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DURABILITY ASSESSMENT OF CELLULAR CONCRETE THROUGH STRENGTH EVALUATION UNDER ADVERSE ENVIRONMENTAL CONDITIONS

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ABSTRACT: This article presents the results of durability assessment for various types of cellular concrete. The research was conducted on aerated concrete samples utilizing a two-stage foam introduction method, classical foam concrete method, and autoclaved aerated concrete. Adverse factors affecting the material's durability were attributed to the influence of natural-climatic conditions, including temperature cyclicality (both low and high), cyclic wetting (immersion), wind cyclicality, and aggressive environments. The tests were conducted under the following combined exposures: cyclic freezing with prior immersion, cyclic exposure to high temperatures with and without immersion, and exposure to a 10% sulfuric acid solution. Durability loss patterns were observed for each type of adverse exposure based on the experiment duration. An evaluation of the resistance of specific materials to particular adverse influences is provided based on the obtained results. The findings underscore the importance of material selection based on specific operational conditions and contribute to the development of more durable construction materials for use in aggressive environments.

Keywords: Foam, Foam concrete, Two-stage foaming, Pore structure, Cellular concrete.

1. INTRODUCTION

One of the key driving factors for the advancement of the construction industry is the invention and implementation of new materials and manufacturing technologies, including technologies in concrete construction [1-3]. This article explores the modernization of the technological process for producing foam concrete, a variant of lightweight concrete. Currently, a significant portion of the application of lightweight concrete in construction is attributed to aerated concrete blocks (or aerated concrete), owing to its relative ease of production compared to foam concrete [4].

In comparing foam concrete to aerated concrete, a market-offered alternative, foam concrete possesses a logical advantage in several respects. The potential for manufacturing monolithic structures on the construction site, unlike aerated concrete (as aerated concrete expands during solidification, preventing precise geometric dimensions of construction elements, an important indicator of quality and reliability in their usage) [5].

The ability to create horizontal structures from monolithic foam concrete (manufacturing horizontal structures from aerated concrete is labor-intensive and not cost-effective, as aerated blocks are prefabricated elements without reinforcement and are not designed to withstand significant shear stresses). For equal strength of foam concrete and aerated concrete, a structure (e.g., a wall) made of monolithic foam concrete will possess greater compressive and tensile strength compared to a structure made of prefabricated aerated blocks (as in the case of compression, the distribution of stress-strain state in monolithic foam concrete will be more uniform, unlike in prefabricated aerated blocks, and in the case of tension, the strength of the aerated block will be limited by the adhesive bond) [6].

The monolithic nature of foam concrete provides the construction with greater stability compared to prefabricated aerated blocks, improving the resistance of the structure to bending, both in-plane and out-of-plane. The ability to perform spatial reinforcement of load-bearing foam concrete structures expands the material's application compared to prefabricated aerated blocks [7].

However, drawbacks include the relative complexity of assembling structures from monolithic foam concrete, necessitating additional formwork, although with streamlined serial production, this drawback is offset by the complexity of masonry work when using aerated blocks, as well as the arrangement of technological longitudinal reinforcement not provided for in the aerated block structure (i.e., manual groove cutting is required in the aerated block).

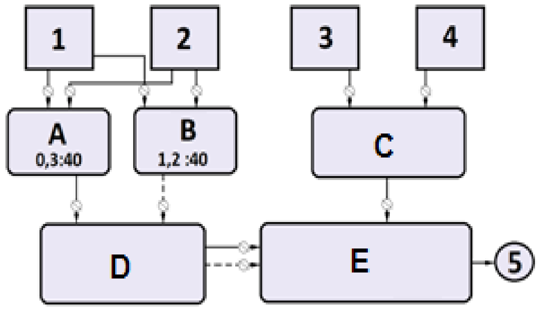
Undoubtedly, advantages of foam concrete over aerated concrete may include the closed pore structure of foam concrete compared to aerated concrete, making it stronger (due to a more robust skeletal structure); relative durability of foam concrete, based on the inclusion of cementitious binding agents in its composition, in contrast to aerated blocks that incorporate lime-gypsum binders, which have lower resistance to mechanical influences (especially water exposure) [8]. However, these advantages remain theoretical, as under other identical conditions (material reliability and durability), the simplification of the production process becomes the prevailing advantage [9]. This article will present durability research on the proposed foam concrete production method compared to the classical method and aerated concrete.

2. RESEARCH SIGNIFICANCE

This research holds paramount significance as it rigorously examines the durability of various cellular concrete types, offering insights into their performance under diverse environmental conditions. The findings have implications for construction material selection, especially in harsh climates. By unraveling the nuanced responses to freezing, thermal exposure, and acid attack, the study contributes valuable knowledge for enhancing construction materials' resilience. This insight is crucial for engineers, architects, and stakeholders, guiding them toward more informed decisions in material choices, ultimately advancing the state of the art in sustainable and durable construction practices.

3. MATERIALS AND METHODS

The proposed method for producing foam concrete, in contrast to the classical method, involves a two-stage introduction of foam. The primary introduction of a low-concentration foam solution occurs during the preparation stage of the sand-cement mixture, thereby improving its wetting properties and subsequent reduction of the water-cement ratio (by reducing foam quenching with water) [10]. Subsequently, during the secondary introduction of a high-concentration foam solution at the stage of manufacturing the cellular concrete structure, reducing the water-cement ratio allows for maximum preservation of the initial foam concentrate multiplicity and facilitates the formation of a uniform structure of the porous material. Figure 1 depicts a schematic representation of the foam concrete production process using the proposed method.



A - container for low-concentrated solution of plasticizing foam concentrate additive in water 0.23:85; B - container for solution of modified foam concentrate in water 1.2:40; C - cement-sand mixer; D - foam generator; E - mortar mixer; ⦸ - dosing unit; ⟶ - primary foam injection; - - ➝ - secondary foam injection.

Fig. 1 Foam concrete production scheme

Durability, in this context, refers to the material's mechanical resistance to the influence of negative factors. Negative factors include the impact of natural-climatic conditions such as temperature cyclicality (both low and high), cyclic wetting (immersion), wind cyclicality, and aggressive environments. In real conditions, these factors often manifest in combination [11-13]. From these conditions, the primary aging methods were identified, and adapted to realistic manifestations of natural influences in various climatic regions that significantly differ from one another:

Method 1: Cyclic Low-Temperature Exposure with Pre-wetting of Samples.

Method 2: Cyclic High-Temperature Exposure with Airflow and Pre-wetting of Samples.

Method 3: Exposure to Aggressive Media through Sample immersion in Sulfuric Acid Solution.

Method 1 was conducted according to the standard procedure outlined in GOST 10060–2012 «Concretes. Methods for Determining Frost Resistance». Tests were carried out on cylinder samples sized 100x100x100 (previously soaked) in an automatic climatic chamber 10 D1429/A CONTROLS (Figure 2A). The freezing time was 4 hours at a temperature of minus 18°C, and thawing was also 4 hours at a temperature of plus 18°C, with a humidity of 95%.

Method 2 was conducted using an adapted version of Method 1, where instead of low temperatures, samples were subjected to high temperatures. The tests were also carried out on cylindrical samples of the same size (previously

Fig. 2 Testing of foam concrete samples

soaked and unsoaked) in an RTFOT aging chamber, Infratest (Figure 2B).

The samples placed on a rotating drum were exposed to a temperature of 163°C and an airflow of 4000 ml/min. The exposure time at high temperatures was 4 hours, after which the samples were soaked in water at a temperature of +18°C for 4 hours.

Method 3 was conducted following an adapted procedure based on GOST 27677 «Concretes. Corrosion protection in construction» [14]. The experimental samples were immersed in a 10% sulfuric acid solution for 60 days. Before testing, the surface of the galvanized bath was treated with acid-resistant paint.

Sample comparisons were made based on strength assessments (Figure 2 A-D). The primary evaluation criteria included mass loss, strength loss, and visual inspection of the sample surface for visible defects.

The investigations of the proposed method (Type 1) were conducted in comparison with classical foam concrete (Type 2) and factory-produced aerated concrete (Type 3). The technological composition of the compared types of foam concrete is presented in Table 1. Table 2 shows the test program. A total of 9 series of samples of each type were prepared, with 3 samples in each series.

Table 1 Technological composition of the compared types of samples

Type	Cement M400, kg	Fine sand, kg	Foaming agent to water ratio at primary injection, g:l	Foaming agent to water ratio at secondary injection, g:l	Water, l	Foaming concentrate, g
Type 1	350	250	0.23:85	1.27:40	-	-
Type 2	350	250	-	-	175	1.5
Type 3	Factory-made aerated concrete					

Table 2 Test program

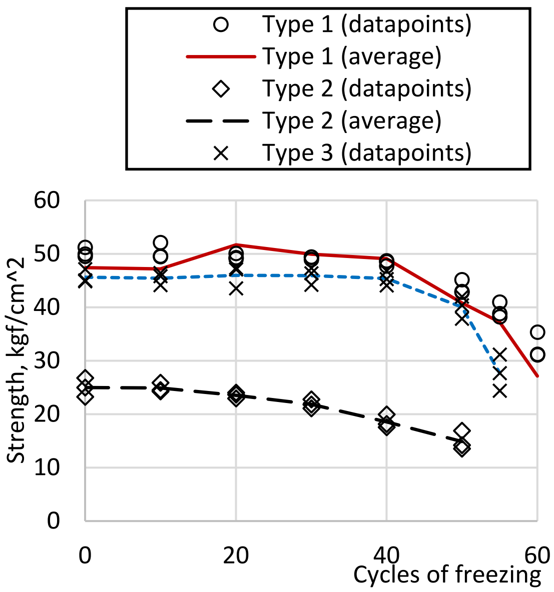
Method / indicator	Test series number								
	1	2	3	4	5	6	7	8	9
Method 1 / number of cycles	10	20	30	40	50	55	60	65	70
Method 2 / number of cycles	20	40	60	80	100	120	140	160	180
Method 3 / number of days	20	25	30	35	40	45	50	55	60

During the frost resistance test, cycle steps that were multiples of 10 and 5 were chosen. That is, with an increase in the total number of cycles, for a more accurate determination of the frost resistance class, the increment of cycles decreased. Tests for each type were conducted until the strength loss was close to 40%. The increment during thermal tests was 20 cycles, and for tests in an aggressive environment, it was 5 days.

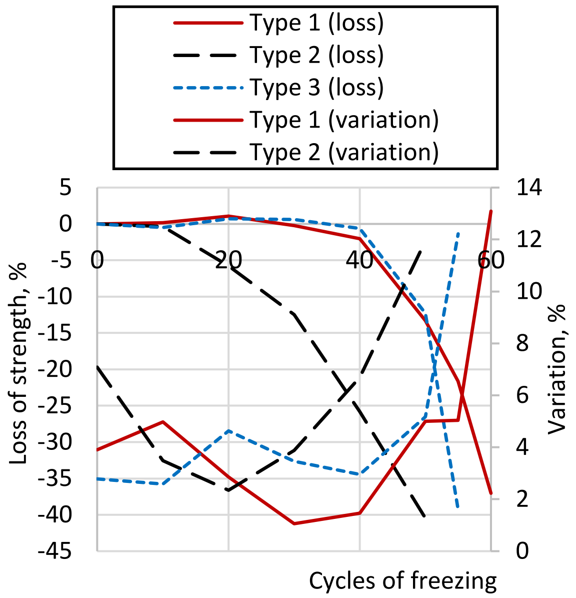
4. RESULTS AND DISCUSSION

Figure 3 presents the results of the samples' frost resistance tests. Figure 3A shows the strength parameters of the samples depending on the number of freezing cycles, while Figure 3B illustrates the strength loss and coefficient of variation values for the same number of cycles.

According to the obtained results, the mean strength value for the foam concrete samples produced by the proposed method (Type 1) was 49.50 kg/cm², for samples of classical foam concrete (Type 2) – 24.98 kg/cm², and for aerated concrete samples (Type 3) – 45.43 kg/cm². Regarding these strength indicators, an assessment of strength loss with an increase in the number of freezing cycles was made. For Type 1 samples, the onset of strength loss was observed at 30 cycles, constituting less than 1%. The loss increment increased with each subsequent decade of cyclic freezing, reaching over 15% on the last cycle. The criterion of strength loss was achieved at 60 cycles, resulting in a 37.03% strength loss. For Type 2 samples, strength loss was observed after 10 cycles, with the critical value reached at 50 cycles. Type 3 samples showed strength loss starting after 40 cycles, with the critical value reached at 55 cycles. Strength loss was identified in Type 3 samples at 10 cycles, amounting to 0.47%.



A



B

Fig. 3 Results of the samples tested using Method 1

However, during further testing, these losses were attributed to statistical error. In both cases (Type 2 and Type 3), an increase in strength loss increment was observed with each subsequent freezing cycle.

The freezing results indicate that Type 1 samples were the most resistant to freezing effects, with an absolute strength value of 31.17 kg/cm² at 60 cycles. Type 3 samples showed similar values, with a strength of 27.71 kg/cm² at 55 cycles. Type 2 samples exhibited the lowest resistance to freezing, with an average strength value of 14.88 kg/cm² at 50 cycles.

The coefficient of variation values for Type 1 samples ranged from 1 to 13%, and for Type 2 and Type 3 samples from 2 to 12%. In all cases, the fluctuation of the coefficients sharply increased as it approached the last decade of cyclic freezing (more than 50% compared to the previous control cycle), indicating a decrease in the stability of strength parameters at larger freezing cycles. In practice, this decrease in material operational reliability (without insulation) is observed with prolonged use under conditions of exposure to negative temperatures.

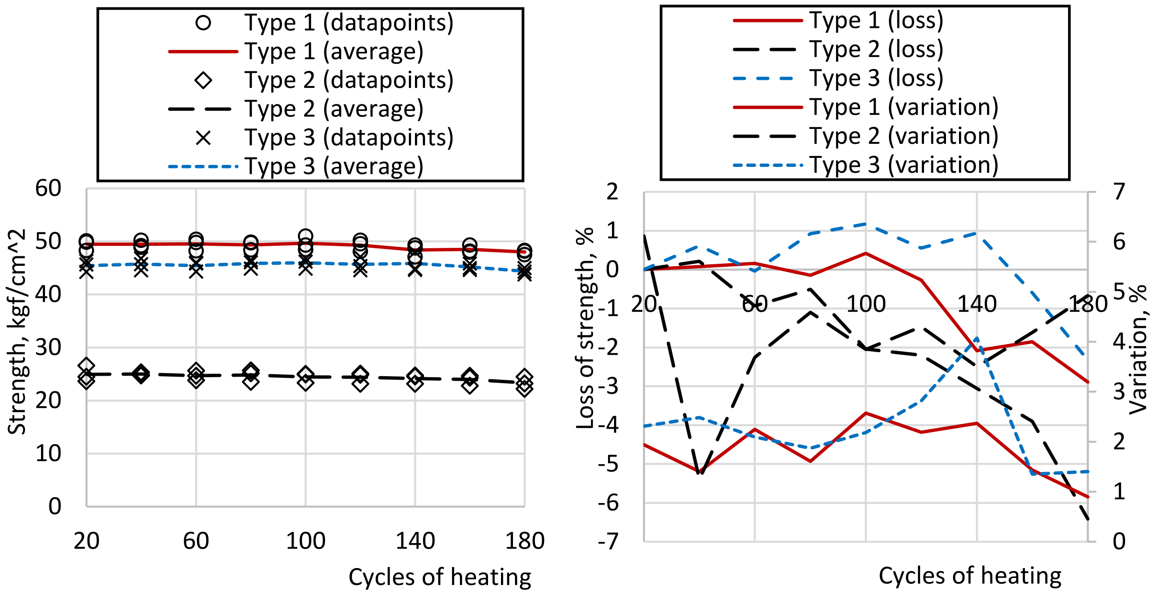
Figures 4 and 5 present the results of tests on samples for resistance to thermal effects. Figure 3 shows tests without prior soaking of the samples. The reference strength, against which its loss was evaluated, was 49.44 kg/cm² for Type 1 samples, 24.94 kg/cm² for Type 2 samples, and 45.43 kg/cm² for Type 3 samples, respectively. According to the results, the impact of thermal exposure was observed for Type 1 samples at 140 cycles, resulting in a 2% strength loss.

At maximum cycles, there was no significant peak strength loss, remaining within 3%. Type 2 and Type 3 samples also showed a minor effect of thermal exposure on strength loss.

For Type 2 samples, thermal influence was observed at 100 cycles, corresponding to a 2% strength loss, and at 180 cycles, it reached 6.5%. For Type 3, a 2% strength loss was registered only at 180 cycles. The coefficient of variation for Type 1 and Type 3 did not exceed 2.5%, while for Type 2, it was around 5% at maximum cycles. This also characterizes the lower resistance of Type 2 samples to thermal effects.

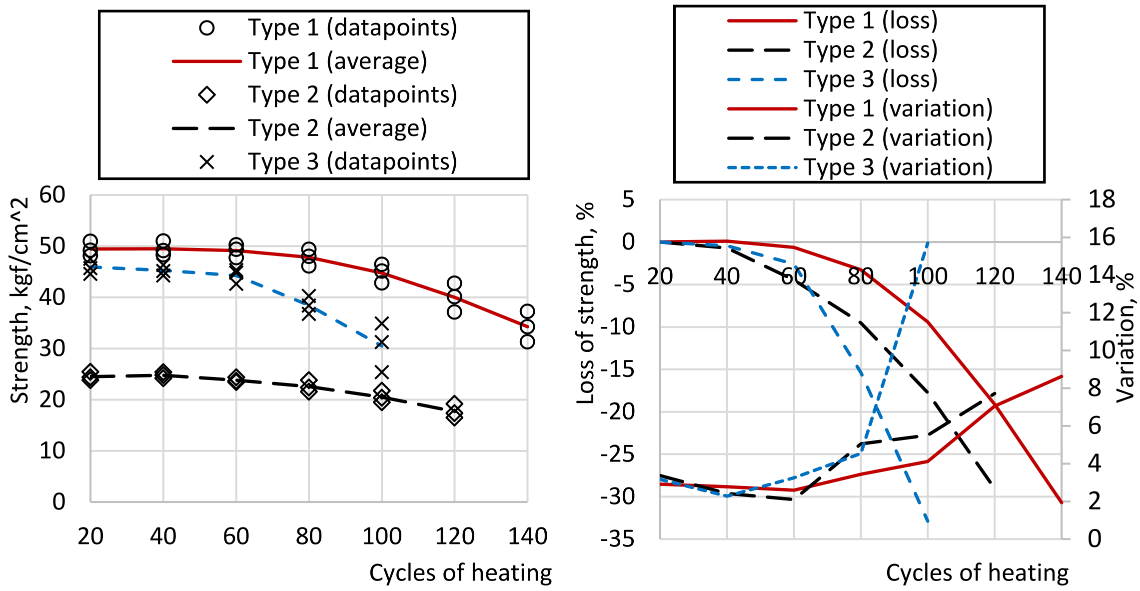
Due to the low impact of thermal exposure on the aging of samples, a decision was made to pre-saturate the samples followed by thermal exposure. Figure 4 shows the results of tests with prior soaking. According to the test results, for Type 1 samples, strength loss is observed at 80 cycles, exceeding 3%. The critical strength loss occurs at 140 cycles, exceeding the conditional 30%. Moreover, an increase in cycles leads to a non-linear strength loss, with an increment exceeding 50%. For Type 2 samples, strength loss begins at 60 cycles and reaches a critical maximum at 120 cycles (a 29% reduction in strength).

The increase in strength loss is also non-linear. For Type 3 samples, the strength reduction starts at 60 cycles, and at 100 cycles, a 33% strength loss is observed. For Type 3 samples, the reduction in strength occurs much faster concerning its initial manifestation (initial strength loss) compared to Type 1 and Type 2 samples. This can be attributed to the binding component used, more specifically its water resistance: gypsum binder for aerated concrete production and cement for foam concrete.



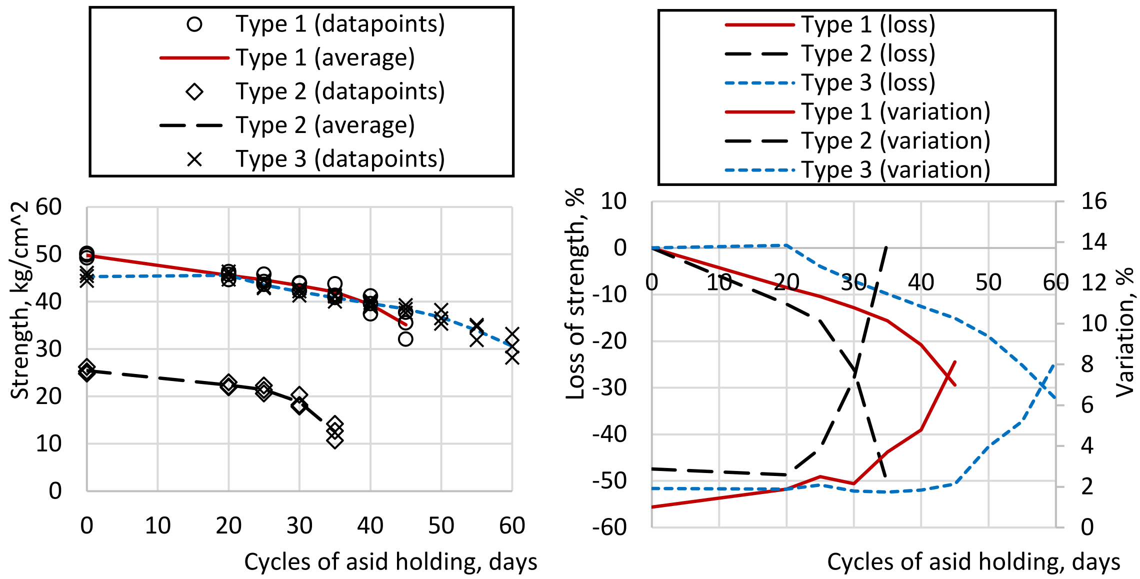
A B

Fig. 4 Results of samples tested using Method 2 without soaking



A B

Fig. 5 Test results of samples according to Method 2 with soaking



A B

Fig. 6 Results of Sample Testing using Method 3

Despite tests with soaking of samples conducted using Method 1, the trend of the water's influence on the depletion of material's strength properties was not conclusive. This could be related to the mechanics of the disruptive effect during the freezing of samples, primarily associated with the temperature expansion of water in the pore space of the cellular structure of the material. In other words, the samples' destruction occurred at relatively small cycles (up to 60), so the influence of soaking as a disruptive effect was not evident. Perhaps, in subsequent cycles, the strength loss of aerated concrete samples would exhibit an exponential pattern. Evaluation of coefficients of variation demonstrated a logical pattern of increasing with an increase in cycles, indicating a decrease in the stability of strength results with each subsequent cycle.

Comparing the results of thermal exposure tests with and without soaking, it can be concluded that soaking has a significant impact on the samples' resistance. From a practical point of view, the use of these materials in hot and humid climatic conditions is limited or requires special measures to protect them from such influences.

Figure 6 shows the test results of samples soaked in sulphuric acid simulating a corrosive environment.

The low stability of foam concrete samples compared to gas concrete (aerated concrete) may be attributed to the alkaline environment of autoclaved gas concrete, particularly due to the utilization of lime in its production. Interaction between lime and sulfuric acid leads to a neutralization reaction, resulting in the formation of gypsum. Autoclave gas concrete predominantly employs air binders (lime-gypsum) and, consequently, the composition of the binder undergoes alterations without explicit disruptions in structure following interaction with sulfuric acid. Upon complete drying of the sample, its strength properties are restored; however, strength loss occurs after the full cycle of the chemical reaction, transitioning from lime binding to gypsum binding.

Foam concrete samples of Type 1 and Type 2 also exhibited distinct outcomes. Non-autoclaved classic-type foam concrete (Type 2) displayed lower resistance to 10% sulfuric acid compared to Type 1 samples. This result can be explained by the significantly fewer micropores in the walls of Type 1 foam concrete pores compared to Type 2 samples. In comparison to gas concrete, the cellular structure of foam concrete is closed (non-communicating pores), although the quality of the pores can vary. The technology of production can significantly influence this final merging. In the case of Type 1 samples, the presence of micropores facilitates the penetration of the aggressive environment, leading to their more ephemeral destruction.

5. CONCLUSIONS

A comprehensive study of cellular concrete samples (foamed concrete using the proposed two-stage introduction method, classic foamed concrete, and autoclaved aerated concrete) was conducted to assess their durability using the following methods: cyclic freezing with pre-wetting (Method 1), cyclic heating with pre-wetting (Method 2a), cyclic heating without pre-wetting (Method 2b), and exposure to acid (Method 3).

According to the results of the study using Method 1, the highest resistance to cyclic freezing was demonstrated by Type 1 samples. At 60 cycles, the absolute strength value was 31.17 kg/cm^2. Type 3 samples showed similar values, with a strength of 27.71 kg/cm^2 at 55 cycles. Type 2 samples exhibited the lowest resistance to freezing, with an average strength value of 14.88 kg/cm^2 at 50 cycles.

The results of the study using Method 2a revealed that thermal exposure without pre-wetting had no significant effect on the durability of the compared materials. However, tests with pre-wetting in Method 2b showed that Type 3 samples experienced a much faster reduction in strength compared to their initial manifestation of strength loss, in contrast to Type 1 and 2 samples. This could be attributed to the use of a gypsum binding component, which is less resistant to water. The lower sensitivity of Type 3 samples to water in Method 1 tests may be due to the relatively small number of cycles (up to 60), compared to Method 2b (140).

According to the results of the study using Method 3, Type 3 samples demonstrated the highest resistance to acidic exposure. At 60 cycles, the loss of strength was 32.4%. Type 1 samples exhibited greater resistance than Type 2 samples. The critical maximum of strength loss for Type 1 occurred at 45 days, while for Type 2, it was at 35 days. The low stability of foamed concrete samples compared to aerated concrete could be attributed to the alkaline environment of autoclaved aerated concrete (presence of lime). Upon interaction with the acid, a neutralization reaction occurs, resulting in the formation of gypsum.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] Lukpanov R., Dyussembinov D., Altynbekova A., Zhantlesova Zh., Research of foam concrete components in the regional production conditions of Nur-Sultan, Technobius, Vol. 2, Issue 3, 2022, pp. 0023.

[2] Altynbekova A., Lukpanov R., Yenkebayev S., Tsygulyov D., Nurbayeva, M., Complex laboratory studies of modified additive influence on concrete physical and mechanical properties, GEOMATE Journal, Vol. 23, Issue 100, 2022, pp. 26-33.

[3] Lukpanov R., Dyussembinov D., Altynbekova A., Zhantlesova Zh., Approximative approach to optimize concrete foaming concentration in two stage foaming, Technobius, Vol. 3, Issue 3, 2023, pp. 0041.

[4] Ramamurthy K., Nambiar E.K.K., Ranjani

G.I.S., A classification of studies on properties of foam concrete, Cement & Concrete Composites, Vol. 31, Issue 6, 2009, pp. 388-396.

[5] Altynbekova A., Lukpanov R., Dyussembinov D., Askerbekova A., Tkach E., Effect of a complex modified additive on the setting time of the cement mixture, Kompleksnoe Ispolzovanie Mineralnogo Syra, Vol. 325 Issue 2, 2022, pp. 29–38.

[6] Kearsley E., Visagie M., Properties of Foamed Concrete as Influenced by Air-Void Parameters, Concrete Beton, Vol. 101, 2002, pp. 9-13.

[7] Kearsley E.P., Wainwright P.J., The effect of porosity on the strength of foamed concrete, Cement and Concrete Research, Vol. 32, Issue 2, 2002, pp. 233-239.

[8] Wainwright P.J., Olorunsogo F.T., Effects of PSD of GGBS on some durability properties of slag cement mortars, Journal of the South African Institution of Civil Engineering, Vol. 41, No. 1, 1999, pp. 9-17.

[9] Amran Y.M., Farzadnia N., Ali A.A., Properties and applications of foamed concrete; a review, Construction and Building Materials, Vol. 101, 2015, pp.990-1005.

[10] Ramamurthy K., Nambiar E.K.K., Ranjani G.I.S., A classification of studies on properties of foam concrete, Cement and Concrete Composites, Vol. 31, Issue 6, 2009, pp. 388-396.

[11] Interstate Standard GOST 10180-2012, Concretes. Methods for strength determination using reference samples, 2013, pp. 1-26. https://internet-law.ru/gosts/gost/56431/

[12] Kearsley E., Visagie M., Properties of foamed concrete as influenced by air-void parameters, Concrete Beton, Vol. 101, 2002, pp. 8-14.

[13] Nambiar E.K.K., Ramamurthy K., Air-void characterisation of foam concrete, Cement and Concrete Research, Vol. 37, Issue 2, 2007, pp. 221-230.

[14] Tikalsky P.J., Pospisil, J., MacDonald W., A method for assessment of the freeze-thaw resistance of preformed foam cellular concrete, Cement and Concrete Research, Vol. 34(5), 2004, pp. 889-893.

[15] Interstate Standard GOST 70109-2022, Concretes. Corrosion protection in construction, 2022, pp. 1-10. https://internet-law.ru/gosts/gost/77836/