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Composite non-autoclaved aerated concrete based on an emulsion

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Abstract. The proposed composite non-autoclaved aerated concrete based on a polymer emulsion is a solution to several problematic issues in the production of non-autoclaved aerated concrete. Using the method of joint emulsification of aluminium powder and polymer component, we obtained a polymer emulsion that contributes to high-quality saponification of the gas-forming agent. The emulsion ensures uniform gas release over the entire volume of the aerated concrete block, thereby providing a uniform pore structure. To assess the uniformity of the pore structure, we determined the density by sampling three sections of aerated concrete (upper, middle and bottom). We studied the quality of the pore structure by calculating water absorption by weight, compressive strength and freeze/thaw resistance. The results of the water absorption study showed the effectiveness of the polymer emulsion due to the hydrophobicity of the polymer component. The research also revealed the structure of composite aerated concrete cell walls. The obtained results of tests on the strength of composite aerated concrete in comparison with traditional aerated concrete also confirmed the effectiveness of using the polymer emulsion. The analysis of the conducted research contributed to the disclosure of the process that affects the increase in the strength of the material. Research on the freeze/thaw resistance of composite aerated concrete has revealed the mechanism of action of the polymer emulsion in the process of alternate freezing and thawing. In general, the paper demonstrates how polymer emulsion and aluminium powder influence the uniform distribution of pores in the composite structure, and therefore, contribute to the uniform density, low water absorption, high strength and freeze/thaw resistance of composite aerated concrete.

1. *Introduction*

Nowadays the construction industry is saturated with various construction materials based on binders from cement to organic [1]. Polymer binders are widely used also in the production of building materials. They have a low density and high acoustic and thermal properties, as well as low water absorption, which also positively characterizes these materials [2]. Despite a number of positive characteristics, the polymer binder has such disadvantages as flammability and non-durability [3].

The advantages of cement binder are high strength and density [4]. However, there are materials with a lower density. These include lightweight concretes on a light aggregate, as well as cellular concretes that have a low density and pore structure [5].

Due to the high demand for this cellular material, the interest in its research and improvement has increased. A major disadvantage of cellular concrete is its instability in the preparation process. Cellular

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concrete is divided into foam concrete and aerated concrete [6, 7]. A distinctive feature of foam concrete is a method for obtaining a cellular structure in the material by introducing a foam concentrate, which contributes to the formation of a closed pore structure of the composite [8]. Foam concrete has many advantages, but in addition to advantages, there are certain disadvantages that negatively affect the quality of the material. A literary review showed that the disadvantages of foam concrete materials were solved by introducing reinforcement materials such as basalt, fibers, steel reinforcement, etc. in the works [9–13]. Taking into account the modern approach and new technologies, foam concrete has eventually occupied its niche in the construction industry as a monolithic thermal insulating material, since the production of construction materials has always been accompanied by a large quantity of poor quality products, foam mortar has given a large shrinkage in shape and the material has become unusable [14], [15]. Aerated concrete, on the contrary, has become more widely used in the construction industry as a wall insulation structural material. The difference between aerated concrete and foam concrete is the use of a gas-forming agent, which in the course of a chemical reaction causes the process of gas formation and thereby inflates the solution, creating communicating pores [16]. Aluminum powder and hydrogen peroxide (technical peroxide) are used as a gas-forming agent [17]. Disadvantages of aerated concrete are high water absorption and low freeze/thaw resistance associated with its communicating pore structure [18, 19]. In the technology of production of aerated concrete, measures have also been taken to improve their physical and mechanical properties by using reinforcing components with modifiers [20]. The production of composite material is of great interest to the construction industry, and therefore improvement and elimination of existing shortcomings is relevant.

After analyzing the existing shortcomings and modern achievements in the field of aerated concrete production, as well as studying the chemical processes of structure formation of the material, the possibility of using polymer components was suggested [16, 21]. Practice has shown that research on this issue has been conducted and certain results have been obtained [22, 23].

But even in these cases, the manufacturer faced certain difficulties, from chemical to technological processes [24–26]. In this regard, our study of the influence of water-soluble polymers on the quality of the composition and technological process of aerated concrete has undeniable importance.

The purpose of the research process is to obtain high-strength non-autoclaved composite aerated concrete with improved physical and mechanical properties.

To achieve this goal, the following tasks were completed:

- to study the theoretical aspects of existing technologies, their features and disadvantages;
- to develop a technological process for the production of composite aerated concrete;
- toinvestigate the influence of polymer on the structure of composite aerated concrete cell walls;
- toconduct a comparative analysis of the effectiveness of composite aerated concrete with its analogues.

2. Methods

Preparation of traditional aerated concrete products was carried out under production conditions according to the standard method. Composite aerated concrete was produced with the addition of a polymer component – polyvinyl acetate (PVA). The composition of this material according to traditional and composite technologies is shown in Table 1.

Table 1.Composition of aerated concrete.

Type of aerated concrete	Cement, kg	Sand, kg	Gas generator, gr	PVA polymer, kg	Sodium hydroxide, gr	Water, l
Traditional aerated concrete	270	350	350	–	500	162
Composite aerated concrete	270	350	370	1.5	–	121

For the preparation of aerated concrete were used:

Cement CEM I 42.5 N with chemical composition of CaO – 60.40 %, SiO_2 – 22.15 %, Al_2O_3 – 5.67 %, MgO – 4.9 %, Fe_2O_3 – 3.8 %.

Sand with fineness modulus 2.23, bulk density 1.5 g/cm^3, true density 2.59 g/cm^3, hollowness 42.8 %, contamination 1 %.

Polyvinyl acetate with a density of 1.15 g/cm^3, viscosity 0.09 Pa*s, hydrogen pH 5.5, polymerization degree 1800.

In the production of traditional aerated concrete, dry components are combined in a mixer: sand and cement. Then water is poured into the mixer. The water temperature should not exceed 55 °C. Then the compound is thoroughly mixed for 5-7 minutes. After this, aluminum powder is prepared, in our case, PAP-2. Aluminum powder and sodium hydroxide are combined in hot water with a temperature not lower than 70 °C. Then a prepared aqueous solution of sodium hydroxide and aluminum powder is added to the cement-sand mixture. Finally, the composition is mixed for 5-7 minutes and distributed in the prepared forms.

After forming, the aerated concrete is expanded before setting, and excess material is removed from the surface of the mold to its level. And after 20-24 hours, the aerated concrete is removed from the formwork and sawn on the template.

For the production of composite aerated concrete, the dry components of sand and cement are also stirred in a mixer, after which water is poured into the compound at a temperature of at least 55 °C and thoroughly mixed for 5-7 minutes. Then the gasifier is prepared. To obtain a saponified gas-forming agent, we use a PVA polymer instead of sodium hydroxide. Based on the above, in the course of solving the problem of effective combination of a polymer component (PVA), a gas-forming agent (aluminum powder) with a mineral binder, a number of issues of interaction of a water-soluble polymer and aluminum powder were taken into account. The most optimal solution was to obtain an emulsion of PVA, water and aluminum powder, which is easily soluble in a cement-sand solution.

The quality of the prepared emulsion may be affected by the method of dispersion (emulsification) and the temperature regime. In this regard, the temperature regime was determined from 70 °C. This temperature allows the PVA polymer to effectively remove the paraffin foil from the surface of aluminum powder.

A rotary pulsating device (RPD) was used as a dispersant. The main factors that determine the emulsification process in a RPD type dispersant are pressure (0.5–1.0 MPa) and centrifugal force (rotor speed is 1200 rpm). These factors cause the occurrence of high-frequency vibrations in the RPD, accompanied by cavitation and hydrodynamic processes, thereby allowing to obtain a high-quality emulsion and saponified gas-forming agent. The resulting emulsion is introduced into the cement-sand compound. After that, the mixture is stirred for 5-7 minutes and poured into pre-prepared molds.

After forming, the aerated concrete is expanded before setting, and excess material is removed from the surface of the mold to its level. Further after 20-24 hours, the aerated concrete is removed from the formwork and sawn on the template.

Testing of samples is carried out according to the standard method for cellular concrete [7, 27–32].

At the end of 28 days, samples were taken. Samples of the cube for research were cut out of prepared composite non-reinforced and traditional aerated concrete blocks. The dimensions of the traditional and composite block were 600 mm in length, 400 mm in width and height. Samples for testing were cut from the upper middle and lower parts of the product, three samples from each part. The margins from the faces of the cubes were made at least 40 mm when cutting. The temperature in premises was 19 °C with a relative humidity of 35 % before the tests. The samples were kept in the laboratory for 24 hours. Samples are 28 days old. 54 samples (cubes) were made: 27 from composite aerated concrete and 27 from traditionally prepared aerated concrete. For sawing out samples, a template was used to obtain items with a smooth geometric surface with an error of up to 1 mm.

The density of the samples was determined for the beginning of the tests. The volume was determined using a caliper, since the samples (cubes) had regular geometric shapes of 100×100×100.

The density was determined according to the Eq. 1 [28]:

$$\rho_w = \frac{m}{V} * 100, \tag{1}$$

where ρ_w isdensity of material,

m ismass of sample, g,

V isvolumeof sample, cm^3.

In order to see the quality of the pore structure and pore walls, the water absorption of aerated concrete by weight was determined. Determination of water absorption of aerated concrete was carried out as follows, samples were weighed on verified calibrated scales with an error of 0.1 %, and then placed in a container with water. Since the density of the material was low, the samples floated, so a load was placed on their surface. The water level in the container was 60 mm higher than the sample level, and the water temperature was 21 °C. The samples were weighed every 24 hours to a constant mass. Fig. 1 shows the stages of the test.

Before each weighing, the samples were wiped with a damp cloth.

Calculation of water absorption by mass was determined according to the Eq. 2 [33]:

$$W_M = \frac{m_B - m_C}{m_C} * 100, \tag{2}$$

where W_M is water absorption by mass;

m_B is weight of the dried sample, g;

m_C is mass of the water-saturated sample, g.

Figure 1.Test of water absorption by mass.

The strength of aerated concrete was determined from control samples. Tests were performed on samples of 100×100×100 size prepared in advance by sawing out of a single block of 600×400×400. The age of the samples is 28 days. Concrete compressive strength test is shown in Fig. 2.

Figure 2.Concrete compressive strength test.

The samples were tested on an automatic press CONTROLS (Pilot) 500 kH. The strength of one series was determined as the arithmetic mean of the tested samples. 18 cubes were tested, 9 from each series.

The test for freeze/thaw resistance was determined on samples-cubes 100×100×100, which reached 28 days. 12 samples of two series-composite and traditional aerated concrete6 samples of each series, placed in a container with water and gradually, every 8 hours in two stages, increased the depth of immersion. After 16 hours, samples were completely submerged and loaded so that the samples could not float, and they were kept in this state for another 24 hours.

Then the samples were loaded onto the mesh racks of the automatic climate chamber 10D 1429 / a CONTROLS, the temperature of the chamber during loading was – 18 °C.

The freezing time was set for 4 hours at –18 °C, thawingisalso for 4 hours at the temperature +18 °C and humidity 95 %.

The freeze/thaw resistance test is shown in Fig. 3.

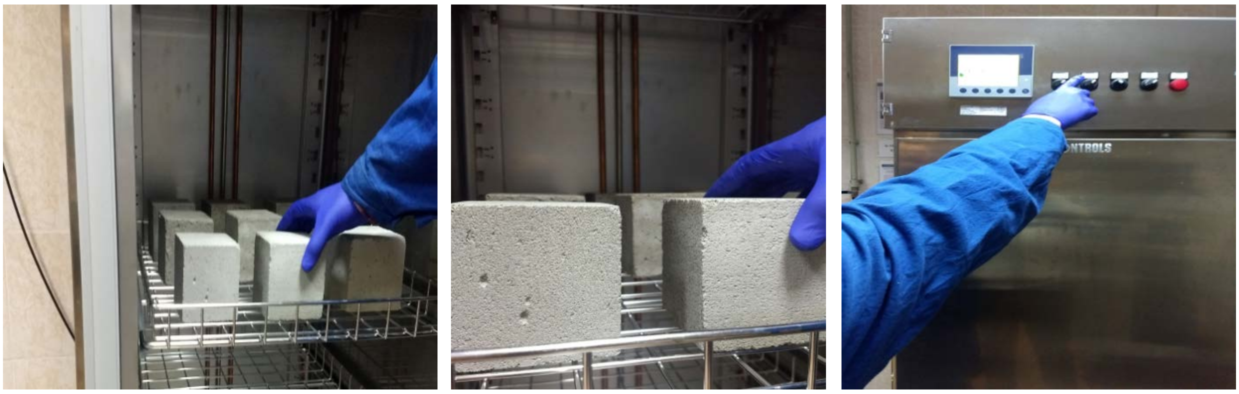


Figure 3. Freeze/thawresistance test.

The main criterion for the end of the test for freeze/thaw resistance was a visual change in the surface of the sample (cracks, chips), as well as a mass loss of more than 5 %. The samples were tested after 15 cycles of freezing and thawing, followed by an interval of 25, 35, 50, 75, 100 cycles.

The relative decrease in strength R_{rel} in $\%$ was determined according to the Eq. 3 [34]:

$$R_{rel} = \left(1 - \frac{R_{mtn}}{R_{mtk}}\right) * 100, \tag{3}$$

where R_{mtn} is average strength of the main samples after the specified test cycles in MPa;

R_{mtk} is average strength of control samples in MPa.

Mass loss Δ_m in $\%$ was calculated according to the Eq. 4 [34]:

$$\Delta_m = \frac{m_n(1 - W_n) - \overline{m}_n(1 - \overline{W}_n)}{m_n(1 - W_n)} * 100, \tag{4}$$

where m_n is average mass of the main samples after water saturation, g;

W_n is average value of humidity of control samples after water saturation,measured in parts of one;

$\overline{m}_n$ is average mass of the main samples after passing the intermediate number of cycles, g;

$\overline{W}_n$ is the average humidity value of the main samples after passing the intermediate number of cycles, measured in parts of one.

3. Results and Discussions

The results of determining the density of traditional aerated concrete in comparison with composite allowed us to objectively assess the quality of the pore structure of materials. According to the study [35, 36] of the pore structure of non-autoclaved aerated concrete, its non-uniformity and, as a result, the density difference in different sections of the material were noted. The quality of the pore structure directly depends on the difference in the density of the material in different sections of the same block.

Table 2. Density of traditional and composite aerated concrete.

Sample	Actual density		
	Upper samples	Middle samples	Bottom samples
Traditionalaerated concrete	617	617.8	619.1
	616.3	617.5	617.8
	616.5	616.9	619.2
Average density	616.6	617.4	618.7
Average density of all samples			617.6
Composite aerated concrete	618.4	618.9	619.1
	618.7	618.5	618.7
	618.2	618.8	619
Average density	618.4	618.7	618.9
Average density of all samples			618.6

Based on the data from Table 2, in traditional aerated concrete, we see a difference in the density of the upper samples compared to the middle and lower ones, which indicates an uneven distribution of the pore structure. This is due to the fact that the density of aluminum powder together with paraffin foil is significantly lower than the density of the solution. As a result, during the preparation of the material, part of the aluminum powder, not fully saponified, rushed to the surface of the material in the process of mixing. However, most of the aluminum powder after forming, after passing certain stages of interaction with the surface of the cement binder, warm water and alkaline (sodium hydroxide), loses the protective paraffin foil and increases the amount of hydrogen released on the surface of the block.

Composite aerated concrete, in contrast to traditional, has a more stable density in all areas of the tested material, which is explained by its production technology. We get a positive effect from the productive saponifying of aluminum powder. This process takes place by producing an emulsion of polymer, water and a gas-forming agent in a rotary pulsating device, which under pressure and due to centrifugal force forms high-frequency vibrations accompanied by cavitation with hydrodynamic processes. The resulting water-based emulsion of PVA polymer and aluminum powder easily dissolves in water for further use. This property guarantees a uniform distribution of all components in the structure of the material, thereby providing a high-quality pore base of composite aerated concrete.

Thus, a slight difference in the density of the composition is the result of an uneven distribution of saponified grains of aluminum powder, which leads to a decrease in the quality of the material.

The next stage of determining the quality indicators of traditional and composite aerated concrete was the study of water absorption. Literary review showed that water absorption, strength, frost resistance corresponds to traditional aerated concrete [37, 38].

The results of determining water absorption by weight of traditional and composite aerated concrete are presented in Table 3.

Table 3. Water absorption by weight of traditional and composite aerated concrete.

№	Sample	Weight of the dried sample, g			Mass of the water-saturated sample, g		
		Upper samples	Middle samples	Bottom samples	Upper samples	Middle samples	Bottom samples
	Traditionalaerated concrete	617	617.8	619.1	801.5	800	801.8
		616.3	617.5	617.8	801	799.5	800
		616.5	616.9	619.2	800.8	801	801
	Water absorption, %				29.9 %	29.49 %	29.51 %
					29.9 %	29.47 %	29.49 %
					29.89 %	29.84 %	29.36 %
	Average water absorption, %				29.9 %	29.6 %	29.5 %
	Average water absorption of all samples, %						29.7 %
	Composite aerated concrete	618.4	618.9	619.1	717.5	719	716.5
		618.7	618.5	618.3	718	716.9	718
		618.2	618.8	619	717.3	717	718.2
	Water absorption, %				16.02 %	16.17 %	15.73 %
					16.04	15.9 %	16.12 %
					16.03 %	15.86 %	16.02 %
	Average water absorption, %				16 %	16 %	16 %
	Average water absorption of all samples, %						16 %

The dependence of water absorption on the pore structure of aerated concrete is similar to the results of studies of traditional aerated concrete in the range from 28 to 30 % [39].

Based on the results of the study, we can note a significant contrast between traditional and composite aerated concrete. Taking into account the fact that composite aerated concrete has a hydrophobic component (PVA) in its structure, this difference is obvious. A 46 % reduction in water absorption of composite aerated concrete indicates that most of the water did not penetrate the structure of the aerated concrete and thus provided this result. However, considering the fact that the pore structure of aerated concrete is communicating, we can conclude that the pore can only be communicated in a certain space according to the possibilities of the gas-forming ability of the aluminum powder particle. Based on this conclusion, in the traditional production technology, the particles of the gas-forming agent, contacting the surface of the cement particles, contribute to the release of hydrogen, which, rushing vertically up, forms a pore space. Also, with a vast accumulation of aluminum powder particles, much more hydrogen is released, which reduces the thickness of the walls of the partitions in front of the standing pore, contributing to uneven density. Micro and macropores of partitions increase water absorption, while in composite aerated concrete micro and macropores are isolated by a polymer component, providing hydrophobicity.

Composite aerated concrete has a special structure: the cell walls are completely filled and practically do not have micropores due to the fact that the water-soluble polymer is a surfactant and improves the plastic properties of cement, as well as fills structural defects in the process of hydration of the cement binder, is shown in Fig. 4.

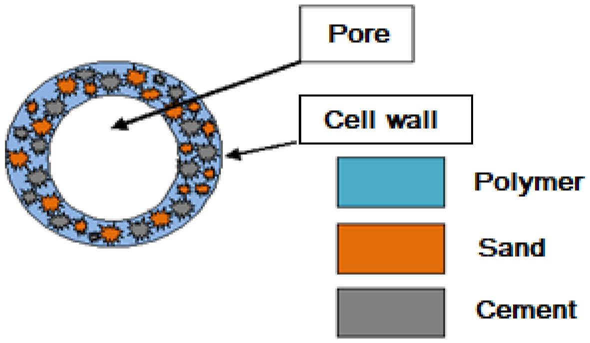


Figure 4. The structure of aerated composite concrete's cell walls.

The use of polymer emulsion and aluminum powder in composite aerated concrete ensures that the communicating pores are closed in space, since the polymer foil creates conditions for their isolation even with a vast release of hydrogen, thereby causing hydrophobic features of the material. Fig. 4 shows a scheme of the cell structure.

The results of determining the compressive strength of traditional and composite aerated concrete are presented in Table 4.

Table 4. Compressive strength of traditional and composite aerated concrete.

Sample	Average density, kg/m^2	Sample's strength in MPa		
		Upper samples	Middle samples	Bottom samples
Traditionalaerated concrete	600	2.4	2.9	3.7
		3.5	3.4	3.8
		2.9	3.8	3.1
The average strength	600	2.9	3.4	3.5
The average strength of all samples				3.3
Composite aerated concrete	600	5.1	5.2	5.3
		5.0	5.0	5.3
		4.9	5.1	5.0
The average strength	600	5	5.1	5.2
The average strength of all samples				5.1

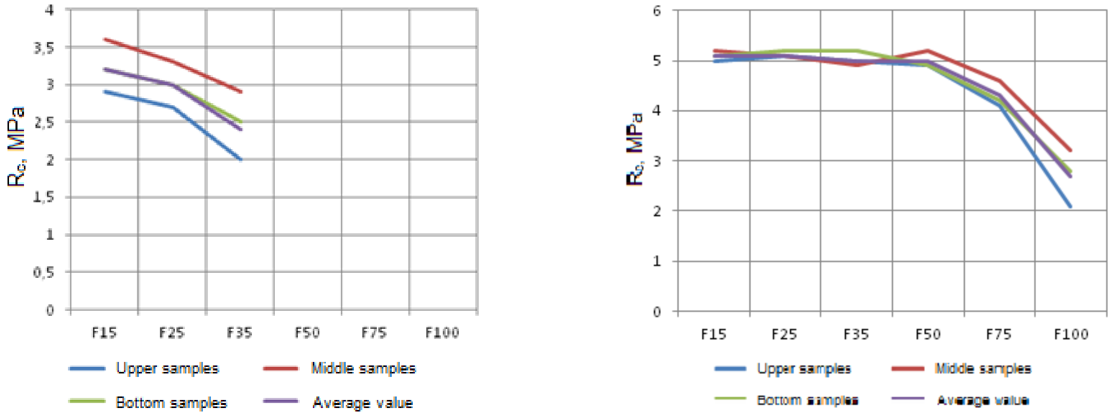
The strength properties of aerated concrete were studied in the papers [35]. The experience of studying the strength of samples non-autoclaved aerated concrete shows the result similar to the traditional one in the range from 3 to 3.5 MPa [40].

The strength of traditional aerated concrete is 51 % lower than that of composite. As mentioned above, the reason for this difference in material strength is the quality of the pore structure. One of the essential factors that contribute to reducing the strength of traditional aerated concrete is the saponifier (sodium hydroxide), since it has a strongly alkaline environment, which negatively affects the hardening process. The second factor in reducing strength is the pore walls: the presence of a huge number of micro- and macropores, which are caused by a high water-cement ratio. Rapid loss of moisture in the process of gaining strength during the first days of hardening requires special care of the product, which is an additional technological process.

The explanation for the high strength of composite aerated concrete is the use of a polymer emulsion with a gas-forming agent.

Composite aerated concrete, having water-soluble polymers in its structure, which are also surfactants, plasticizes the solution, positively affecting the process of hydration of the cement binder. The polymer component, forming a foil in the structure of aerated concrete, retains moisture, which positively influences the hardening process of the material, without requiring additional care. This increases the strength by filling micropores and microcracks with a polymer that serves as a binder.

The results of freeze/thaw resistance of traditional and composite aerated concrete are shown in Fig. 5.



a) freeze/thaw resistance of traditional aerated concrete

b) freeze/thaw resistance of composite aerated concrete

Figure 5. Freeze/thaw resistance of traditional and composite aerated concrete.

The freeze/thaw resistance of non-autoclaved aerated concrete does not contradict the results of the study of traditional aerated concrete, which also varies in the range of 25 to 35 cycles [41].

It is known that in cellular concrete, major pores are not filled with water completely, since due to small capillary forces, water is not retained in them during the extraction of samples from water. In addition, in conventional non-hydrophobized cellular concrete, water is aspirated by capillaries from larger pores. Therefore, the released major pores make up the so-called reserve, i.e. they form a buffer space, which is a damper during the transition of water to ice, which increases the freeze/thaw resistance of cellular concrete. The freeze/thaw resistance of aerated concrete was researched in the works [42].

The mechanism of destructive action is related to the phase transition of water into ice and to the crystallization of salts in process of drying in the concrete pores.

Many authors explain the destruction by hydraulic pressure of water pressed by ice, the crystallization pressure of ice and salts, the specifics of ice segregation in micropores and capillaries, the formation of ice lenses as the concrete freezes layer by layer, and other reasons.

An external sign of concrete failure is an increase in its volume due to the expansion of water in the concrete pores during freezing, as well as shrinkage during thawing and drying. In this case, a system of micro and macro-cracks is formed, and their own structural tensile stresses occur.

Chemical and mineral additives play an important role in giving concrete structural strength and higher freeze/thaw resistance. By introducing various additives, it is possible to improve the properties of concrete mixtures, regulate the time of setting and hardening of concrete, as well as increase its physical and mechanical properties and durability in structures and buildings.

The mechanism of formation and movement of ice in the pores and capillaries of concretes modified with hydrophobizing additives proceeds according to completely different schemes. It is known that ice has a high adhesion to concrete. Hydrophobization significantly reduces the bonding force of ice with the material, so when it crystallizes, the pressure in the concrete pores is significantly reduced.

Our research on determining the freeze/thaw resistance of composite aerated concrete has also shown their higher resistance in comparison with traditional aerated concrete that does not contain polymer components. Thus, composite aerated concrete withstood 75 cycles of alternating freezing and thawing without external signs of destruction, while traditional concrete withstood only 35 cycles.

The validity of the pore structure and the influence of various factors on it were carried out by many authors, however, all actions were considered from the point of view of raw material activation by adding various kinds of additives that increase the activity of aluminum powder, or cement binder [43]. However, in some cases, given the positive effect of the additive on gas formation, the quality indicator of the binder decreases, or vice versa. The studied work of using sodium hydroxide in the production of non-autoclaved aerated concrete, the gas generation rate of a reasonably high alkaline medium of sodium hydroxide undoubtedly during the chemical reaction, the gas-forming features of aluminum powder significantly increase, but in the process of interaction of strong alkali and cement binder, its strength characteristics significantly decrease its strength characteristics, the material structure begins to peel off. Non-autoclaved composite aerated concrete is primarily focused on the effectiveness of the polymer component on the properties of all raw materials, and for the effective saponification of aluminum powder, both the chemical characteristics of the polymer and the mechanical effects of the rotor-pulsation apparatus were used.

Thus, the emulsion obtained is much safer, since it does not dust during its application, and its effective saponification provides high-quality interconnected pores of the wall, which have a polymer-cement structure. The hydrophobicity of the polymer component provides high freeze/thaw resistance and low water absorption, and the plasticizing effect of the polymer reduces the number of micro and macro pores in the structure of the walls of communicating pores providing high strength.

4. Conclusion

1. Conducted studies of the density difference of traditional aerated concrete on three sections of the material (upper, middle, bottom) samples showed a difference in density from the average density of all samples:

- for upper samples below 0.16 %;
- for middle samples below 0.03 %;
- for bottom samples higher by 0.18 %.

The obtained results indicate that the pore structure of traditional aerated concrete has uneven pores with a certain dynamics of increasing the density of the upper part of the material. However, the density of composite aerated concrete samples showed stability in all sections of the tested block. Indicators of the difference in density of composite aerated concrete from the average density of all samples:

- for upper samples below 0.08 %;
- for middle samples below 0.02 %;
- for bottom samples higher by 0.05 %.

Hence, after analyzing the results, we can conclude that composite aerated concrete has a uniform pore structure that provides a stable density in all areas of the tested block. The density stability of composite aerated concrete in contrast to traditional aerated concrete is 78 % higher.

2. Tests of composite aerated concrete showed an increase in water absorption by 46 %. The dependence of water absorption on changes in the density of the material is also determined. A study on the water absorption of traditional aerated concrete in three sections of the material (upper, middle, bottom samples) showed a difference in the average density of all samples:

- for upper samples with an average density of 616.6, the water absorption difference is higher than 0.8 % of the average water absorption of all samples;
- for average samples with an average density of 617.4, the water absorption difference is less than 0.3 % of the average water absorption of all samples;
- for bottom samples with an average density of 618.7, the water absorption difference is less than 0.7 % of the average water absorption of all samples.

The obtained data indicate that the density of the material does not fully reflect the dependence of the density difference and water absorption. Water absorption of composite aerated concrete is 16 % in all three sections of the tested block, which indicates the stability of the pore structure and the closeness of communicating pores in space.

3. Compressive strength tests of composite aerated concrete showed a 52 % increase in strength. The strength value for three sections (upper, middle, bottom) of the tested material showed the difference in strength from the average value of all samples:

- for upper samples below 12 %;
- for middle samples higher by 3 %;
- for bottom samples higher by 6 %.

These results show the dependence of water absorption and strength of the material, which indicates that the pore communicating structure is closed in space, providing an increase in strength and limiting the spread of water through the structure of the material.

The study of the strength of composite aerated concrete showed a difference in the strength of the material sections (upper, middle, bottom samples) from the average strength of all samples:

- for upper samples below 2 %;
- for average samples it is equal to the average strength of all samples;
- for bottom samples higher by 2 %.

According to the obtained results, it can be concluded that composite aerated concrete on all sections of the block has almost uniform strength, with the exception of an error of ± 2 %.

4. The freeze/thaw resistance of aerated concrete depends directly on the water absorption, strength and density of the material. Composite aerated concrete, having a polymer component in its structure, provides hydrophobicity of cell walls and closeness in the space of the communicating pore structure; in contrast to traditional aerated concrete, it is characterized by an increase in freeze/thaw resistance by 53 %.

5. Acknowledgments

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References

1. Serdar, M., Bjegović, D., Štirmer, N., Banjad Pečur, I., Marijana Serdar, A., Dubravka Bjegović, P. Research challenges for broader application of alternative binders in concrete. DOI: 10.14256/JCE.2729.2019. URL: https://doi.org/10.14256/JCE.27-29.2019 (date of application: 11.04.2020).
2. Wu, Y., Wang, J.Y., Monteiro, P.J.M., Zhang, M.H. Development of ultra-lightweight cement composites with low thermal conductivity and high specific strength for energy efficient buildings. Construction and Building Materials. 2015. 87. Pp. 100–112. DOI: 10.1016/j.conbuildmat.2015.04.004
3. Tonet, K.G., Gorninski, J.P. Polymer concrete with recycled PET: The influence of the addition of industrial waste on flammability. Construction and Building Materials. 2013. 40. Pp. 378–389. DOI: 10.1016/j.conbuildmat.2012.09.049
4. Liu, Q., Liu, W., Li, Z., Guo, S., Sun, G. Ultra-lightweight cement composites with excellent flexural strength, thermal insulation and water resistance achieved by establishing interpenetrating network. Construction and Building Materials. 2020. 250. DOI: 10.1016/j.conbuildmat.2020.118923
5. Chica, L., Alzate, A. Cellular concrete review: New trends for application in construction. Construction and Building Materials. 2019. 200. Pp. 637–647. DOI: 10.1016/j.conbuildmat.2018.12.136. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950-061818331258 (date of application: 11.04.2020).
6. Kalpana, M., Mohith, S. Study on autoclaved aerated concrete: Review. Materials Today: Proceedings. 2020. 22. Pp. 894–896. DOI: 10.1016/j.matpr.2019.11.099. URL: https://linkinghub.elsevier.com/retrieve/pii/S2214785319337824
7. Interstate Standard GOST 25485-2019: Cellular concretes. General specifications.
8. Nguyen, T.T., Bui, H.H., Ngo, T.D., Nguyen, G.D., Kreher, M.U., Darve, F. A micromechanical investigation for the effects of pore size and its distribution on geopolymer foam concrete under uniaxial compression. Engineering Fracture Mechanics. 2019. 209. Pp. 228–244. DOI: 10.1016/j.engfracmech.2019.01.033
9. Amran, M., Fediuk, R., Vatin, N., Huei Lee, Y., Murali, G., Ozbakkaloglu, T., Klyuev, S., Alabduljabber, H. Fibre-Reinforced Foamed Concretes: A Review. Materials. 2020. 13(19). Pp. 4323. DOI: 10.3390/ma13194323. URL: https://www.md-pi.com/1996-1944/13/19/4323
10. Sun, H.Y., Gong, A.M., Peng, Y.L., Wang, X. The Study of Foamed Concrete with Polypropylene Fiber and High Volume Fly Ash. Applied Mechanics and Materials. 2011. 90–93. Pp. 1039–1043. DOI: 10.4028/www.scientific.net/AMM.90-93.1039. URL: https://www.scientific.net/AMM.90-93.1039
11. Fedorov, V., Mestnikov, A. Influence of cellulose fibers on structure and properties of fiber reinforced foam concrete. MATEC Web of Conferences. 2018. 143. Pp. 02008. DOI: 10.1051/matecconf/201814302008. URL: https://www.matecconferences.org/10.1051/matecconf/201814302008

12. Mahzabin, M.S., Hock, L.J., Hossain, M.S., Kang, L.S. The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite. Construction and Building Materials. 2018. 178. Pp. 518–528. DOI: 10.1016/j.conbuildmat.2018.05.169. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950061818312455
13. Abbas, W., Dawood, E., Mohammad, Y. Properties of foamed concrete reinforced with hybrid fibres. MATEC Web of Conferences. 2018. 162. Pp. 02012. DOI: 10.1051/matecconf/201816202012. URL: https://www.matecconferences.org/10.1051/matecconf/201816202012
14. Hilal, A.A., Thom, N.H., Dawson, A.R. Failure Mechanism of Foamed Concrete Made with/without Additives and Lightweight Aggregate. Journal of Advanced Concrete Technology. 2016. 14(9). Pp. 511–520. DOI: 10.3151/jact.14.511. URL: https://www.jstage.jst.go.jp/article/jact/14/9/14_511/_article
15. Raj, A., Sathyan, D., Mini, K.M. Physical and functional characteristics of foam concrete: A review. Construction and Building Materials. 2019. 221. Pp. 787–799. DOI: 10.1016/j.conbuildmat.2019.06.052. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950061819314771
16. Hamad, A.J. Materials, Production, Properties and Application of Aerated Lightweight Concrete: Review. International Journal of Materials Science and Engineering. 2014. DOI: 10.12720/ijmse.2.2.152-157. URL: http://www.ijmse.net/index.php?m=content&c=index&a=show&catid=34&id=73
17. Font, A., Borrachero, M.V., Soriano, L., Monzó, J., Payá, J. Geopolymer eco-cellular concrete (GECC) based on fluid catalytic cracking catalyst residue (FCC) with addition of recycled aluminium foil powder. Journal of Cleaner Production. 2017. 168. Pp. 1120–1131. DOI: 10.1016/j.jclepro.2017.09.110
18. Gyurkó, Z., Jankus, B., Fenyvesi, O., Nemes, R. Sustainable applications for utilization the construction waste of aerated concrete. Journal of Cleaner Production. 2019. 230. Pp. 430–444. DOI: 10.1016/j.jclepro.2019.04.357. URL: https://linkinghub.elsevier.com/retrieve/pii/S0959652619314581
19. Zapotoczna-Sytek, G. Durability of autoclaved aerated concrete based on Polish experience. ce/papers. 2018. 2(4). Pp. 53–62. DOI: 10.1002/cepa.850. URL: http://doi.wiley.com/10.1002/cepa.850
20. Kalpana, M., Mohith, S. Study on autoclaved aerated concrete: Review. Materials Today: Proceedings. 2020. 22. Pp. 894–896. DOI: 10.1016/j.matpr.2019.11.099. URL: https://linkinghub.elsevier.com/retrieve/pii/S2214785319337824
21. Narattha, C., Thongsanitgarn, P., Chaipanich, A. Thermogravimetry analysis, compressive strength and thermal conductivity tests of non-autoclaved aerated Portland cement–fly ash–silica fume concrete. Journal of Thermal Analysis and Calorimetry. 2015. 122(1). Pp. 11–20. DOI: 10.1007/s10973-015-4724-8. URL: http://link.springer.com/10.1007/s10973-015-4724-8
22. Qu, X., Zhao, X. Previous and present investigations on the components, microstructure and main properties of autoclaved aerated concrete – A review. Construction and Building Materials. 2017. 135. Pp. 505–516. DOI: 10.1016/j.conbuildmat.2016.12.208.
23. Shuisky, A., Stelmakh, S., Shcherban, E., Torlina, E. Recipe-technological aspects of improving the properties of non-autoclaved aerated concrete. MATEC Web of Conferences. 2017. 129. Pp. 05011. DOI: 10.1051/matecconf/201712905011. URL: http://www.matec-conferences.org/10.1051/matecconf/201712905011
24. Wang, C., Ni, W., Zhang, S., Wang, S., Gai, G., Wang, W. Preparation and properties of autoclaved aerated concrete using coal gangue and iron ore tailings. Construction and Building Materials. 2016. 104. Pp. 109–115. DOI: 10.1016/j.conbuildmat.2015.12.041. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950061815307145
25. Chen, Y.-L., Ko, M.-S., Chang, J.-E., Lin, C.-T. Recycling of desulfurization slag for the production of autoclaved aerated concrete. Construction and Building Materials. 2018. 158. Pp. 132–140. DOI: 10.1016/j.conbuildmat.2017.09.195. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950061817320032
26. Yuan, B., Straub, C., Segers, S., Yu, Q.L., Brouwers, H.J.H. Sodium carbonate activated slag as cement replacement in autoclaved aerated concrete. Ceramics International. 2017. 43(8). Pp. 6039–6047. DOI: 10.1016/j.ceramint.2017.01.144. URL: https://linkinghub.elsevier.com/retrieve/pii/S0272884217301669
27. EN 771-4:2011+A1:2015 specification for masonry units – Part 4: Autoclaved aerated concrete masonry units.
28. Interstate Standard GOST 12730.1-78: Concretes. Methods of determination of density.
29. EN 772-11:2011 “Methods of test masonry units – Part 11: Determination of water absorption of aggregate concrete, manufactured stone and natural stone masonry units due to capillary action and the initial rate of water absorption of clay masonry units”.
30. EN 772-1:2011 + A1:2015 Methods of test for masonry units – Part 1: Determination of compressive strength.
31. EN772-13:2000: Methods of test for masonry units – Part 13: Determination of net and gross dry density of masonry units (except for natural stone).
32. EN 15304 Determination of the freeze-thaw resistance of autoclaved aerated concrete.
33. Interstate Standard GOST 12730.3-78: Concretes. Method of determination of water absorption.
34. Interstate Standard GOST 25485-89: Cellular concretes. Specifications. Appendix 3 (required).
35. Ramamurthy, K., Narayanan, N. Factors influencing the density and compressive strength of aerated concrete. Magazine of Concrete Research. 2000. 52(3). Pp. 163–168. DOI: 10.1680/macr.2000.52.3.163. URL: http://www.icevirtuallibrary.com/doi/10.1680/macr.2000.52.3.163
36. Nambiar, E.K.K., Ramamurthy, K. Air-void characterisation of foam concrete. Cement and Concrete Research. 2007. 37(2). Pp. 221–230. DOI: 10.1016/j.cemconres.2006.10.009. URL: https://linkinghub.elsevier.com/retrieve/pii/S0008884606002699
37. Shabbar, R., Nedwell, P., Wu, Z. Porosity and Water Absorption of Aerated Concrete with Varying Aluminium Powder Content. International Journal of Engineering and Technology. 2018. 10(3). Pp. 234–238. DOI: 10.7763/IJET.2018.V10.1065. URL: http://www.ijetch.org/index.php?m=content&c=index&a=show&catid=93&id=1253
38. Raj, I.S., John, E. A study on the properties of air-entrained concrete for masonry blocks. International Journal of Scientific Engineering and Technology. 2014. 3(11). Pp. 1367–1370. URL: http://www.indianjournals.com/ijor.aspx?target=ijor:ijset1&volume=3&issue=11&article=008
39. Muthu Kumar, E., Ramamurthy, K. Influence of production on the strength, density and water absorption of aerated geopolymer paste and mortar using Class F fly ash. Construction and Building Materials. 2017. 156. Pp. 1137–1149. DOI: 10.1016/j.conbuildmat.2017.08.153. URL: https://linkinghub.elsevier.com/retrieve/pii/S0950061817317610
40. Narayanan, N., Ramamurthy, K. Structure and properties of aerated concrete: a review. Cement and Concrete Composites. 2000. 22(5). Pp. 321–329. DOI: 10.1016/S0958-9465(00)00016-0. URL: https://linkinghub.elsevier.com/retrieve/pii/S0958946500000160

41. Hang, M., Cui, L., Wu, J., Sun, Z. Freezing-thawing damage characteristics and calculation models of aerated concrete. Journal of Building Engineering. 2020. 28. Pp. 101072. DOI: 10.1016/j.jobe.2019.101072. URL: https://linkinghub.elsevier.com/retrieve/pii/S2352710219315141
42. Kočí, V., Maděra, J., Jerman, M., Černý, R. Experimental Determination of Frost Resistance of Autoclaved Aerated Concrete at Different Levels of Moisture Saturation. International Journal of Thermophysics. 2018. 39(6). Pp. 75. DOI: 10.1007/s107-65-018-2398-8. URL: http://link.springer.com/10.1007/s10765-018-2398-8
43. Halyushev, A., Holodnyak, M., Nazhuyev, M. Effect of caustic soda on the intensity of gassing in the production of non-autoclaved aerated concrete. MATEC Web of Conferences. 2017. 129. Pp. 05012. DOI: 10.1051/matecconf/201712905012. URL: http://www.matec-conferences.org/10.1051/matecconf/201712905012

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