Features of setting and strength gain of the foam concrete massif

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Abstract. The paper presents a study of the regularities of the processes occurring in the matrix and aerated concrete mass at the initial time after laying and later, during the strength gain. The colloidal properties that appear in the foam concrete mix begin at the stage of mixing the components containing binder and aggregate particles, and are activated by the mixer blades. In this case, the mixture is transformed by mass transfer of the matrix material onto the foam grid and a new spatial reorientation of the bubbles under conditions of physical and mechanical effects on the thin-film structure of the foam. In technology, it should be taken into account that the processes occurring in the foam concrete mixture can be attributed to two opposite actions occurring simultaneously. First, in a freshly laid foam concrete mixture, as in any thermodynamically unstable system, sedimentation and coalescence of air pores begins, which is especially manifested at forcedly high water-solid ratios. This can lead, if the technology is not followed, to complete stratification of the mixture. Secondly, in the cement slurry, the setting and further formation of the cement stone occurs. A necessary technological condition for product quality is compliance with the optimal water-solid ratio of the mixture and ensuring the beginning of the setting of the foam concrete mass before its stratification.

It was also experimentally determined that an increase in the hardening duration of foam-cement systems for more than 28 days is impractical, since it was revealed that an increase in the strength of foam concrete is similar to the same process in structural concrete. It is quite possible to achieve the strength required for foam concrete according to GOST 25485-89 within 28 days and even earlier due to the high technological discipline and the use of modern plasticizing additives.

1. Introduction

In Russia, foam concrete is used in construction mainly for the construction of enclosing structures due to its low thermal conductivity, environmental friendliness, and fire resistance. But in terms of manufacturability, the issues of accelerating the setting time and strength gain remain relevant [1,2,3]. In this regard, there is a need to investigate the processes occurring in foam concrete in the initial period after laying and later, during setting and aging to gain brand strength. The purpose of this article is to determine the specific features of the transition of a foam concrete mass from a colloidal solution to a porous stone.
2. Materials and methods

2.1. Materials
To assess the strength of the matrices, as well as the dynamics of strength gain, experiments were carried out on a cement matrix of foam concrete containing surfactants (surfactants). The surfactants used were cement grade PC-500-D0 produced by JSC Angarskcement, protein foaming agent Ompor and synthetic foaming agent PentaPAV (PPAV-430).

2.2. Methods
Studies of the dynamics of growth of the strength of the matrix were carried out on samples of beams 40x40x160. A foaming agent (surfactant) at a concentration of 0.5% to cement was introduced into the composition of the cement slurry without filler. In parallel, surfactant-free control beams were made. After stripping the formwork, the beams gained strength in the normal hardening chamber for 3, 7, 14, 28, 56 days. During these periods, further probes were taken from the batch of samples and the halves of the beams were tested for compressive strength in accordance with GOST 310.4-81.

3. Results
The tendency towards a decrease in strength and density with an increase in the concentration of the foaming agent was confirmed. Both protein and synthetic foaming agents caused a decrease in strength, density and loosening of the matrix stone. This effect clearly shows the difficulty of growing neoplasms and leads to a change in the microporosity of the cement stone towards an increase, and strength - towards a decrease. According to the Taube rule, the activity of the foaming agent in the cement system depends on the length of the molecular chain of the active substance. In protein surfactants, the molecule consists of thousands of atoms, which is probably why samples containing Ompor protein foaming agent lost their strength least of all.

According to the results of preliminary experiments obtained when determining the strength of the matrix, depending on the concentration of foaming agents in the samples with the content of surfactants of different nature, carried out earlier on the basis of the laboratory of the Department of PGS, it was shown that the steric effect in the cement matrix is expressed in a decrease in density and strength (Figure 1). To identify the further influence of negative factors, it is necessary to consider the hardening process as the foam concrete mass.

![Figure 1. The strength of the cement matrix from the concentration of foaming agents. 1 - matrix with Ompor foaming agent; 2 - matrix with PentaPAV-430.](image-url)
In this regard, the question arises about the refinement of the hydration kinetics, which can be estimated from the strength of the matrix containing the surfactant during the standard hardening period and in the future.

Based on the results obtained, graphs of strength growth were plotted at 3, 7, 14, 28 and 56 days of age of the matrix on M600 cement, which contains a surfactant and a control one (Figure 2).

![Figure 2](image)

**Figure 2.** Comparative graph of the dynamics of growth of the strength of the matrix on cement M600, control and containing a foaming agent. 1 - control, the matrix does not contain surfactants; 2 - matrix with Ompor foaming agent; 3 - matrix with foaming agent PentaPAV-430.

In general, it can be argued that the value of the intermediate values of the strength of the cement stone of the matrices in the standard 28-day time range is adequately described by the logarithmic model:

$$R_n = R_{28} \frac{\log n}{\log 28}$$  \hspace{1cm} (1)

![Figure 3](image)

**Figure 3.** An approximated graph of the growth of the strength of the matrix with a synthetic foaming agent (1) and the differential curve of the growth of the strength of the sample on cement M600 with the OMPOR protein foaming agent (2).

This mathematical model of strength growth is consistent with the general laws [4].
The highest strength was obtained on matrices made on M600 cement. The model of the strength
dynamics of the matrix containing the Ompor foaming agent is described by the equation:
\[ R_n = 23,839 \ln n + 7,424 \]  
where \( R_n \) is the compressive strength of the matrix for \( n \) days.

Strength gain can be estimated from the first derivative of the function of equation (2). After the
first differentiation of this model, there is the following expression:
\[ R_n' = \frac{23,839}{n} \]  

Analyzing equation (3), it can be argued that after 28 days of hardening, the increase is less than
one percent, therefore, further holding of the samples is impractical. In foam concrete, a similar pattern
of strength growth is observed (Figure 4).

![Figure 4. Graph of strength growth of non-autoclaved aerated concrete D700.](image)

4. Discussion

As a result of ensuring all quality factors, it is possible to achieve the best structure of the material
structure and maximum strength. It is known that in the presence of surfactants in a foamed cement
mortar, the setting time of the massif slows down and its strength decreases. This deceleration is due
to the fact that surfactants create a thin adsorption layer on the surface of the solvation shells of cemen
grain, which gives the same charges of particles and initiates the steric repulsion effect [5].

Foam concrete mixtures in their structure are multiphase and non-stationary. The stability of the
structure in such mixtures is predetermined by the degree of decompaction of the solid phase. In foam
concrete mixtures, its value is such that the stability of the mixture in the period of early structure for
mation can be provided only due to the optimal ratio between gravitational and electrostatic forces [5].

The colloidal properties that appear in the foam concrete mix begin at the stage of mixing the com
ponents containing binder and aggregate particles, and are activated by the mixer blades. In this case,
the mixture is transformed by mass transfer of the matrix material onto the foam grid and a new spatial
reorientation of the bubbles under conditions of physical and mechanical effects on the thin-film struc
ture of the foam. This is accompanied by partial destruction of the foam, and when low-density foam
concrete of grades D200-D300 is obtained - to the formation of a torn cellular structure and heteroge
neous open cellular porosity.

Thermodynamic equilibrium formed in the foam concrete mixture during mixing is established
from the equilibrium between gravitational, electrostatic and capillary forces immediately after the
termination of the external influence.

In technology, it should be taken into account that the processes occurring in the foam concrete
mixture can be attributed to two simultaneously acting and oppositely directed groups of actions. First-
ly, in a freshly laid foam concrete mixture, as in any thermodynamically unstable system, sedimentation manifests itself, especially when it is forced to have high water-solid relations. If the technology is not followed, this leads to complete stratification of the mixture (Figure 5). Secondly, setting begins in the cement slurry, the formation of solvation shells of cement grains, the nucleation of new formations from the solvation shells, the formation of clusters from particles and their accretion, leading to the setting of the entire foam concrete mass.

A necessary technological condition for product quality is to ensure the setting of the foam concrete mass before its stratification, in other words, the reduction of the "first" of these processes and the acceleration of the "second".

At the initial stage of the structure formation of foam concrete mixtures, when the mixing of the components is completed, but crystalline intergrowths have not yet formed, gravitational forces in combination with the energy capabilities of the surfactant films with changing properties of the binder control the redistribution of water within the dispersed system, which is carried out mainly through viscous contacts between them. The viscosity control in this system is carried out by the water-solid ratio or by plasticization of the mixture. Moisture on the surface of solid phase particles is physically firmly bound to them and does not contain surfactants. Therefore, the surfactant concentration in the bulk of the liquid phase of the mixture inevitably increases, which leads to an abrupt decrease in the viscosity of the liquid phase and a decrease in the elasticity of foam films [4]. As the process continues, this causes rupture of the foam films, initiating coalescence at the gas-liquid interface, leading to the coalescence of small gas bubbles into larger ones (Figure 5).

In this case, there is a redistribution of surfactants in the volume of the concrete mixture. Excess surfactants from the gas-liquid interface during coalescence are forced to move deep into the liquid phase of the concrete mixture. Then energy conditions arise for the formation of surfactant micelles, which reduce the viscosity of water. In the case when elastic bonds are formed between the particles of the solid phase and their strength is sufficiently developed to preserve the macrostructure of the concrete mixture, an increase in the concentration of surfactants in the liquid phase cannot lead to negative consequences. If only viscous bonds are formed between the components of the solid phase, with a high mobility of the foam mixture, then the development of coalescence naturally leads to the rupture of interpore partitions, stratification and sediment of the foam concrete mixture [5].

The first - the initial stage - occurs immediately after mixing and lasts from 30 minutes to 1 hour. The second - the main stage - begins approximately 5-6 hours after the start of mixing. There is a long induction period between the two stages of the process. The dissolution of the C3S mineral occurs simultaneously with the predominant transition of Ca2+ ions into a true solution. The silica remains in the solid phase as an orthosilicic acid gel. After reaching saturation of the liquid phase with respect to Ca (OH)2, the process of formation of calcium hydrosilicate begins and proceeds rapidly by the reaction of Ca (OH)2 in solution with orthosilicic acid gel in the solid phase. At the same time, the excess lime by crystallization precipitates into a solid phase. During hydration, there can be several (2...4) such elementary hydration cycles. At a certain stage, due to the formation of hydrosilicate under the primary shell, this shell is mechanically destroyed, which creates the conditions for the main hydration period to proceed.

Since it can be conditionally considered that the steric effect partially inhibits the hydration reaction, then, as indicated above, the presence of surfactants near the reacting atoms can prevent the approach of these atoms and make the reaction difficult or make it impossible in a certain number of bonds. Almost all foaming agents slow down the reaction of interaction of clinker minerals with a grout, and change the rate of formation of hexagonal hydrate phases, especially for the most active mineral of cement clinker - C3A. Moreover, large dosages of additives have a more significant effect on the crystallization kinetics of hydrated neoplasms and to a lesser extent affect the phase composition. In solutions of foaming agents, the interaction of C3A with water does not proceed completely, and even after 28 days of the hydration process, the unreacted part of the original alite partially remains in the system.
| Styling process | System Liquid - gas | System Liquid - solid |
|-----------------|---------------------|----------------------|
| Adverse events  | Coalescence         | Flocculation         |
| With high mobility of the mixture | Dispersed system (foam concrete mixture) |                |
| Sedimentation   |                      |                      |
| End result of the laying process with residual flow of the mixture (not desirable) | Complete stratification | Complete upbringing |
| System transition into a new quality - Coagulation condition - foam stabilization | Nucleation of neo-plasms from solvate shells of cement grains | 1. The processes of coagulation and sedimentation in solution proceed simultaneously |
|                 | Combining particles into clusters | 2. Factors of influence: |
|                 | Accumulation of clusters | Accelerators |
|                 |                        | Plasticizers |
|                 |                        | Water-solid relation |
|                 |                        | Foaming agent |

**Figure 5.** Process flow diagrams in foam concrete mix.
The elimination of these disadvantages can be achieved by a significant increase in \(W/T > 0.7\), but this negatively affects the strength and quality of the material. It is also possible to use dry mineral compositions of reduced wettability and water demand. However, the resulting low-density foam concrete in this case has a non-uniform cellular structure with many enlarged contact pores, which means low strength. When these foams are combined with a binder solution, it is necessary to increase the water-solid ratio [6,7,8].

5. Summary
The difficulty of growing neoplasms caused by the presence of a foaming agent leads to loosening of the structure of the cement stone, the formation of communicating micropores and, accordingly, a clear decrease in density and strength. It is generally accepted that the regularities of hardening of non-autoclave foam concrete based on Portland cement are expressed in the lengthening of the setting time, low set speed and low final strength, and a tendency to crack formation [9,10,11,12,13]. This is the traditional approach, but it turns out that these negative properties are formed only during the mixing, laying and setting of the mixture. Subsequently, the course of hydration in foam concrete is identical to the process of hydration of structural concrete.

Based on the assumption that the growth dynamics of the strength of the control matrix, which does not contain surfactants, is reference (Figure 2), then to compare a similar process in matrices containing foaming agents, the ratio of matrix strengths was determined according to formula (4) at different times of hardening according to points 3,7,14,28,56.

\[
\frac{Rn(matrix+Surf\,actant)}{Rn(matrix)}
\]

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