Strength of cellular concrete as a function of density under axial uniaxial compression

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Abstract. The purpose of this work is a comparative analytical assessment of the axial compressive strength of foam concrete depending on its density grade, taking into account strength losses in the presence of surface-active substances, porosity, and strength characteristics of the matrix material. The values specified in GOST 25485-89 and calculated according to the proposed analytical laws and regulatory data are compared. The effect of the foaming reagent on the strength of the foam matrix was evaluated in accordance with GOST 30744-2001 on standard samples-beams 40x40x160 mm in size from the control cement test without additives and with additives of synthetic and protein foaming agents of different concentrations in the sealer (from 0.3 to 3\%). The degree of influence of the foaming agent on the strength of the finished foam concrete prepared using classical technology was performed on samples-cubes of 100x100x100 mm in size according to GOST 10180-90. The article presents the results of a study of uniaxial compression strength calculated for cellular concrete depending on the density grades known from these regulatory documents and other sources. Analytical expressions for determining the strength calculated for cellular concrete with an average density of 300-900 kg/m\(^3\) are presented.

The proposed approach, based on the assessment of the initial data — the strength class of the binder, porosity, matrix strength, type and concentration of the foaming agent — allows us to predict the final strength of foam concrete products of this average density. Their rational accounting will help in the production of construction products of the maximum possible strength at a given density. This will expand the use of foam concrete in construction.

With modern heat engineering and environmental requirements for constructed objects, the main task is to reduce the energy intensity and cost of construction production. The use of cellular concrete, which includes foam concrete, allows you to ensure high quality of construction and meet the necessary strength and thermal engineering requirements for heat-insulating wall materials in accordance with GOST25485-89.

Foam concrete is an inexpensive, economical, durable, environmentally friendly, chemically and biologically resistant material, it is close to wood in terms of environmental friendliness, but it is fireproof and long – lasting. Foam concrete is used very widely and can be used in the following areas:

– production of building blocks of various sizes for the construction of wall fencing of residential buildings and the device of interior partitions;
– frame-monolithic housing construction of low-rise buildings;
– construction of enclosing structures, thermal insulation of walls, floors, floors and coverings of industrial buildings;
– filling of trench cavities due to the property of foam concrete does not settle and does not require vibration compaction, ensuring complete filling of sinuses and voids;
– thermal insulation of pipelines and main heating mains.

The production of foam concrete products with apparent simplicity is a complex technological process that requires careful compliance with the recipe and high production culture. Therefore, there are difficulties in the production of foam concrete, both technological and theoretical. Sometimes it is necessary to specify the recipe of the mixture at the place of preparation, taking into account the influence of local factors – water quality, binder activity, characteristics of the supply of the mixture to the place of laying, which include the height of the mixture supply and the distance to the place of laying.

Since foam concrete is a complex multi-component system, in order to achieve its high quality, it is necessary to take into account many elements that affect its physical and mechanical properties. From all the variety of factors, there are three main groups:
– technological factors (type of cooking technology, parameters of laying the mixture);
– composition of the mixture (type and activity of the binder, water-solid ratio, quality of the aggregate, type and concentration of the foaming agent);
– the conditions of curing (temperature of mix and environment)

In this paper, we consider a comparative analytical assessment of the axial compressive strength of foam concrete depending on some of its parameters: density grade, taking into account strength losses in the presence of surfactants, porosity, and strength characteristics of the matrix material. It is necessary to compare the values specified in GOST25485-89 and calculated according to the proposed analytical patterns according to regulatory and other documents.

Cellular concrete mix is a colloidal solution consisting of solid, liquid and gaseous phases. To form a porous structure, surfactants (surfactants) are introduced into the mixture. In [1-5], it was noted that, depending on the type of technology, the introduction of surfactants can be made either by mixing the cement solution together with a separately prepared foam (classical technology), or by whipping a mixture containing all the components (barotechnology). But the presence of surfactants in the mixture, firstly, increases the setting time of the foam concrete mass, and secondly, slows down the growth of its strength. At the same time, the interpore partitions are loosened and, as a result, the final strength of the product or monolithic mass is reduced, since surfactants envelop the solvate shells of cement particles and form an adsorption layer with a thickness of one molecule on their surface, which causes a "steric repulsion effect" [1, 2, 6, 7].

Figure 1. The strength of the cement matrix from the concentration of foaming agents.
The influence of the foaming agent concentration on the mechanical properties of the matrix was determined in a number of experiments and revealed quantitatively through the regularities of strength reduction depending on the concentration of the introduced surfactant (Figure 2). Since the cement matrix is a dense material that makes up the interpore partitions, it is for the most part it provides the required physical and mechanical characteristics of cellular concrete products [6]. Therefore, by obtaining high mechanical properties of the matrix, it is possible to increase the final strength of the concrete.

The strength of cellular concrete is also affected by the activity of cement. For the production of modern non-autoclaved foam concrete it is advisable to apply Alitalia Portland cement grade 500, 550 or 600.

Protein foaming agent introduced into the mixture, does not effect of reducing the like-ness as synthetic because it has a lower frequency and during hydration of cement in a solvent-re with a synthetic foaming agent, a steric effect is largely due to its excessive blowing activity.

Results and discussion

When evaluating the relationship between the average density and the axial strength of foam concrete, it can be stated that the greater the average density of cellular concrete and the lower the total porosity, the more dense matrix material in the array and, consequently, the increasing final strength of the porous cement stone with aggregate. In [8-11], studies were carried out that confirm the reliability of the directly proportional relationship between the strength and the average density of the foam matrix.

The normative sources (GOST 25485-89) specify the required range of strength of cellular concretes corresponding to their brand in density. The average values over the range are given in the graph in figure 3, taking into account the strength class formula:

\[ B = R_b (1 - V_t) \]  

where \( B \) is the concrete strength class; \( R_b \) is the average strength value; \( V \) is the coefficient of variation; \( t \) is the student coefficient with a confidence level of 0.95.

If to approximate the graphs of the strength of cellular concrete (see Fig. 2) calculated according to ГОСТ25485-89 polynomial type, we get the following equation:

\[ \text{Strength according to the formula} \quad (7), \quad b = 2.35 \]

\[ \text{Strength according to GOST 25485 for autoclave foam concrete} \]

\[ \text{Strength according to the formula} \quad (7), \quad b = 2.3 \]

\[ \text{Strength according to GOST 25485 for non-autoclave foam concrete} \]

**Figure 2.** Average value of strength of cellular concrete from grade on density.

If to approximate the graphs of the strength of cellular concrete (see Fig. 2) calculated according to ГОСТ25485-89 polynomial type, we get the following equation:
for autoclaved cellular concrete:

\[ R_b = 2 \cdot 10^{-5}D^2 - 0.0084D + 1.914; \]  

(2)

for non-autoclaved aerated concrete:

\[ R_b = 10^{-5}D^2 - 0.0048D + 1.07; \]  

(3)

where \( D \) – grade density, kg/m\(^3\).

Power approximation of curves according to GOST 25485-89 reveals the following strength equations:

- for autoclaved cellular concrete:
  \[ R_b = 5 \cdot 10^{-6}D^{2.096}; \]  
  (4)

- for non-autoclaved cellular concrete:
  \[ R_b = 3 \cdot 10^{-6}D^{2.077}. \]  
  (5)

With such approaches to the correlation of the brand density and axial compressive strength, in both cases, the accuracy of the approximation is \( R^2 = 0.99 \). This characterizes these models as quite adequate. However, these formulas do not take into account the porosity, strength of the matrix, and the influence of the foaming agent.

When considering the effect of porosity on strength, it is noted that with an increase in the average density of cellular concrete, the strength increase is observed in a parabolic relationship, which is reflected in [8-11, 12]. The reason for this phenomenon is that with increasing density, the negative influence of two simultaneously acting factors gradually decreases. First, the presence of surfactants in cement systems reduces the strength of the cement stone in proportion to the concentration of surfactants in the solution (Figure 2). This is quantitatively expressed by the formula (6). Secondly, there is an inversely proportional effect of organized porosity, this is shown in formulas (1-4, 8), where the exponent of the density value \( D \) is greater than one.

There is a solution that takes into account the porosity and mechanical properties of the matrix. The strength of cellular concrete \( R_b \) depending on the porosity \( n \) and the strength of the matrix \( R_m \) can be expressed according to [9] by the following Kirsley-Wainwright equation:

where \( b \) is an empirical indicator.

The value of total porosity, which is the ratio of the volume of voids to the total volume of concrete, can be formed by several known technological methods indicated in the sources [1-5]. Due to various technological requirements, to obtain a given design porosity, it is necessary either to introduce foam into the binder solution, or to foam the solution by rapid rotation of the mixer rotor, but with any technology for preparing a cellular-ton mixture, the foaming agent must be minimally sufficient, but such that its concentration does not lead to a significant decrease in the strength of the finished product. This amount is determined empirically in each case, when the critical concentration of micelle formation (CMC) in the surfactant solution is reached, as indicated in [6, 13-15].

Considering the strength reduction of the matrix on the concentration of the introduced foaming agent, approximately graphs in Fig. 2, we can derive the following relation in a General form:

\[ R_m = R_0 - k \cdot c, \]  

(6)

where \( R_0 \) is the strength of the matrix without foaming agent, MPa; \( k \) – the linear reduction factor so on-ness matrix from the type of foaming agent. It is determined for protein surfactant \( k=1,338 \), for synthetic Surfactant \( k=2,757 \); \( C \) – the concentration of the foaming agent in the cement test, % by weight of cement.

Substituting the \( R_m \) value in the formula (5) and taking into account the fact that \( n = 1 - \frac{\rho_b}{\rho} \), in the end

\[ R_b = (R_0 - k \cdot c) \cdot \left(\frac{\rho_b}{\rho}\right)^b \]  

(7)
where the index \( b \) depends on the average density of foam concrete and ranges from 3 to 4.5 \( D_{400} \) and \( D_{900} \) for; \( \rho_b \) is the average density of foam concrete of this brand, (kg/m\(^3\)), \( \rho \) is the density of matrix (kg/m\(^3\)).

A. T. Baranov Central scientific-research Institute of building structures (tsniisk) V. A. Kucherenko [16, 17] proposed a pattern – this is a simplified expression of formulas (1, 2). It quite adequately describes the strength of autoclave cellular concrete depending on the average density (see Fig. 2):

\[
R_b = 2 \times 10^{-5} D^2
\]  

Figure 4 shows graphs of the dependence of the strength of cellular concrete on the average density, which compares the strength according to GOST25485-89 for autoclaved and non-autoclaved concrete with the values obtained by the Baranov formula (8).

Thus, these formulas can help in calculating the axial compressive strength of cellular concrete in the range of average densities from 300 kg/m\(^3\) to 900 kg/m\(^3\). This will facilitate the work of both manufacturers of cellular concrete products, as well as designers and consumers.

The considered analytical methods for estimating the axial compressive strength can serve as an auxiliary material for calculating and predicting the physical and mechanical properties of cellular concrete. When designing the composition of such concrete, it is necessary to take into account the most significant quality factors that ensure the strength of the matrix and the finished cellular concrete product. These include the water-solid ratio, the strength class of the binder, and the type and nature of the foaming agent. Their rational accounting will help in the production of construction products of the maximum possible strength at a given density. This will expand the use of foam concrete in construction.

![Graph showing the strength of cellular concrete depending on the average density.](image)

**Figure 3.** The strength of foam concrete density according to the formula Baranov in comparison with GOST 25485-89

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