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Non-autoclaved aerated concrete with a modified carbonate-sulfate additive based on soda ash production waste

J. Turgaev[1][a], V. Soy[2][b], N. Mukhammadiev[2][c]
[1]Karakalpak state university, Nukus, Uzbekistan
[2]Tashkent state transport university, Tashkent, Uzbekistan

Abstract: The article considers the technology for producing non-autoclaved aerated concrete using a modified carbonate-sulfate additive prepared from the solid sludge fraction of soda ash production waste. The distinctive feature of the proposed development is the preliminary preparation of technogenic raw material, including separation of the liquid phase, washing from water-soluble chlorides, carbonation, drying, fine grinding, and mechanochemical activation. It has been established that such treatment reduces the negative influence of soluble salts, stabilizes the alkalinity of the additive, improves the uniformity of gas formation, and densifies the interpore partitions of the cement matrix. The developed non-autoclaved aerated concrete with an average density of D500–D600 is characterized by compressive strength of 2.75–4.65 MPa, reduced water absorption, and lower shrinkage. The proposed technology makes it possible to use local technogenic raw materials, reduce energy consumption by eliminating autoclave treatment, and improve the resource efficiency of cellular concrete production.

Keywords: non-autoclaved aerated concrete, cellular concrete, carbonate-sulfate additive, soda ash production waste, chloride washing, carbonation, mechanochemical activation, porous structure, interpore partitions, water absorption, shrinkage

1. Introduction

Cellular concretes are among the most demanded types of energy-efficient building materials. Their use makes it possible to reduce the weight of enclosing structures, improve the thermal performance of buildings, and decrease the consumption of traditional construction materials. The most widespread industrial technology is the production of autoclaved aerated concrete; however, this technology requires autoclave equipment, considerable thermal energy consumption, and strict control of saturated-steam curing regimes.

Under regional production conditions, the development of non-autoclaved cellular concretes becomes especially relevant, since their hardening can take place under normal conditions or under mild heat-and-moisture treatment. The main problems of non-autoclaved aerated concrete are unstable gas formation, non-uniform pore structure, increased water absorption, shrinkage, and insufficient strength of interpore partitions.

One promising approach to solving these problems is the use of modified mineral additives based on technogenic wastes. For the Republic of Karakalpakstan, the use of soda ash production waste is of particular interest. However, the direct introduction of such waste into an aerated concrete mixture is undesirable due to the possible presence of water-soluble salts and chlorides. Therefore, the waste should not be used in its initial form but only after special technological preparation.

The aim of the study is to develop the composition and production technology of non-autoclaved aerated concrete with a modified carbonate-sulfate additive that stabilizes the porous structure, increases strength, and reduces water absorption.

2. Research methodology

Portland cement, a siliceous component, hydrated lime, gypsum, an aluminum gas-forming component, water, a polycarboxylate superplasticizer, and a modified carbonate-sulfate additive were used as the main components of the aerated concrete mixture.

The modified carbonate-sulfate additive was prepared from the solid sludge fraction of soda ash production waste. The preparation of the additive included several sequential stages. At the first stage, the solid sludge fraction was separated from the liquid phase. Then the material was washed with water in 2–3 stages to reduce the chloride ion content to not more than 0.5% by mass of dry substance. After washing, carbonation was carried out using a CO_2-containing gas until the pH of the aqueous extract reached 8.5–9.5.

The washed and carbonated material was dried at 105±5 °C to a residual moisture content of not more than 1.5%. After drying, the additive was ground to a specific surface area of 3800–4500 cm²/g and subjected to mechanochemical activation with silica fume. This preparation reduced the salt load, stabilized alkalinity, and increased the microfilling effect of the additive.

The aerated concrete mixture was prepared by sequential dosing of dry components, their mixing, addition of water with a polycarboxylate superplasticizer, and subsequent introduction of the aluminum gas-forming component. The gas-forming component was introduced at the final mixing stage to ensure uniform distribution and prevent premature reaction. After preparation, the mixture was poured into molds, kept until completion of expansion, cut, and subjected to non-autoclaved hardening.

[a] https://orcid.org/0000-0003-2483-9727
[b] https://orcid.org/0009-0006-9599-1776
[c] https://orcid.org/0000-0002-2306-3317

TECHNOLOGICAL SCHEME FOR PRODUCING THE MATERIAL

The technological scheme includes two main lines. The first line is intended for preparing the modified carbonate-sulfate additive and includes separation of the liquid phase, washing, chloride content control, carbonation, drying, grinding, and mechanochemical activation. The second line is intended for preparing the aerated concrete mixture and includes dosing of Portland cement, siliceous component, hydrated lime, gypsum, modified additive, water, and superplasticizer; mixture preparation; introduction of the aluminum gas-forming component; molding; expansion; cutting; and non-autoclaved hardening.

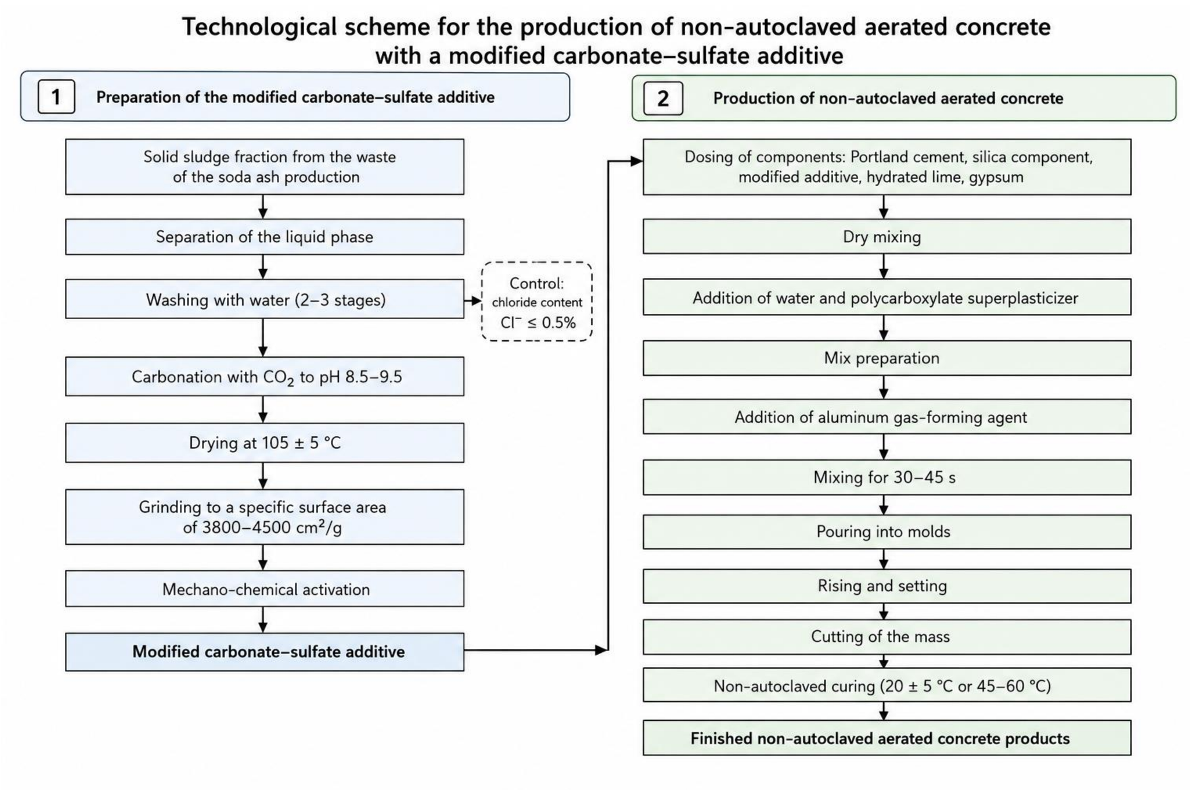

Fig. 1. Technological scheme for producing non-autoclaved aerated concrete with a modified carbonate-sulfate additive

Table 1

Compositions of the Developed Aerated Concrete Mixtures

Component	Mix 1, wt.%	Mix 2, wt.%	Mix 3, wt.%
Portland cement	26.00	28.50	31.00
Siliceous component	33.00	30.00	26.00
Modified carbonate-sulfate additive	7.00	9.50	12.00
Hydrated lime	2.00	3.00	4.00
Gypsum	0.80	1.40	2.00
Silica fume	1.50	2.50	4.00
Dispersed wollastonite	0.50	1.00	1.50
Polycarboxylate superplasticizer	0.25	0.35	0.45
Organosilicon water repellent or hydrophobizing component	0.10	0.20	0.30
Gas-structure stabilizer	0.02	0.04	0.06
Aluminum gas-forming component	0.09	0.07	0.05
Water	28.74	23.44	18.64

The developed compositions are characterized by an increased content of structure-forming finely dispersed components. Increasing the proportion of the modified carbonate-sulfate additive from 7 to 12% is accompanied by

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a decrease in water content and an increase in the density of interpore partitions. At the same time, the amount of aluminum gas-forming component decreases, since a denser and more stable cement-mineral suspension provides the formation of a uniform pore structure at a lower gas-formation intensity.

3. Results and discussion

The physical and mechanical properties of the developed compositions were compared with control mixtures of non-autoclaved aerated concrete that did not contain the modified carbonate-sulfate additive.

Table 2

Component Contents and Properties of Aerated Concrete Specimens

Indicator	Mix 1	Mix 2	Mix 3	Control 1	Control 2	Control 3
Portland cement, wt.%	26.00	28.50	31.00	28.00	33.00	38.00
Siliceous component, wt.%	33.00	30.00	26.00	26.00	28.50	31.00
Modified additive, wt.%	7.00	9.50	12.00	–	–	–
Hydrated lime, wt.%	2.00	3.00	4.00	2.00	3.00	4.00
Gypsum, wt.%	0.80	1.40	2.00	1.50	1.60	1.80
Silica fume, wt.%	1.50	2.50	4.00	3.00	2.40	2.00
Density, kg/m³	505	615	725	520	640	760
Compressive strength after 24 h, MPa	1.35	2.05	2.70	0.82	1.28	1.85
Compressive strength after 7 days, MPa	2.10	3.05	3.80	1.62	2.35	3.05
Compressive strength after 28 days, MPa	2.75	3.85	4.65	2.30	3.20	3.90
Water absorption, %	38.5	34.8	31.6	45.2	40.6	36.8
Drying shrinkage, mm/m	2.35	2.05	1.82	2.95	2.58	2.24
Thermal conductivity coefficient, W/(m·°C)	0.118	0.137	0.156	0.126	0.146	0.169

Analysis of the results shows that the introduction of the modified carbonate-sulfate additive increases the strength of aerated concrete at all curing ages. Mix 2 is of the greatest practical interest: at an average density of 615 kg/m³, it has a 28-day compressive strength of 3.85 MPa, water absorption of 34.8%, and drying shrinkage of 2.05 mm/m.

GRAPHICAL INTERPRETATION OF THE RESULTS

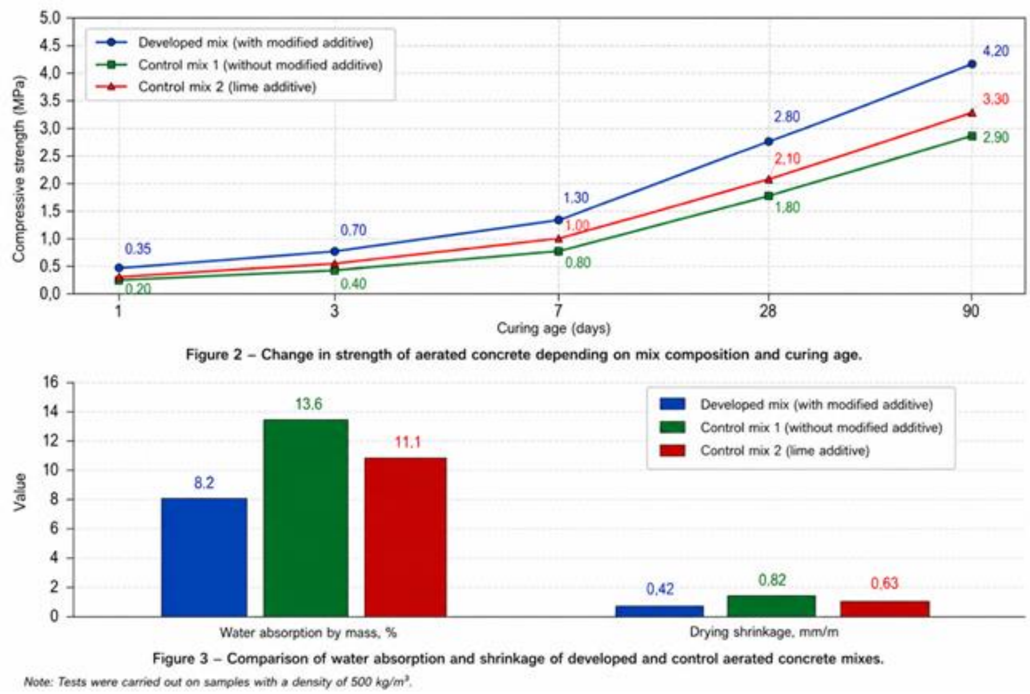

Fig. 2. Compasrison of the water absorption and shrinkage of developed and control aerated concrete mixes

Graphical analysis shows that the developed compositions have higher early and design strength compared with the control compositions. At the same time, water absorption and shrinkage decrease, indicating densification of interpore partitions and reduction of the proportion of open capillary pores.

DISCUSSION

The obtained results are explained by the complex action of the modified carbonate-sulfate additive. Washing the waste from water-soluble chlorides reduces the risk of efflorescence formation and decreases the negative effect of the salt phase on cement hydration. Carbonation stabilizes alkalinity and converts active calcium-containing compounds into a more stable carbonate form.

Fine grinding to a specific surface area of 3800–4500 cm²/g provides a microfilling effect. Particles of the modified additive are located in the intergranular space of the cement-siliceous system and contribute to densification of interpore partitions. Mechanochemical activation with silica fume enhances the formation of low-basic calcium silicate hydrates, which increases the strength of the cement stone.

The additional introduction of dispersed wollastonite promotes micro-reinforcement of interpore partitions and reduces the probability of shrinkage microcrack formation. The polycarboxylate superplasticizer reduces water demand, while the gas-structure stabilizer reduces settlement of the mass after expansion.

Thus, the proposed system affects the aerated concrete structure at several levels: it regulates gas formation, increases mass stability, densifies interpore partitions, and reduces the capillary permeability of the hardened material.

ECONOMIC AND TECHNOLOGICAL EFFICIENCY

The developed technology makes it possible to produce aerated concrete without autoclave treatment, which reduces capital and operating costs. The economic effect is achieved by reducing thermal-energy costs, eliminating autoclave equipment, partially replacing traditional mineral raw materials with modified waste, and reducing cement consumption while maintaining the required strength characteristics.

Compared with traditional autoclaved aerated concrete, the developed non-autoclaved aerated concrete provides savings due to a simpler technological line and the use of local technogenic raw material. At a conditional annual production volume of 50,000 m³, the economic effect may reach 1.97 billion UZS, confirming the industrial significance of the proposed technology.

4. Conclusion

A raw material mixture has been developed for producing non-autoclaved aerated concrete with a modified carbonate-sulfate additive based on soda ash production waste. The preparation of the additive includes washing from chlorides, carbonation, drying, grinding, and mechanochemical activation, which ensures its effective performance in the cement gas-forming system.

It has been established that the use of the modified additive increases the strength of aerated concrete, reduces water absorption, decreases shrinkage, and improves thermal performance. The most rational composition is Mix 2, which provides an average density of 615 kg/m³, a 28-day compressive strength of 3.85 MPa, water absorption of 34.8%, and shrinkage of 2.05 mm/m.

The proposed technology can be recommended for pilot industrial implementation in the production of thermal-insulating and structural-thermal-insulating products from non-autoclaved aerated concrete.

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Information about the author

Jambul Turgaev	Head of the department of “Urban planning and economy” Karakalpak state university, PhD Phone.: + 998973550840 E-mail: jambulturgaev46@gmail.com https://orcid.org/0000-0003-2483-9727
Vladimir Soy	Tashkent State Transport University, DSc Phone.: + 998909521576 E-mail: volodya_tsoy@inbox.ru https://orcid.org/0009-0006-9599-1776
Nematjon Mukhammadiev	Tashkent State Transport University, Head of the department of “Building and industry facilities construction”, DSc Phone.: + 998909111106 https://orcid.org/0000-0002-2306-3317

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