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RESEARCH INTO STRUCTURE FORMATION AND PROPERTIES OF THE FIBER-REINFORCED AERATED CONCRETE OBTAINED BY THE NON-AUTOCLAVED HARDENING

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Досліджено вплив співвідношення цемент:зола винесення та температури води замішування на властивості газобетонних сумішей та газобетонів. Встановлено, що раціональним цементнозольним співвідношенням є 1:1, а температура води замішування 40 °C. Експериментальними дослідженнями підтверджено, що за рахунок введення відходів переробки солі і метакаоліну, до складу в'яжучих композицій відбувається утворення замість метастабільних гексагональних гідроалюмінатів кальцію стійких сполук у структурі міжпорових перегородок типу гідрокалюміту і гідрокарбоалюмінату. Завдяки цьому стало можливим направлене структуроутворення міжпорових перегородок неавтоклавного газобетону, що приводить до підвищення щільності перегородок та міцності газобетону. Показано, що введення поліпропіленової фібри в склад газобетону не впливає на кінетику спучування газобетонного масиву. Однак при введенні поліпропіленової фібри міцність газобетону на основі модифікованої в’яжучої композиції, що містить метакаолін, зростає на 47 %, модифікованої в’яжучої композиції, що містить карбонатвмісні відходи – на 32 %. Для класу газобетонів В1,5–В2 при середній густині в межах 615–625 кг/м^3 розрахунковий коефіцієнт теплопровідності становить 0,16 Вт/(м·К), що дозволяє зменшити теплові втрати через зовнішні огороджувальні конструкції.

Таким чином, є підстави стверджувати про можливість направленого регулювання процесів формування міцної структури міжпорових перегородок шляхом використання модифікованих в’яжучих композицій, що містять додаткові цементуючі матеріали. Використання поліпропіленової фібри забезпечує армування ніздрюватобетонного масиву, створюючи міцний структурний каркас міжпорових перегородок, що забезпечує зростання міцності неавтоклавного газобетону

Ключові слова: неавтоклавний газобетон, кінетика спучування, середня густина, міцність, поліпропіленова фібра

1. Introduction

In December 2015, at the 21st Conference of the parties to the UN Framework Convention on climate change, a new international climate agreement was adopted – Paris Agreement, according to which the new Energy strategy and the Strategy of low-carbon development must be based on reducing energy consumption by increasing energy efficiency and energy saving. The adoption of the climate agreement is very important for Ukraine. Implementation of the agreement implies the need to build its energy strategy with a mandatory vision of complete abandonment of fossil fuels and a transition to 100 % renewable energy as early as mid-century [1]. Providing energy saving in the housing and communal sector of Ukraine is achieved by constructing energy efficient buildings by using the materials with improved thermal insulation properties. Scientific research in the field of innovative building materials is aimed at the development of building materials, the use of which is economically expedient, and can reduce energy costs and consumption of natural resources. Aerated concrete is the optimal material for construction due to the possibility to change its density and strength in a sufficiently wide range. This is important for solving various structural tasks in construction, particularly when constructing external enclosures [2]. The main factors that affect operational properties of these materials is the component structure, volume of porous space, size and uniformity of pore distribution [3]. In addition, an important factor is the possibility of targeted regulation of the microstructure of partitions between pores through the directed synthesis of hydrated phases.

The improvement of quality indicators of the non-autoclaved aerated concretes is achieved mainly by modifying the binding compositions of traditional aerated concrete mixtures with admixtures of the multifunctional purpose [4]. To this end, widely applied are the chemical additives, such as micelle-forming surface-active substances [5], carbon nanotubes [6], nano-modifiers [7], and supplementary cementitious materials, specifically natural zeolite [8], residues of the shale gas pyrolysis [9]. Therefore, it is a relevant task to undertake a research aimed at modifying the binding compositions with supplementary cementitious materials by regulating the composition of hydrated phases in order to obtain the non-autoclaved aerated concretes with high functionality. Such aerated concretes are characterized by the improved porous structure and operational characteristics; they provide the designed strength for compression, as well as appropriate quality indicators.

2. Literature review and problem statement

According to the trends in the application of modern building materials for the construction of external enclosures, there is a common tendency to use effective structural heat-insulating materials, particularly aerated concretes. The primary reserve for increasing the strength of aerated concretes is to increase the strength of partitions between pores by modifying the cement matrix with chemical and mineral additives, by regulating the dispersity and homogeneity of components distribution [10, 11].

The feasibility of using natural zeolite, especially with larger size particles, is confirmed by the results of research [8]. It is shown that natural zeolite makes it possible to obtain the autoclaved aerated concretes with a strength of 3.25 MPa at an density of 553 kg/m^3. An analysis of results of the application of shredded clay bricks as a filler in aerated concrete revealed a decrease in the density and coefficient of thermal conductivity, an increase in the porosity and compressive strength in the autoclaved aerated concrete [12]. Despite the practical significance of such results, it should be noted that the autoclaved treatment of aerated concrete significantly increases its energy consumption. There is known practice in the technology of the non-autoclaved aerated concrete to use both mineral additives and industrial waste in the form of sand, sieving of stone crushing, slag, waste of claydite production, ash from TPP and other industrial waste [13–15]. Authors of [16] used a carbonate filler to regulate physical-mechanical and operational characteristics of the non-autoclaved aerated concretes by optimizing the structure of the binding matrix, which made it possible to obtain the non-autoclaved aerated concrete of grade D600 for density and class B1 for strength. Specifically, the study conducted by authors of [17] showed the possibility to use phosphogypsum in order to obtain the non-autoclaved aerated concrete, which is not inferior to the autoclaved aerated concrete in terms of its characteristics. The widespread use of technogenic waste makes it possible to obtain a high-quality building material and to solve the problems related to the improvement of environmental situation at industrial zones. In Ukraine, particularly in its western part, there are considerable amounts of accumulated waste from the production of food salt: the practice of its utilization in the technology of aerated concrete is lacking.

Typical disadvantages of products with low density are usually the low resistance to tensile stresses, increased brittleness, insignificant tensile strength at bending, reduced fracture toughness. As a result, the articles are exposed to the unwanted chips and cracks, both when they are manufactured and during transportation and installation [18]. One of the techniques to overcome the above drawbacks, along with increasing the strength and the microstructure optimization through the use of highly active mineral and chemical additives, is the application of reinforcement materials. Dispersed reinforcement of the non-autoclaved aerated concrete with mineral, polymeric or other non-metallic fibers significantly improves the strength and deformation properties of the material and improves the reliability of articles and structures during operation [19]. It was established [20] by determining the influence of polypropylene fibers on properties of the composite aerated concrete panel that the strength of the article at bending, deflection and compression increased; the ability to control the propagation of a crack in the concrete panel was also identified, which confirms the feasibility of using the fibers. Thus, for large-size articles made from the non-autoclaved aerated concrete, it is a relevant issue to stabilize basic properties, such as strength, increased resistance to tensile stresses, enhanced crack resistance, minimization of shrinkage deformation and reduction of material brittleness using the reinforcement fibers.

Thus, there is reason to believe that the influence of carbonate-containing waste from the production of food salt on the processes of structure formation of partitions between pores in the non-autoclaved aerated concretes has not been investigated in detail. That necessitates the research into the regulation of the composition of hydrated phases in order to obtain the non-autoclaved fiber-reinforced aerated concretes with high functionality that are characterized by the improved porous structure and increased strength.

3. The aim and objectives of the study

The aim of this study is to determine the influence of technological factors, supplementary cementitious materials, a superplasticizer and a polypropylene fiber on the rheological properties of aerated concrete mixtures, and quality parameters of the non-autoclaved aerated concretes, as well as to investigate the physical-chemical patterns in the processes of hydration and structure formation of partitions between pores. This would make it possible to reduce the consumption of cement, bring down the cost of production of the non-autoclaved aerated concrete, and reduce negative impact on the environment through the disposal of waste.

To accomplish the aim, the following tasks have been set:

– to conduct experimental study to establish the dependence of properties of the non-autoclaved aerated concretes on the technological factors and composition of aerated concrete;

– to establish patterns in the structure formation of partitions between pores of the non-autoclaved aerated concrete based on the modified binding compositions, interdependent on the physical-mechanical properties of aerated concrete.

4. Materials and methods to study the influence of admixtures on the properties of aerated concrete mixes and aerated concretes

4. 1. Materials used in the research

To conduct the study, we used the Portland cement CEM I 42,5 R produced at PSH “Ivano-Frankivsk cement” (Yamnitsa, Ivano-Frankivsk region, Ukraine) with specific surface 332 m^2/kg, the residue on sieve No. 008 is 0.5 %, the initial setting time is 1 hour 20 min, the finish setting time is 5 hours 50 min. We used, as a finely dispersed filler, fly ash (FA) from the Burshtyn TPP; as a water-reducing additive – the superplasticizer Glenium 115 of polycarboxylate type. We utilized, as supplementary cementitious materials, metakaolin and carbonate-containing waste of food salt processing (chemical composition of the waste, mass. %: SiO_2 – 1.8, Al_2O_3 – 1.64, Fe_2O_3 – 0.54, CaO – 39.42, MgO – 4.21, Na_2O – 6.42, R_2O – 6.57; Cl^- – 6.67, LDC (losses due to calcination) – 39.12). To obtain a aerated structure, we used, as a gasifier, the aluminum powder PAP-1 (content of active aluminum is 82 %, fineness of grinding is 5,000...6,000 cm^2/g). We applied, as the reinforcement fibers, a polypropylene fiber (with a fiber length of 12 mm).

We examined the structure formation of partitions between pores of the non-autoclaved aerated concrete using an X-ray phase analysis (the diffractometer DRON-3), electronic microscopy (the raster electronic microscope REM-106I equipped with the energy dispersing X-ray spectrometer EDAR). Differential-thermal analysis of the aerated concrete was performed applying the derivatograph OD-1500 Q, the Paulik-Paulik-Erdey system.

Experimental samples of aerated concrete were fabricated from the aerated concrete mixes that are characterized by the flow spread of Suttard cylinder of 190 mm, which corresponds to the optimal conditions of the technology for obtaining the non-autoclaved aerated concrete. The aerated concrete mix components were agitated at a laboratory blade concrete stirrer. The superplasticizer admixture was added with the mixing water calculated as 1 mass. % of cement.

Experimental samples, the cubes with an edge of 100 mm, were made by casting; they hardened under normal conditions for 28 days.

4. 2. Procedure for determining the indicators of properties of the samples

An indirect assessment of the impact of technological factors, a superplasticizer, supplementary cementitious materials and a polypropylene fiber, on the kinetics of swelling of the aerated concrete mix was performed based on the results of determining the multiplicity of swelling of the aerated concrete mix (the ratio of volume of the swollen mix to the starting volume).

We have chosen the following basic indicators of the properties of aerated concrete samples that were determined in the experiment: density and compressive strength.

Determining the density was conducted in line with the following procedure: the samples of aerated concrete were dried to a constant mass; the volume was calculated based on the geometrical dimensions. The size of the samples was determined by a ruler with the error not exceeding 0.1 mm. Mass of the samples was determined by weighing. The concrete density ρ was determined with an accuracy of up to 1 kg/m^3 from formula:

$$\rho=\frac{m}{V},$$

where m is the mass of the sample, kg; V is the volume of the sample, m^3.

Determining the compressive strength at was conducted in line with the following procedure: samples, the cubes, were placed by one of the selected edges onto the bottom supporting plate, centrally relative to its longitudinal axis. The strength of concrete, MPa, was calculated with an accuracy of up to 0.1 MPa for each sample from formula:

$$f_{\text{cube}}=(\alpha \cdot F k_w)/A,$$

where α is the scaling factor; F is the destructive load, N; k_w is a correction factor for aerated concrete, which accounts for the moisture content of samples at the time of testing; A is the area of the working cross-section of the sample, mm^2.

5. Results of research into properties of aerated concrete mixes and aerated concretes

It was established based on the experimental data on determining the influence of the ratio Portland cement:fly ash (C:FA) on the processes of gas evolution and the swelling kinetics of an aerated concrete mix that the highest multiplicity of swelling is demonstrated by the aerated concrete mix with the largest consumption of cement (K_s=3.0). However, the coagulation of an aerated concrete array consequently occurs, which leads to the increase of the density of aerated concrete (Fig. 1).

Results of determining the influence of the cement-fly ash ratio on the density and the compressive strength of the non-autoclaved aerated concrete samples are shown in Fig. 2. We established in the course of our study that the rational cement-fly ash ratio with respect to ensuring the minimum density and sufficient strength of aerated concrete is the ratio C:FA=1:1; we applied it in the subsequent research.

Results of determining the influence of water temperature for the preparation of an aerated concrete mix on the multiplicity of swelling of the aerated concrete mix, density and strength of aerated concrete are given in Table 1.

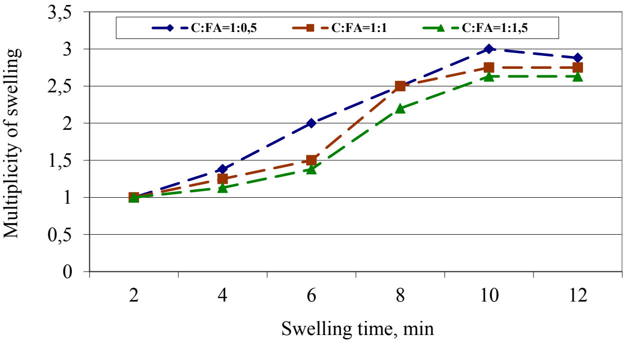


Fig. 1. Effect of cement-fly ash ratio on the swelling kinetics of aerated concrete mix

It should be noted that increasing the temperature of water for the preparation of an aerated concrete mix to 60 °C causes a rapid thickening that negatively affects the multiplicity of swelling and, respectively, on the density of aerated concrete. At a temperature of 40 °C, we achieve optimal parameters of time and the multiplicity of swelling, which make it possible to obtain aerated concrete with a density of 700 kg/m^3 and the compressive strength in 28 days of hardening under normal conditions of 3.1 MPa (Table 1), which is consistent with the results of studies by authors of [21].

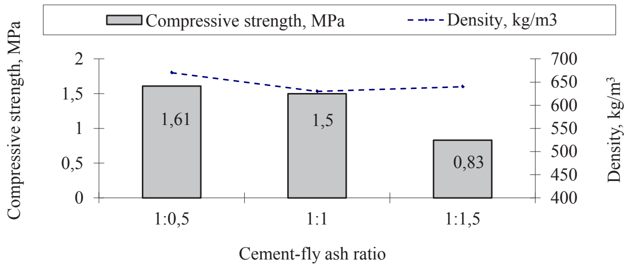


Fig. 2. Effect of cement-fly ash ratio on the properties of aerated concrete

Table 1

Effect of temperature of water for the preparation of an aerated concrete mix on the properties of aerated concrete

Water temperature, °C	Multiplicity of swelling	Swelling time, min	Density of aerated concrete, kg/m^3	Compressive strength, MPa, after 28 days
20	2.4	25	720	2.3
40	2.5	15	700	3.1
60	1.8	7	950	3.3

To determine the impact of supplementary cementitious materials and a superplasticizer on the plastic strength of aerated concrete mixes, we performed an experimental study and obtained the results shown in Fig. 3.

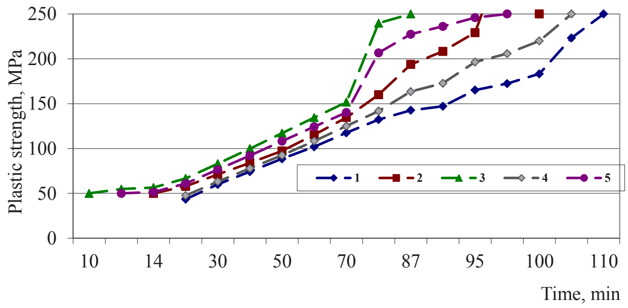


Fig. 3. Kinetics of attaining the plastic strength by the binding compositions containing: 1 – CEM I 42,5 R; 2 – CEM I 42,5 R + 10 mass. % of carbonate-containing waste; 3 – CEM I 42,5 R + 10 mass. % of carbonate-containing waste and 1 mass. % of Glenium 115; 4 – CEM I 42,5 R + 10 mass. % of metakaolin; 5 – CEM I 42,5 R + 10 mass. % of metakaolin and 1 mass. % of Glenium 115

We established based on the results of experimental study (Fig. 3) that the introduction of mineral additives predetermines the acceleration of acquiring plastic strength. Thus, Portland cement is characterized by a plastic strength of 250 Pa in 109 min; when introducing 10 mass. % of metakaolin (MK) the duration of attaining the same plastic strength is shortened to 105 minutes; 10 mass. % of carbonate-containing waste of salt processing (CW) – to 100 min. When introducing a superplasticizer, the time of acquiring the plastic strength of an aerated concrete mix based on the modified binding composition containing metakaolin reduces to 97 min.; based on the binding composition with carbonate-containing waste – to 87 min.

We established in the course of investigation into physical-chemical processes of structure formation of partitions between pores (Fig. 4) that after 28 days of hardening of the aerated concrete based on the Portland cement CEM I 42,5 R the main crystalline phases are portlandite (*d/n*=0.490; 0.262 nm) and ettringite (*d/n*=0.960; 0.387 nm). When obtaining the aerated concrete based on the modified binding composition containing metakaolin, the diffractograms in 2 days of hardening demonstrate diffraction maximum that match hydrocalumite (*d/n*=0.820; 0.288; 0.244 nm), the intensity of which increases. During subsequent time of hardening, characteristic is the small intensity of lines of $Ca(OH)_2$ (*d/n*=0.262; 0.490 nm), confirming its binding into hydrated new formations. When introducing the carbonate-containing waste as an supplementary cementitious material to the formulation of the modified binding composition, there forms stable calcium hydrocarboaluminate $3CaO{\cdot}Al_2O_3{\cdot}CaCO_3{\cdot}12H_2O$ whose structure-forming role increases over time.

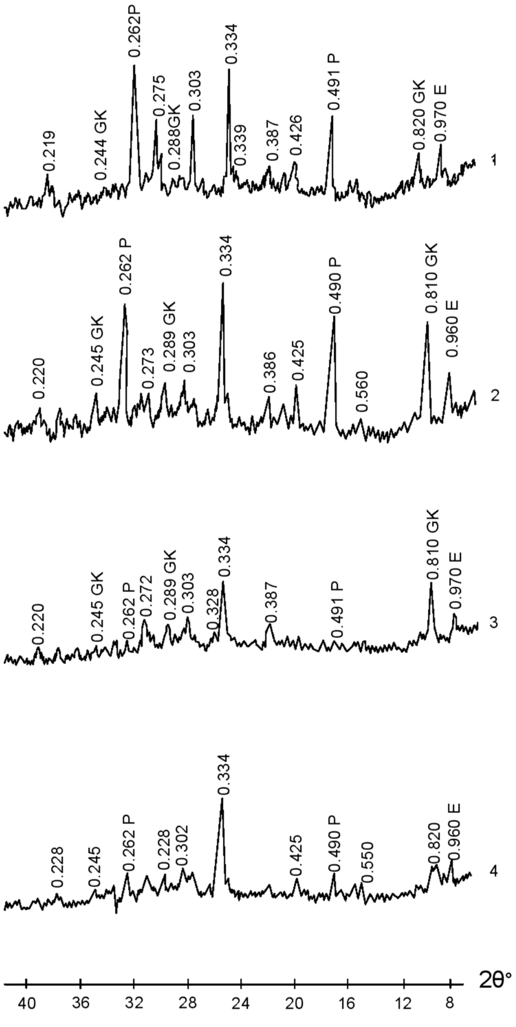
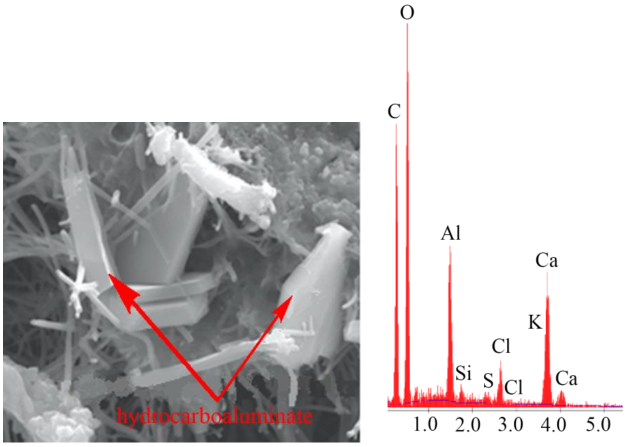


Fig. 4. Diffractograms of partitions between pores of aerated concrete based on CEM I 42,5 R + 10 mass. % of metakaolin, hydrated for: 1 – 2; 2 – 7; 3 – 28 days; 4 – aerated concrete based on CEM I 42,5 R, hydrated for 28 days

Results of electronic-microscopic study into partitions between pores of aerated concrete based on the binding composition containing carbonate-containing waste are shown in Fig. 5. We emphasize the fact that the use of a modified binding composition with carbonate-containing waste of salt processing illustrates the formation of a dense structure of partitions between pores of aerated concrete.



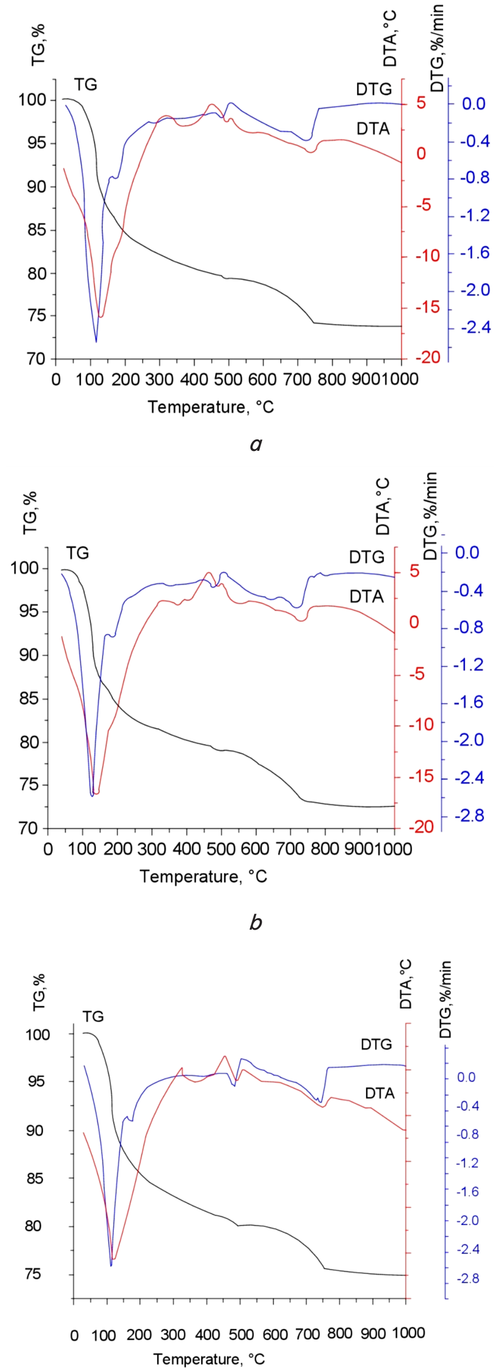
a *b*

Fig. 5. The partition between pores of aerated concrete based on the binding composition containing carbonate-containing waste: *a* – microstructure, *b* – spectra of X-ray characteristic radiation

Generalization of this fact can be stated in the form of the following argument: "Using a binding composition that contains carbonate-containing waste ensures the formation of a structure from the X-ray-amorphous CSH-phase, reinforced by the crystals of ettringite and the plate hexagonal crystals of hydrocarboaluminates. This is confirmed by data from a microprobe spectral analysis (Fig. 5, *b*)".

We observe, based on the results of thermal analysis (Fig. 6), that the derivatograms of aerated concrete based on the Portland cement, hydrated for 90 days, demonstrate endoeffects in the region of temperatures 30–160 °C, 160–315 °C, 460–510 °C, 700–900 °C. The first and second endoeffects correspond to the release of physical and adsorption water, respectively, from ettringite and calcium hydro silicates. The third endoeffect matches decomposition of calcium hydroxide. The fourth endoeffect manifests itself as a result of several processes – the decomposition of hydrocarboaluminates and calcium carbonate with the evolution of CO_2.

As evidenced by the results of a thermographic analysis, in the aerated concrete based on the Portland cement after 90 days of hydration, the loss of mass is 18.6 %. In the aerated concretes based on the modified binding compositions containing metakaolin and carbonate-containing waste of food salt processing, the total loss of mass increases to 19.6 % and 19.5 %, respectively. The estimated value of the amount of $Ca(OH)_2$ in aerated concrete based on the Portland cement after 90 days of hydration is 12.8 mass. %. In the aerated concrete based on the modified binding compositions containing metakaolin – 2.9 mass. %; carbonate-containing waste of salt processing – 4.5 mass. %. Data on the high degree of binding portlandite by mineral additives are also confirmed by results of determining the strength of aerated concretes (Fig. 7).



a

b

c

Fig. 6. Derivatograms of aerated concrete that hardened over 90 days under normal conditions, based on: *a* – CEM I 42,5 R; *b* – CEM I 42,5 R + 10 mass. % of metakaolin; *c* – CEM I 42,5 R + 10 mass. % of carbonate-containing waste

We established in the course of research into the porous structure of aerated concrete using optical microscopy that when applying as a binder the Portland cement CEM I 42,5 R, the pores the size of 1.1–2.2 mm dominate; their amount is 61 %. When applying the modified binding composition containing metakaolin, we observed an increase in the number of small pores the size of 0.2–1.0 mm, from 23.5 % to 76.4 %.

Based on the results of experimental study, it was established that the introduction of a polypropylene fiber to the composition of aerated concrete does not affect the kinetics of swelling of the array of aerated concrete. Thus, the multiplicity of swelling of the aerated concrete mix that does not contain a reinforcing component in its composition is 2.71; the aerated concrete mix containing a polypropylene fiber is characterized by the magnitude of swelling multiplicity of 2.68. Increasing the content of fiber does not affect the kinetics of gas evolution and the growth of the aerated concrete array.

When analyzing the results of experimental research, it was found that the introduction of the reinforcing component makes it possible to increase the strength of aerated concretes at a density of aerated concrete articles of 615–625 kg/m^3 (Fig. 7). Thus, the strength of the aerated concrete based on the modified binding composition containing metakaolin is 1.5 MPa. When one introduces a polypropylene fiber to the composition of the non-autoclaved aerated concrete, its strength increases to 2.2 MPa. For the aerated concrete based on the modified binding composition containing carbonate-containing waste of salt processing, the strength is 2.2 MPa. When a reinforcing component is introduced to its composition, its strength increases to 2.9 MPa.

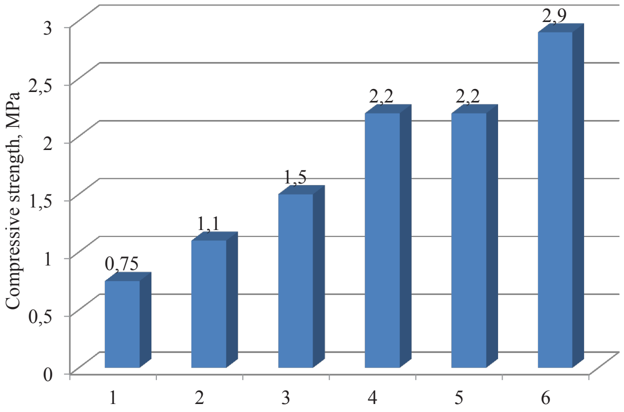


Fig. 7. Influence of polypropylene fiber on the strength of aerated concrete after 28 days of hardening under normal conditions, obtained based on: 1 – CEM I 42,5 R; 2 – CEM I 42,5 R + polypropylene fiber; 3 – CEM I 42,5 R + 10 mass. % of metakaolin; 4 – CEM I 42,5 R + 10 mass. % of metakaolin + polypropylene fiber; 5 – CEM I 42,5 R + 10 mass. % of carbonate-containing waste; 6 – CEM I 42,5 R + 10 mass. % of carbonate-containing waste + polypropylene fiber

Based on these results, we can state the presence of an interesting pattern related to the formation of the structure of partitions between pores. In particular, the use of a polypropylene fiber creates a structural strengthening frame of the array of aerated concrete, that is, it reinforces the partitions between pores, optimizes the structure and increases the strength of the entire material.

It is established that the non-autoclaved aerated concretes of the B1.5–B2 class of strength, obtained with the use of the modified binding compositions that contain supplementary cementitious materials and a polypropylene fiber, demonstrate the improved porous structure, which provides for the enhanced thermal insulation characteristics. For concretes of the B1.5–B2 class of strength, at the density within 615–625 kg/m^3, the estimated coefficient of thermal conductivity reaches the value of 0.16 W/(m·K), which make it possible to reduce the heat loss through the wall. Building the external enclosures using the developed non-autoclaved aerated concretes, under condition of maintaining all other parameters of the structure, makes it possible to reduce the difference between the estimated value of specific heat consumption and the maximally permissible value by 15.3 %.

6. Discussion of results of studying the influence of admixtures on the properties of aerated concrete mixes and aerated concretes

When determining a rational ratio of cement:fly ash for obtaining the non-autoclaved aerated concretes, as it follows from the obtained results (Fig. 1, 2), taking into consideration providing for the minimum density and sufficient strength of aerated concrete, the rational ratio is C:FA=1:1. It should be noted that the optimal parameters of swelling time and the multiplicity are achieved at a mixing water temperature of 40 °C (Table 1). Production technology of the non-autoclaved aerated concretes must maintain a balance between the rate of acquiring plastic strength and the processes of gas evolution [22]. Apparently, the use of supplementary cementitious materials and chemical additives is the factor of regulation of the plastic strength of binding compositions due to which it is possible to shorten the duration needed by an aerated concrete mix to acquire plastic strength by 11.5–20.3 % (Fig. 3).

Of particular interest is the interpretation of the results from a raster electronic microscopy, which confirms the compaction of the microstructure of partitions between pores of the non-autoclaved aerated concretes based on the modified binding compositions. The presence in the modified binders of metakaolin and carbonate-containing waste of food salt processing enables the formation of lamellar hexagonal crystals of calcium hydrocarboaluminates and hydrocalumite, respectively. To prove this argument, it will suffice to carefully examine data from the differential thermal analysis given in Fig. 5, which prove the high level of binding of $Ca(OH)_2$ by supplementary cementitious materials into stable structure-active phases. This is evidenced by the low content of portlandite in the aerated concrete based on the modified binding compositions – in 90 days of hardening its amount is 2.9–4.5 mass. % compared with 12.8 mass. % in the aerated concrete based on the Portland cement. The establishment of this fact testifies to the improvement of strength characteristics of the finished articles. That means that taking a given fact into consideration opens up a possibility for effective control over the processes of structure formation of partitions between pores and the properties of the non-autoclaved aerated concrete directly under industrial conditions.

The synergistic effect of using supplementary cementitious materials, a superplasticizer and a polypropylene fiber manifests itself in the compaction of the microstructure of partitions between pores by reducing the water-solid ratio, by forming the hexagonal plate crystals of hydrocarboaluminates and by additional spatial reinforcement by fiber. That is confirmed by comparing the strength of the fiber-reinforced aerated concrete based on the modified binding composition containing metakaolin, which confirmed its increase from 1.5 MPa to 2.2 MPa; with carbonate-containing waste – from 2.2 MPa up to 2.9 MPa, which is not different from practical data reported in papers [18, 19]. However, in contrast to the research results published in [18, 19], the data obtained on the influence of supplementary cementitious materials and a superplasticizer on the structure formation of partitions between pores, allow us to argue about the following:

– using as supplementary cementitious materials metakaolin and carbonate-containing waste of food salt processing in the composition of the modified binders ensures the targeted structure formation of partitions between pores. In this case, the stable products of hydration form, which enables obtaining highly efficient non-autoclaved aerated concretes;

– the targeted structure formation of the modified binding compositions for the non-autoclaved aerated concretes leads to the improved gas-retaining capacity of aerated concrete mixes, increasing the compressive strength, ensuring high technical effect; this does not diverge from the practical data know from papers [7, 16].

Such conclusions can be considered feasible from a practical point of view, as they make it possible to reasonably tackle the issue of determining the type and the required amount of supplementary cementitious materials. From a theoretical point of view, this allows us to argue about determining the mechanism of the processes of structure formation, which is a rather valuable benefit of our research. However, it is impossible not to note that the results of determining the impact of supplementary cementitious materials on the strength of the non-autoclaved aerated concretes are not sufficient to assess the impact on the operational characteristics of the designed materials; that can be interpreted as the shortcomings of our study. The impossibility to eliminate above limitations within the framework of our study might lead to a potentially interesting area for the further research. Study into the influence of supplementary cementitious materials could tackle the deformations of setting, modulus of elasticity, and a Poisson's coefficient for the non-autoclaved aerated concretes. Such a study would make it possible to establish the impact of supplementary cementitious materials on quality indicators of the non-autoclaved aerated concretes.

7. Conclusions

1. We established in the course of our research the patterns of influence of supplementary cementitious materials on the microstructure and strength of partitions between pores of the non-autoclaved aerated concrete, which imply the targeted structure formation of partitions between pores with the creation of stable products of hydration. Given this, it can be argued that metakaolin and carbonate-containing waste of food salt production significantly affect the processes of structure formation of partitions between pores of the non-autoclaved aerated concrete and its characteristics. That is evident by the increased density of the structure of partitions between pores of the non-autoclaved aerated concretes, improved strength and durability.

2. The patterns in the structure formation of partitions between pores of the non-autoclaved aerated concretes containing metakaolin and carbonate-containing waste of food salt processing imply the creation of stable AF_m-phases – hexagonal calcium hydro-aluminates. The presence of these phases contributes to the compaction of the microstructure of partitions between pores of the non-autoclaved aerated concretes. Owing to a given mechanism and to the introduction of polypropylene fiber, there is a growth of the strength of the non-autoclaved aerated concretes based on the modified binding compositions containing metakaolin and carbonate-containing waste, by 47 % and 32 %, respectively. Compared with the use of the Portland cement, this allows us to argue about the effectiveness of the application of supplementary cementitious materials when obtaining the non-autoclaved aerated concretes. That testifies to the possibility of targeted control over the processes of structure formation of partitions between pores when using the binding compositions containing metakaolin, carbonate-containing waste, and polypropylene fiber. Building the stronger partitions between pores makes it possible to prolong the life cycle of the material and to contribute to the rational use of natural resources.

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STUDY OF THE EFFECT OF MICELLAR CATALYSIS ON THE STRENGTH OF ALKALINE REACTIVE POWDER CONCRETE

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За певних умов підвищення швидкості гідратації в'яжучої речовини сприяє підвищенню міцності бетону при стиску. Особливо це стосується реакційних порошкових бетонів.

Вивчений вплив поверхнево-активних речовин, здатних утворювати міцели, на швидкість формування та кінцеву величину міцності при стиску лужних реакційних порошкових бетонів. Особливістю досліджень було вивчення одночасного впливу поверхнево-активних речовин, які утворюють міцели, та реакційного порошку або заповнювача на зміну міцності бетонів. Встановлено, що означені міцелярні розчини та реакційні порошки змінюють характер формування міцності лужних реакційних порошкових бетонів. Збільшується швидкість формування міцності у початкові терміни за рахунок міцелярного каталізу гідратації доменного гранульованого шлаку, та зберігається підвищена їхня міцність при стиску на пізніх стадіях твердіння.

Міцність лужних реакційних порошкових бетонів при застосуванні поверхнево-активних речовин, спроможних утворювати міцели, досягає 260 % від міцності таких бетонів без добавок.

Доведено, що для управління процесами тужавіння в'яжучої речовини, яка складається із доменного гранульованого шлаку та лужного компоненту, й формування міцності отриманого штучного каменя можна використовувати міцелярний каталіз. За рахунок цього зменшується час, для досягнення проектної міцності бетону, та підвищується абсолютна величина міцності при стиску таких бетонів у віці 28 діб

Ключові слова: доменний гранульований шлак, луги, міцелярний каталіз, міцність бетону, порошковий бетон, міцели, поверхнево-активні речовини

1. Introduction

The volume of construction, which uses monolithic concrete that should meet numerous requirements, grows every year. The first requirement is the high rate of strength formation, as well as a high tensile strength depending on the type and conditions of operation.