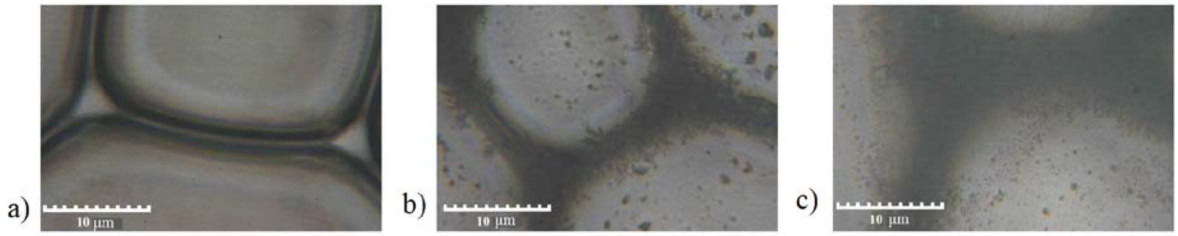


Figure 5. Microstructure of foam systems depending on the composition: a) Foam; b) Penostrom + chalk; c) Penostrom + NM.

Thus, the synthetic foaming agent used in the work is specified by satisfactory characteristics. In this case, the use of a nanostructured modifier in obtaining a foam system leads to an increase of its stability in time and volume, which is due to its stabilizing function. This will help to reduce shrinkage deformations in the cellular concrete mix both during hardening (strength set) and during the operation of finished products.

4. Summary (conclusion)

It is shown that the use of a nanostructured modifier in the preparation of a foam system leads to an increase in its stability in time and volume. This is due to its stabilizing function. This helps to reduce shrinkage deformation of the cellular concrete mix both during hardening and strength-setting, and during the operation of finished products.

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