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Features of Producing Non-Autoclaved Aerated Concrete With Additives of Mineral and Technogenic Raw Materials

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This article discusses issues related to the study of the possibility of developing a technology for the production of non-autoclaved cellular concrete. The results of testing the mechanical strength and density of non-autoclaved cellular concrete samples synthesised by varying the nature and concentration range of the introduced modifier components are presented. It has been established that modification of the original non-autoclaved cellular concrete containing ash and slag materials of the Kazakhstan TPP by adding 3 to 10 % (by weight of cement) of natural clinoptilolite from the Taizhuzgen deposit in Kazakhstan and 0.075-0.03 % (by water) of fullerenol (C60) allows stabilising the properties of the developed non-autoclaved cellular concrete. The studies are promising and will continue to obtain cellular concrete with specified characteristics suitable for the construction of earthquake-resistant residential buildings.

1. Introduction

Modern production of construction mixtures is impossible without the use of modifiers. In spite of the fact that the main processes of building mixture formation are determined by the interaction of binding material - filler - water, by adding a modifier, it is possible to obtain mortars with specified properties. Such modified materials can be used even in extreme conditions. Traditionally, aerated concrete was prepared on the basis of Portland cement, and then began to use binders based on slag and ash. It was possible to obtain not only insulating but also structural aerated concrete for enclosing structures of low-rise buildings. Today non-autoclaved aerated concrete is produced with the use of modern technological equipment and new types of heat and humidity treatment. Optimal compositions of aerated concrete mixes are selected taking into account the achievements in the field of material dispersion. Non-autoclave aerated concrete is produced on the basis of special cement, ground lime, some wastes (ash, slag and others) and a foaming agent, which is aluminium powder. The production of non-autoclaved aerated concrete is hundreds of times cheaper than autoclaved aerated concrete. However, non-autoclaved aerated concrete, unlike autoclaved (AAC), does not fully meet the requirements for frost resistance, fire resistance and some other parameters. To improve the properties of non-autoclaved aerated concrete, various modifying additives are introduced into the mixture: semi-aqueous gypsum, microsilica, calcium chloride, etc. Dispersed reinforcing fibres of artificial origin (polymeric fibres of different composition, glass fibres, etc.) and natural origin (asbestos, basalt fibres), as well as additives of acidic fly ash in the amount of 5-10 % of cement weight are considered to be promising modifiers for strength increase.
The authors (Sekkal and Zaoui, 2021) believe that nanoengineering or nanomodification of cement is an emerging field. It involves techniques to manipulate structure at the nanometre scale to develop a new generation of multifunctional cement composites with greater stiffness and durability. The new generation of cementitious materials will have a number of new properties such as self-sensing, self-cleaning, self-repair and self-crack control, making concrete a true smart material. The strength and durability of smart nanoengineered cement composites are improved by incorporating another type of nanomaterials, such as fullerene buckyballs (C60). A nanoscale analysis of the incorporation process of C60 nanomaterials into calcium silicate hydrates (C-S-H) was performed. The mechanical response as a function of the density and dispersion of fullerene molecules, as well as the porosity of C-S-H, has been evaluated using molecular dynamic modelling. Under

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shear stress, the nanostructure shows an increase in shear strength along the x and y directions due to the long silicate chains and Ca-O bonding.

Other authors (Zolotarev et al., 2013) have synthesised cement-gypsum plaster nanomodified with water-soluble fullerenols. Their experimental data demonstrate a sharp increase in the specific impact strength of nanomodified samples compared to unmodified ones. The authors (Marushchak et al., 2016) evaluated the effectiveness of ultra disperse mineral additives by differential surface activity coefficient. It was found that nanomodified Portland cement compositions containing ultra disperse mineral additives, polycarboxylate superplasticiser, alkaline-containing curing accelerator, as well as nanosized calcium hydro silicate particles are characterised by intensive early strength gain. The features of formation of phase composition, microstructure and strength synthesis of nanomodified cement stone were determined.

Another modifier of interest to the modern concrete/gas concrete construction industry is zeolite. Zeolite is intended as an active mineral admixture in the manufacture of cement, concrete mortars, foam and aerated concrete. A mixture of cement and zeolite in proportions ranging from 19:1 to 6:1 is used to produce high-strength concrete. According to the U.S. Bureau of Mines, this makes it possible to produce concrete with higher compressive strength than Portland cement. Partial replacement of clinker with 15-20 % of zeolite allows to obtain cement of 400, 500, and pozzolanic Portland cement of 300 grade with reduced setting time and end-setting time. In this study (Karakurt et al., 2010)), natural zeolite (clinoptilolite) was used as an aggregate and bubble-forming agent in the production of autoclaved aerated concrete. Prior to use in AAC mixtures, the pulverised and ultrafine samples were separated into particles of two different sizes: 100 μm (fine ZF) and 0.5-1 mm (coarse ZC). The effect of particle size, amount of replacement (25 %, 50 %, 75 % and 100 % compared to quartz) and curing time on the properties of aerated concrete was experimentally investigated. The use of natural zeolite, especially with larger particle sizes, was found to have a favourable effect on the physical and mechanical properties of AAC. The optimum replacement amount was determined to be 50 %, and the measured values of compressive strength, specific gravity and thermal conductivity of autoclaved aerated concrete were 3.25 MPa, 0.553 kg/dm^3 and 0.1913 W/(m×K).

The unique properties of zeolite and its high pozzolanic activity determined the possibility of its application as an active mineral admixture in the production of durable, frost-, moisture-, acid-, sulphate-resistant high-strength concrete (website of the company "Volga Region Zeolites"). Such concretes are used in the construction of hydraulic structures, as well as bridges, overpasses, and port facilities. It is known that the introduction of zeolite in the amount of 10-15 % allows to reduce cement consumption and the use of binder of optimal ratio in mortars and heavy concretes of B15-B10 class. When introducing activated zeolite of fraction up to 200 μm into concrete in the amount of 10-20 % of cement weight (M400, M500), plasticisers may not be used, as zeolite gives high plasticity and workability to a concrete mixture. If a plasticiser is used, its consumption should be 0.3-0.4 % of the dry weight of cement. The introduction of zeolite into concrete allows an increase in the concrete grade up to 750-800 and the water resistance index up to W14-20. Zeolite, used as a filler or additive in the production of foam concrete, gas silicate, and polystyrene concrete, gives good results, namely: increases strength, saves cement consumption by up to 20 %, increases the frost resistance of products and water resistance, as well as reduces shrinkage and increases crack resistance. The introduction of zeolite in the amount of 10 % in these concretes, although it slightly increases the density, at the same time reduces the thermal conductivity.

The novelty and relevance of this work lie in the development of a technology for the production of modular concrete blocks suitable for constructing seismically robust buildings. The purpose of this work is to study the possibility of developing a technology for the production of aerated concrete blocks that meet the requirements for the construction of earthquake-resistant residential buildings by modifying non-autoclaved aerated concrete containing ash and slag materials from Ust-Kamenogorsk TPP (Kazakhstan) by adding natural zeolite such as clinoptilolite and nanopreparation fullerenol (C60). It is supposed that the study of regularities of the genesis of composite structures by varying the nature of modifiers will allow the synthesis of building materials with specified properties. The new generation of modifying additives includes water-soluble fullerenes and zeolites. This study is a continuation of our earlier work (Galkina et al., 2021).

2. Materials and methods

To investigate the possibility of developing a technology for the production of non-autoclave ash-and-slag-containing aerated concrete that meets the requirements for the construction of earthquake-resistant residential buildings, we used the basic methodology of the construction company (Altaistroymash, 2024). We used the traditional recipe of aerated concrete from this construction company (Table 1). However, we made our own changes to modify the formulation, as shown in Table 2. We aimed to achieve the parameters of aerated concrete that meets the requirements of the D800 grade, as this grade is more in line with the seismic resistance characteristics in terms of strength and density of aerated concrete blocks. To modify aerated concrete in this work, we used zeolite additives in the amount from 3 to 10 % of cement mass, and the amount of added fullerenol varied in the range of 0.075-0.03 % of water. Portland cement of CEM I 52.5H grade of Bukhtarma Cement Company (Kazakhstan) was used as a binder. Chemical composition of cement, %: CaO 63.07, SiO_2 19.95, Al_2O_3 5.58, Fe_2O_3 4.98, MgO 4.5, SO_3 0.36. Physical and mechanical characteristics of cement: fineness of grinding on specific surface 2961 cm^3/g; true density 3191 kg/m^3; setting time 160 min (beginning), 240 min (end); uniformity of volume change 7.2 mm, flexural strength at 28 days 9.9 MPa; compressive strength at 28 days 64.5 MPa. Ash-and-slag materials (ASM) from the coal-fired thermal power plant of Ust-Kamenogorsk (Kazakhstan) were used as silica aggregate. Preliminary ash and slag waste was sieved on a sieve with a mesh size of 1.25 mm. Chemical composition of ash and slag waste: quartz low SiO_2 35.3 - 45.6; Mullite $3Al_2O_3$-$2SiO_2$ 53.9 - 64.0; hematite Fe_2O_3 0.3 - 1.8; magnetite Fe_3O_4 0.2 - 1.1. Physical and mechanical characteristics of ash and slag waste: uniformity of volume change 4.5 mm; humidity 0 %; bulk density (specific weight) 1140 kg/m^3; true density 2112 kg/m^3; specific surface 2530 cm^2/g; total residues, % on sieves (mm) 0.63-1.2, 0.315-2.6, 0.16-5.0, 0.08-89.5, 0.06-98.7, < 0.06-100.

Table 1: Recipe for gas blocks of AltaiStroyMash construction company (approximate recipe per 1 m^3)

Composition	Aerated concrete mark		
	D700	D700	D700
Cement, kg	312	318	286
Sand, kg	403	312	234
Water, l	264	256	208
Aluminium powder/paste, g	544	544	544
Sodium sulphate, kg	4.6	4.6	4.6

Table 2: Recipe of experimental modified aerated blocks (per 1m^3)

Composition	Mark D700	Mark D800
Cement, kg	278	330
Cinder, kg	222	264
Water, l	330	436.5
Aluminium powder, g	0.65	0.77
Lime, kg	56	66
Caustic soda, kg	3.5	4.15
Zeolite, (% of cement weight)	-	3-10
Fullerenol, (% of water quantity)	0.075-0.03	--

As a powder-forming agent in the work, we used a gas-forming agent - aluminium powder of PAP-1 grade, corresponding to the normative requirements. In addition, we used caustic soda corresponding to the normative documents and quicklime. In the work, additional modifiers were used: natural zeolite of clinoptilolite type from Taizhuzgen deposit of East Kazakhstan and nanopreparation (fullerenol (C60)). The characteristics of zeolite are described in (Mambetova et al., 2023), and the properties of fullerenol by Charykov et al (2023). The chemical composition of starting materials was determined by spectral analysis on an inductively coupled plasma mass spectrometer ICP-MS Agilent 7500cx and chemical analysis according to known methods. X-ray phase analysis on X'Pert PRO X-ray diffractometer was used to determine the phase composition of starting materials and neoplasms. Structural analysis was determined on scanning electron microscope JSM-6390-LV with an energy-dispersive microanalysis system. The specific surface area was determined on a PSX-10a instrument using the Kozeny and Karman gas permeability method according to the instructions for the instrument. Physical and mechanical tests were carried out according to standard methods.

Experimental samples were manufactured in the laboratory of the Centre of Competence and Technology Transfer in the field of construction of D. Serikbayev EKTU. The amount of dry components was selected so that the volume of finished aerated concrete was not less than 0.01 m^3. The ratio of cement and ash was taken 1:1. The amount of water was determined by the blurring of the cone, which should be 200±5 mm. Solid components were used in the dry state. Dosing of dry components was carried out by weight. In the first stage, cement, lime, and aggregate were mixed. Mixing was carried out using a construction drill mixer.

The Fullerenol solution of the required concentration was prepared separately. In a small amount of solution (50 ml), soda ash was dissolved. When zeolite was used, it was pre-soaked in water and then added together with water in the form of a solution. The quicklime used in the study was pre-crushed on a jaw crusher to a fraction of 0.63 mm or less. The aqueous solution for making aerated concrete was heated to 500 °C. Heated water and soda ash solution were added to the dry mixture and mixed for 3 min. After that, aluminium powder was added to the obtained solution and stirred for 2 min. The ready mixture was poured into the moulds to 2/3 of the height.

The rise of aerated concrete and minimum strength gain took place in normal conditions. Then, the samples were unploughed and placed for storage in the chamber of normal hardening for 28 days.
During the experiment, specimens with different contents of zeolite and fullerenol were produced and compared with the base specimen without zeolite and fullerenol. In the first stage, to determine the effect of fullerenol on the properties of aerated concrete, samples were made with the following concentrations: 0.015; 0.02; 0.025 and 0.03 %. In the second step, the effect of zeolite on aerated concrete properties was determined. For this purpose, samples with zeolite content of 3, 5, 7 and 10 % were made.

3. Results

Statistical processing of the test results was carried out, taking into account the homogeneity characteristics of aerated concrete. Aerated concrete is a structural and heat-insulating material, so not only the change in strength is important, but also the change in density and, as a consequence, the change in thermal conductivity. The experimental results for determining the effect of fullerenol and zeolite are given in Table 3.

Table 3: Effect of fullerenol and zeolite on aerated concrete properties

Composition	Additive, %	Compressive strength, MPa	Increase in compressive strength compared to control sample, %	Density of aerated concrete, kg/m^3	Reduction of aerated concrete density compared to the control sample, %	Thermal conductivity, W/(m°C)	Reduction of thermal conductivity compared to the control sample, %
With the concentration of fullerenol from the mass of water							
1	0	2.289	0	695	0.0	0.163	0
2	0.015	3.011	31.5	647	6.9	0.151	7.4
3	0.02	3.107	35.7	634	8.8	0.148	9.2
4	0.025	3.238	41.5	621	10.7	0.145	11.0
5	0.03	3.212	40.3	629	9.5	0.147	9.8
With zeolite content from the mass of cement							
1	0	2.50	0.0	740	0	0.163	0
2	3	3.02	20.8	750	-1.4	0.164	-0.6
3	5	2.91	16.4	758	-2.4	0.164	-0.6
4	7	2.55	2.0	768	-3.8	0.165	-1.2
5	10	2.01	-19.6	775	-4.7	0.166	-1.8

Visualization of the influence of fullerenol on the strength, density and thermal conductivity of aerated concrete is shown in Figure 1.

(a) (b)

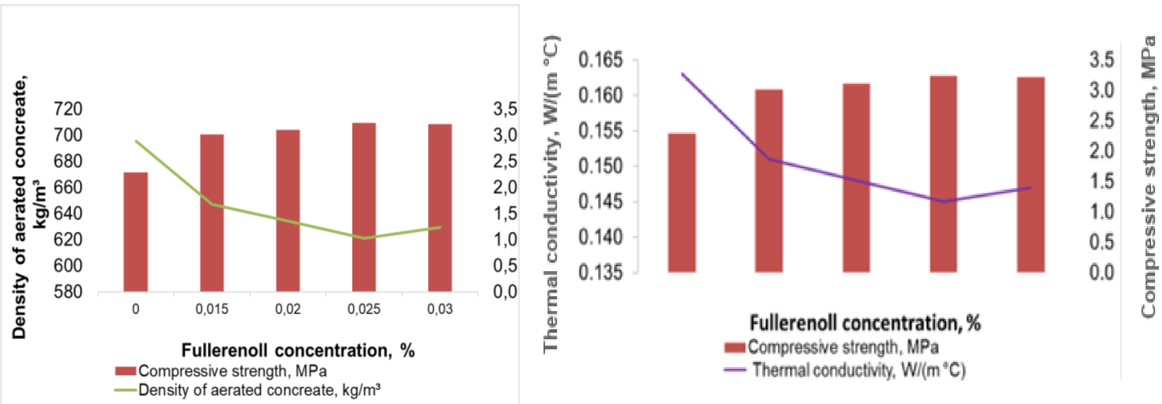

Figure 1: Effect of fullerenol (a) on strength and density of aerated concrete, (b) on strength and thermal conductivity of aerated concrete

Addition of fullerenol to the composition of aerated concrete showed Addition of fullerenol to the composition of aerated concrete showed a significant increase in strength. Strength at a fullerenol concentration from 0.015 % to 0.025 % increased and reached a maximum of 41.5 % (Figure 1a). At the same time, there was a decrease in density, which led to a decrease in thermal conductivity (Figure 1b). Despite the fact that this effect was not as global as that of strength, it still remained significant and reached 10.7 % for density and 11 % for thermal conductivity. A further increase in the concentration of fullerenol reduced the effect of its use. An increase in concentration to 0.03 % led to a decrease in strength, an increase in density and thermal conductivity by 1.2 % compared to the result obtained at a fullerenol concentration of 0.025 %. It should be noted that the increase in strength allowed the concrete class to move from B1.5 (2.289 MPa) to B2.5 (3.238 MPa) in terms of compressive strength. The spread of density values with the addition of fullerenol is within the permissible limits of the density class of 700 kg/m^3. The optimal concentration of fullerenol is 0.025%. This leads to an increase in the compressive strength of aerated concrete by 41.5 %, and at the same time, shows a decrease in density by 10.7 % and thermal conductivity by 11 % (Figures 1a, 1b). Visualisation of the effect of zeolite on the strength, density and thermal conductivity of aerated concrete is shown in Figure 2.

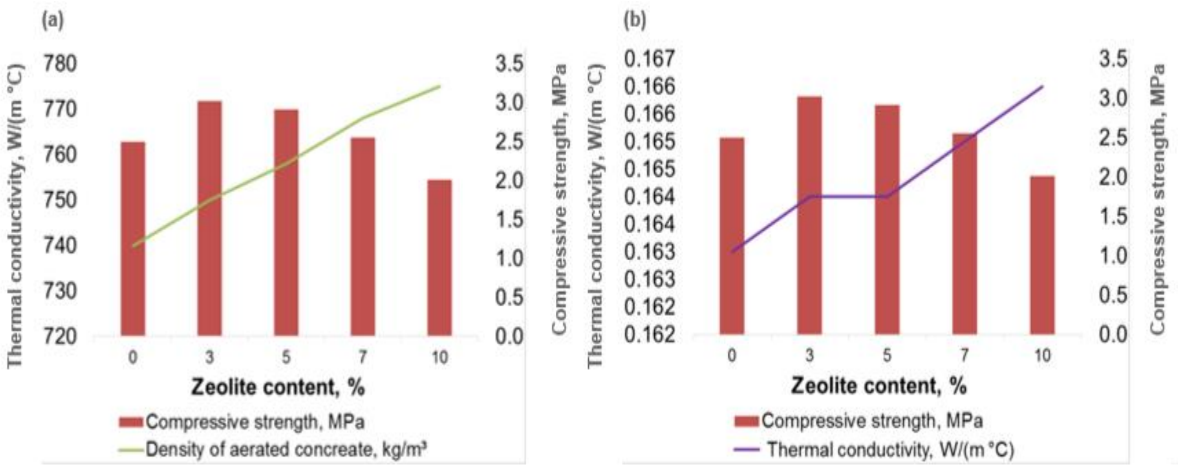

Figure 2: Effect of zeolite (a) on strength and density of aerated concrete, (b) on strength and thermal conductivity of aerated concrete

Replacing some of the cement with natural zeolite in small amounts of 3–5 % increased the compressive strength of aerated concrete by 20–16 % (Figure 2a). Further increasing the amount of zeolite to 7 % resulted in an insignificant improvement of only 2 %. Replacing 10 % of the cement with zeolite gave a negative result and reduced the strength by 19.6 %. Using 3 % zeolite allowed us to move the compressive strength class of concrete from B2 (2.5 MPa) to almost B2.5 (3.02 MPa). The introduction of zeolite into the composition of aerated concrete also leads to an increase in density by 1.4 % at 3 % zeolite to 4.7 % at 10 % zeolite, which slightly worsens the thermal conductivity of aerated concrete by 0.6–1.8 %. The greatest effect from the introduction of zeolite is achieved by replacing 3 % of cement, which leads to an increase in strength by 20 %, density by 1.4 % and thermal conductivity by 0.6 % (Figures 1a, 1b). Such a change in thermal conductivity fits even into statistical results and may not be taken into account, so the result obtained can be considered positive. Also, the change in density values with the addition of zeolite is within the permissible limits of the density grade of 800 kg/m^3 and does not change significantly, which indicates the stabilising effect of this additive. Experimental results show that the introduction of modifier additive - fullerenol generally improves the properties of aerated concrete, and the introduction of natural zeolite allows for stabilising the properties of the developed non-autoclave aerated concrete.

4. Conclusions

Currently, continuous improvements and technological breakthroughs in the manufacture of cement-based building materials offer the opportunity to combine natural zeolites with carbon nanotubes and other nanomaterials (Alexa-Stratulat et al., 2024). The most significant benefits of using natural zeolites are the reduction of carbon emissions due to the use of less cement and the improvement of the durability properties of cement-based materials. These benefits can be further enhanced by using natural zeolites together with other pozzolanic materials.

This article deals with the issues related to the study of the possibility of developing the technology of non-autoclaved aerated concrete production by adding from 3 to 10 % (of cement mass) of natural clinoptilolite and 0.075-0.03 % (of water) of fullerenol (C60). It has been established that modification of initial non-autoclaved aerated concrete containing ash and slag materials of Kazakhstani thermal power plant by trace amounts of additive-modifier - fullerenol in general improves the properties of aerated concrete, and introduction of natural clinoptilolite of Kazakhstani Taizhuzgen field allows to stabilise the properties of developed non-autoclaved aerated concrete. To use aerated concrete in seismically dangerous areas, it is necessary to maintain the strength and density ratio; for concretes of density grade D700, the compressive strength class must be at least B2, and for D800 – B2.5. The use of the studied additives – fullerinol and zeolite – allows achieving the required result. The research is promising and will continue to obtain aerated concrete with specified characteristics suitable for the construction of earthquake-resistant residential buildings.

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