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Research of foam concrete quality by two-stage foam injection method in comparison with classical foam concrete

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Abstract. The article presents a method of production of foam concrete, which involves two-stage injection of foam. The proposed method involves improving the pore structure of foam concrete, due to a more uniform distribution of pores throughout the volume of the material. Laboratory tests were carried out for two types of samples, represented by the proposed method of foam concrete production by two-stage foam injection with the use of modified additive in comparison with the classical foam concrete. The density of Type 1 samples varies from 410 to 793 kg/m^3 (coefficient of variation from 5.12 to 7.31%), while the density of fiberboard samples lies within the range from 539 to 655 kg/m^3 (coefficient of variation from 2.66 to 3.14%). The results of greater variation of densities by height in the Type 1 sample relative to the Type 2 sample indicate the influence of the technological process of foam concrete production on the quality of the pore structure of the material. The results of strength evaluation showed a large scatter of Type 1 samples in relation to Type 2 samples. The highest values of CM strengths are logically observed in the lower part of the sample and the lowest in the upper location: 44.04 and 32.33 kg/cm^2 (coefficient of variation from 5.15 to 9.54%). For Type 2 samples, the same values are 55.18 and 44.44 kg/cm2, for the lower and upper locations, respectively (coefficient of variation from 2.79 to 5.35%). The results of thermal conductivity measurements of Type 1 samples range from 0.098 to 0.203 W/m^{0}C (coefficient of variation from 4.59 to 11.88%), while the densities of Type 2 samples lie between 128 and 162 W/m^{0}C (coefficient of variation from 3.38 to 3.55%).
Keywords: foam concrete, blowing agent, microsilica, post-alcohol bard, density, strength, thermal insulation properties, production technology.

1. Introduction

In recent decades, intensive research in the field of concrete has led to significant progress in both theoretical aspects and technological developments. This includes the development of new admixtures, the optimization of compositions and mixing techniques, and the application of specialized processing and curing methods. These efforts have made possible the creation and production of concretes with a wide range of properties, from heavy to lightweight, with unique characteristics of strength, durability, thermal and acoustic insulation, and the ability to adapt to different operating conditions and environments [1-3].

In modern conditions, there is an active development of foam concrete production, which is due to the introduction of new, more efficient blowing agents and the use of energy-saving technologies based on the principles of non-autoclave production. New blowing agents offer more precise control over the process of foam formation, which allows to obtain more stable product quality and reduce production costs [4-6].

The development of new approaches to foam concrete production is an integral part of the evolution in the construction industry. Modern production methods face challenges such as structure heterogeneity and material shrinkage during the setting process [7, 8]. Despite the progress, shrinkage remains an issue as it can influence the final properties of building products. Nevertheless, the classical production method continues to be widely used in the construction industry, with the constant introduction of various additives and improvements. The continuous search for new foam concrete production methods is driving innovation in the construction industry. This search is aimed at improving the quality of building materials and providing increased efficiency and durability of building structures in general [9-11].

To solve the problems associated with instability of structure and non-uniformity of foam concrete density, an approach based on two-stage introduction of foam into the material is proposed. The initial introduction of a low-concentrated blowing agent solution allows to achieve uniform foam distribution within the mixture. This helps to create a more homogeneous and stable material structure. This is followed by the addition of a highly concentrated solution, which further enhances the formation of a stable foam concrete structure. This approach ensures that the foam is evenly distributed in the material, making the final product more homogeneous and stable. Reducing the water-cement ratio at the production stage shortens the setting time, which in turn improves the strength characteristics of the foam concrete. These results are confirmed by numerous studies in the field of construction materials and technologies [12-24].

Foam concrete producers are regularly challenged by structural instability, material shrinkage and uneven density, which can ultimately affect the stability and quality of the finished product. These deficiencies are often caused by high water-cement ratios, which affect the texture and overall quality characteristic of the concrete. To solve these problems, producers resort to the use of plasticizing admixtures, which not only improve the mortar characteristics but also achieve more stable results in production [25, 26]. The addition of various modifying admixtures makes it possible to customize the properties of concrete according to the requirements and improve its performance, providing more durable and better quality end products. Modified admixtures and plasticizers represent an integral part of the foam concrete improvement process in the construction industry. Research and experimental applications of these additives demonstrate their significant contribution in strengthening the structure, reducing material shrinkage and providing uniform density. These factors significantly improve the strength and thermal insulation properties of foam concrete, making it a more competitive and sought-after material for various construction applications. However, it is important to note that when choosing modified additives and plasticizers it is necessary to take into account not only their technical characteristics, but also their environmental impact [27-29].

The developed modified additive for foamed concrete includes two key components: microsilica and post-alcohol bard. Microsilica, which is a finely dispersed substance, helps to improve the strength and stability of the material structure, as well as to increase its thermal insulation properties by optimizing the internal structure. Post-alcohol bard, in turn, has properties that help to increase density and improve adhesion, which affects the durability and stability of foam concrete. The combination of these ingredients creates an effective additive that can improve the quality and performance of foam concrete, making it a stronger, more thermally insulating and durable material for building structures. Both of these components are important ingredients for creating high quality foam concrete with improved performance.

The aim of the study is to evaluate the homogeneity of the pore structure of the proposed method of foam concrete production by two-stage foam injection using a modified additive in comparison with classical foam concrete.

2. Methods

In order to realize the set goal it is necessary to solve the following tasks:

- to prepare large samples of foam concrete produced by the classical method and the two-stage foam injection method, GOST 25485-2019, GOST17177-94 [30, 31];

- to prepare samples by segmenting large samples and taking them from different locations for further laboratory testing, GOST 25485-2019, GOST17177-94 [30, 31];
- laboratory testing of foam concrete samples to determine the density, strength and thermal insulation values (Figure 1), GOST 25485-2019, GOST17177-94 [30, 31].

Figure 1 – Laboratory testing of foam concrete

From the technological point of view, the proposed production method is fundamentally different from the previous technologies and includes two-stage foam injection, which was not practiced earlier (Figure 2). The proposed method provides maximum distribution of foam concentrate over the entire volume of the sample: the primary introduction of low-concentrated foam solution occurs at the stage of preparation of sand-cement mortar, thereby improving its wettability and subsequent reduction of water-cement ratio (reducing foam quenching by water). Subsequently, at the secondary introduction of highly concentrated foam solution at the stage of manufacturing the structure of cellular concrete, the reduction of water-cement ratio allows to maximally preserve the primary multiplicity of foam concentrate, contributes to the formation of a uniform structure of porous material.

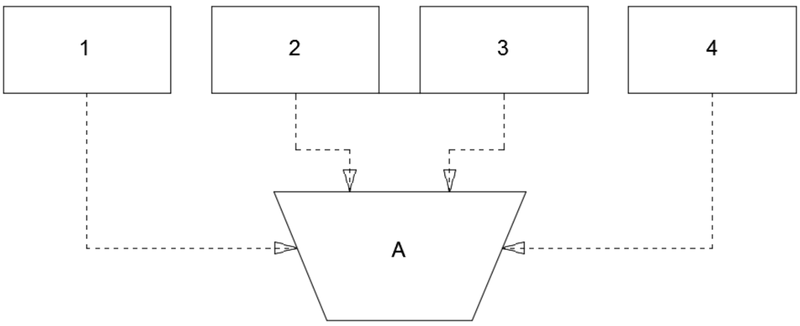


Figure 2 - Scheme of foam concrete production by two-stage foam injection

The technological process is represented by the following production stages: stage 1 - introduction of microsilica with post-alcohol bard, in the ratio of 10:1 by mass (60 kg per 6 liters per 1 cube), kneading 5 minutes; stage 2 - introduction of sand-cement mixture, in the ratio of sand to cement 1: 1.40-1.45 by weight (220 kg to 320 kg per 1 cube), kneading 2-3 minutes; stage 3 - introduction of foam with water in the ratio of 0.23 grams of foam per 75 liters of water per 1 cube, kneading 5 minutes; stage 4 - leading foam with water in the ratio of 1.27 grams of foam per 40 liters of water per 1 cube, kneading 2 minutes.

The studies will be performed for foam concrete samples made by the proposed method of two-stage introduction of foam with additive. The results will be compared with the reference sample - with the classical foam concrete production technology. The technological composition of manufacturing of each method is presented in Table 1.

Table 1 – Technological composition of the compared samples

Index	Unit	Type 1	Type 2
Microsilica	kilogram	-	-
M400 cement	kilogram	320	320
Fine sand	kilogram	220	220
Post-alcohol bard	liter	-	6
Foaming agent to water ratio at primary injection	gram : liter	1.5:115	0.23:75
Foaming agent to water ratio at secondary injection	gram : liter	-	1.27:40

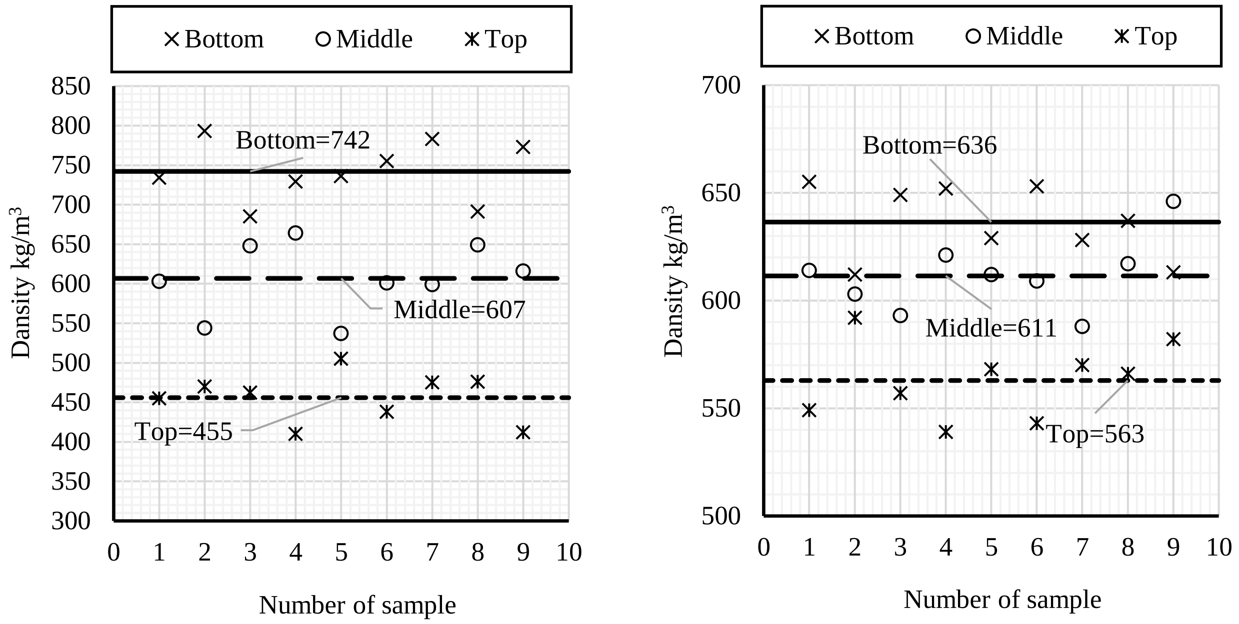
A total of 6 samples were tested for each of the compared types of foam concrete samples in order to obtain statistical measurement data. To evaluate the quality of pore structure of foam concrete, a large cube-shaped sample with dimensions 500x500 mm was prepared. To assess the volumetric homogeneity (distribution of pores throughout the volume of the material), the large sample was segmented into cubes (samples) with dimensions 100x100 mm. Control sampling for evaluation of physical-mechanical and strength characteristics was performed in the middle and peripheral (upper and lower) parts of the sample. The variability of sampling in the vertical direction is primarily due to the fact that the heterogeneity of the pore structure of foam concrete is manifested in the vertical direction. The latter is due to the fact that during foam quenching the formed soapy water tends downward, under the influence of gravitational forces, until the setting of the cement-sand mixture. Therefore, analyzing the vertical distribution of the pore structure is the prerogative of this study. The vertical variation in sampling, however, is primarily due to the statistical necessity required to obtain a stable average result. For convenience, the samples were labeled, vertically with Latin letters and horizontally with Arabic and Roman numerals. A total of 27 samples were collected, 9 samples from each distinct vertical level.

3. Results and Discussion

Figure 3 shows the results of density determinations of the compared foam concrete samples. Figure 3a shows the results of partial values of classical foam concrete (Type 1), Figure 3b - of foam concrete with two-stage foaming (Type 2).

According to the measurement results, the Type 1 samples show a significant vertical variation in density values. Samples from the lower part of the Type 1 sample showed the highest values, ranging from 685 to 793 kg/m^3, with an average value of 742 kg/m^3. The lowest density values were found in the upper part of the large sample: 410 to 505 kg/m3, with an average value of 455 kg/m^3. In the middle part of the sample, the density is maximally consistent with the D600 foam concrete grade, ranging from 537 to 664 kg/m^3, with an average value of 607 kg/m^3. Relatively dense density results are observed in Type 2 samples. The densities in the lower part range from 612-655 kg/m^3 and the average is 636 kg/m^3. The densities in the lower part are in the range of 539-592 kg/m^3 and the average is 563 kg/m^3. The density results in the middle part, also maximally corresponding to the D600 foam concrete grade, ranges from 588 to 617 kg/m^3, and the average is 611 kg/m3. Comparison of the coefficients of variation showed that the stability of the private values of Type 1 samples is much lower than Type 2 samples. The variation of Type 1 samples ranges from 5.12 to 7.31% while that of type 2 samples ranges from 2.66 to 3.14%. The maximum variation of data of Type 1 samples is 50% higher than that of Type 2 samples. Nevertheless, the relationship of the individual values remains close as the maximum variation values do not exceed 10%.

The results of a greater variation of densities by height in the sample of Type 1 relative to the sample of Type 2 indicates the influence of the technological process of foam concrete production on the quality of the pore structure of the material.

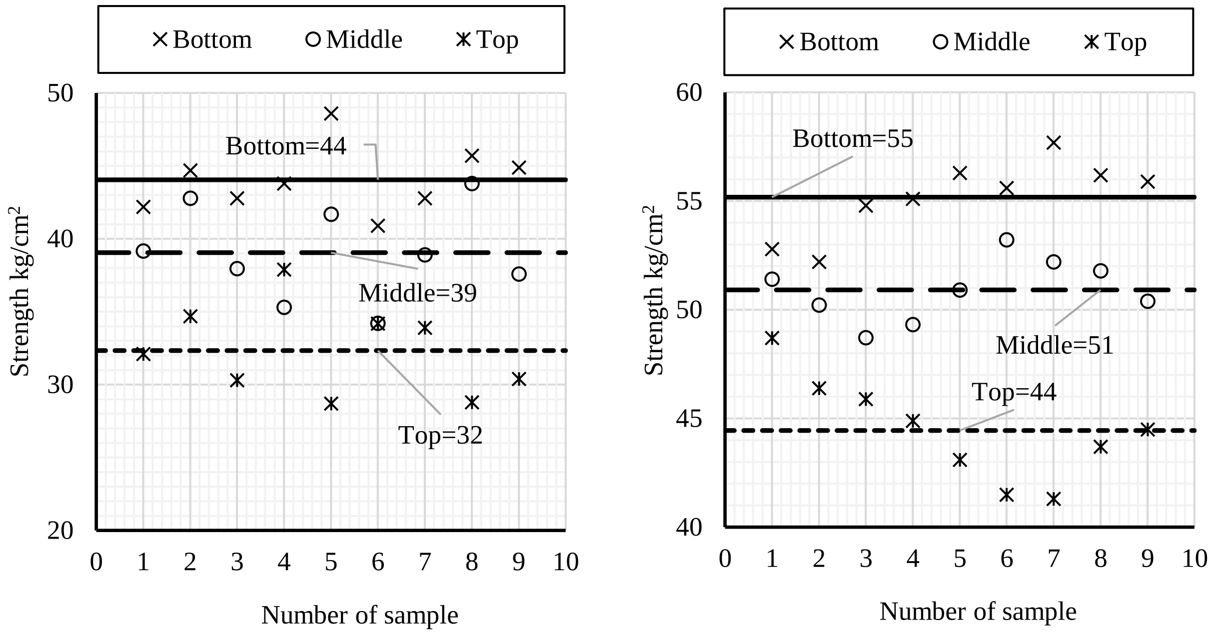


a) Values of classical foam concrete

b) Values of foam concrete with two-stage foaming

Figure 3 – Results of density measurements

Figure 4 shows the results of determinations of strength values of the compared foam concrete samples. Figure 4a shows the results of private values of Type 1 foam concrete, Figure 4b – Type 2 foam concrete.

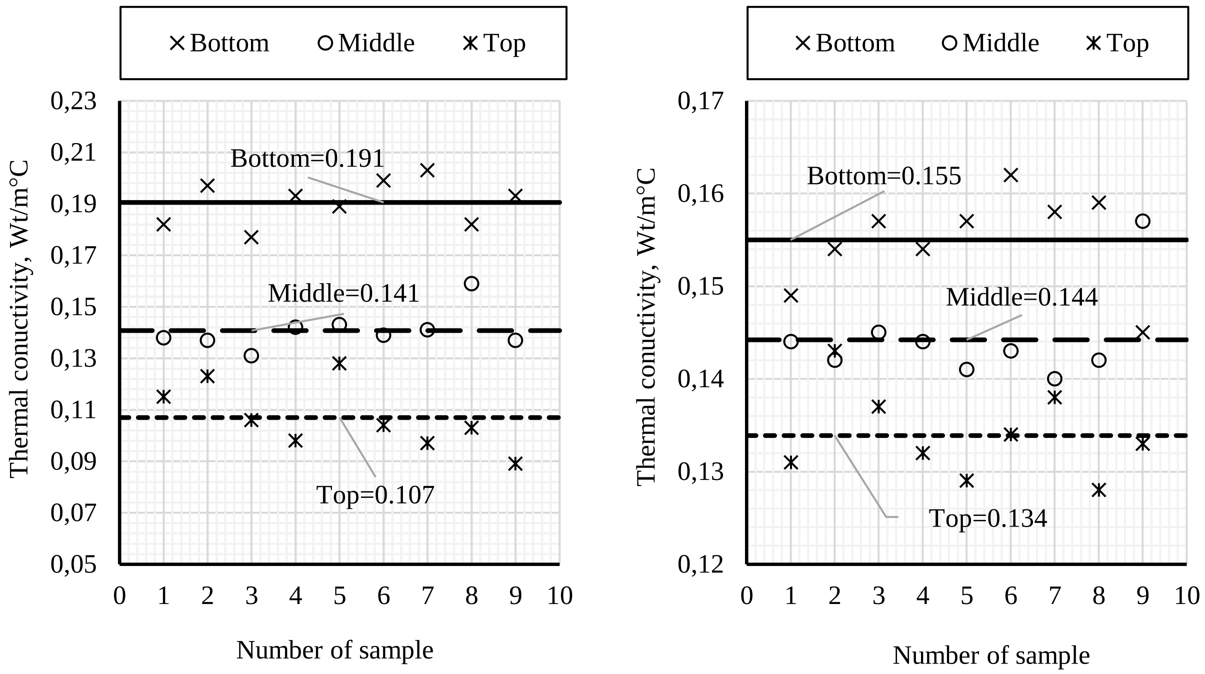


a) Results of Type 1

b) Results of Type 2

Figure 4 – Results of strength measurements

Figure 5 shows the results of determinations of thermal conductivity values of the compared foam concrete samples. Figure 5a shows the results of partial values of Type 1 foam concrete, Figure 5b – Type 2 foam concrete.



a) Results of Type 1 b) Results of Type 2

Figure 5 – Results of thermal conductivity measurements

The results of thermal conductivity measurements logically showed a similar dependence with the estimation of densities: the Type 1 samples show a significant vertical variation of values. The highest values are also observed in the lower part of the sample, which corresponds to the maximum density: thermal conductivity varies from 0.177 to 0.203 W/m^{0}C, with an average value of 0.191 W/m^{0}C. The lowest thermal conductivity values are logically found in the upper part of the large sample, which corresponds to the lowest thermal conductivity values: 0.098 to 0.159 W/m^{0}C, with an average value of 0.107 W/m^{0}C. In the middle part of the sample, the thermal conductivity varies from 0.131 to 0.159 W/m^{0}C, with an average value of 0.141 W/m^{0}C. In the lower part of the type 2 image, the thermal conductivity ranges from 0.145-0.162 W/m^{0}C and the average strength is 0.155 W/m^{0}C. The thermal conductivity in the lower part of the sample ranges from 0.128-0.143 W/m^{0}C and the average strength is 0.134 W/m^{0}C. The results of thermal conductivity in the middle part varies from 0.140 to 0.157 W/m^{0}C, and the average is 0.144 W/m^{0}C.

Comparison of coefficients of variation showed that the stability of private values of Type 1 samples, as in the case of density, is significantly lower than that of Type 2 samples. The variation of Type 1 samples ranges from 4.59 to 11.88%, while that of type 2 samples ranges from 3.38 to 3.55%. The maximum data variation of Type 1 samples is more than 50% higher than that of Type 2 samples. The results of greater variation of thermal conductivity, as in the case of density, by height in sample type 1 relative to sample Type 2 indicates the influence of the technological process of foam concrete production on the quality of the pore structure of the material.

4. Conclusions

The following conclusions can be made on the basis of the experimental studies:

1. The results of density estimation of segmented foam concrete samples produced by the classical method (Type 1) and the two-stage foam injection method (Type 2) were obtained. The results showed a non-uniform distribution of the pore structure of foam concrete in the vertical of the Type 1 samples relative to the Type 2. A large variation in the density of Type 1 is particularly observed in the vertical, where the lower samples showed densities on average 38% higher than those of the upper location samples. The same figure for the fiberboard samples was, on average, only 11%. The density of the Type 1 samples ranged from 410 to 793 kg/m^3 (coefficient of

variation from 5.12 to 7.31%), while the density of the fiberboard samples ranged from 539 to 655 kg/m^3 (coefficient of variation from 2.66 to 3.14%). The results of greater variation of densities by height in the sample of Type 1 relative to the sample of Type 2 indicate the influence of the technological process of foam concrete production on the quality of the pore structure of the material.

2. The results of strength evaluation of the same segmented foam concrete samples were obtained. The results expectedly showed a large variation of Type 1 samples with respect to the fiberboard samples. The highest values of Type 1 strengths are logically observed in the lower part of the sample and the lowest in the upper location: 44.04 and 32.33 kg/cm^2 (coefficient of variation from 5.15 to 9.54%). For fiberboard samples, the same values are 55.18 and 44.44 kg/cm^2, for the lower and upper locations, respectively (coefficient of variation from 2.79 to 5.35%). The maximum variation of Type 1 sample data is 40% higher than the variation of Type 2 sample data. All private strength values of Type 2 samples exceed the private strength values of Type 1 samples (regardless of location), which is not characteristic of previously determined material density in different locations. The latter indicates the influence of the modified additive on the strength values of foam concrete.

3. The results of thermal conductivity estimation of the same segmented foam concrete samples were obtained. The results of thermal conductivity measurements logically showed a similar relationship with the estimation of densities: the Type 1 samples have a significant vertical scatter of values. In percentage terms, the scatter of Type 1 thermal conductivity is as follows: the thermal conductivity of the lower location samples is on average 44% higher than the thermal conductivity of the upper location samples. The same indicator for fiberboard samples was only 13%. The thermal conductivity of Type 1 samples varies from 0.098 to 0.203 W/m^{0}C (coefficient of variation from 4.59 to 11.88%), while the density of fiberboard samples lie in the range from 128 to 162 W/m^{0}C (coefficient of variation from 3.38 to 3.55%). The results of greater variation of thermal conductivity, as well as in the case of density, by height in the sample of Type 1 relative to the sample of Type 2 indicates the influence of the technological process of foam concrete production on the quality of the pore structure of the material.

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Tattigul Seidmarova – interpretation, drafting.

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