An additive for autoclaved aerated concrete on quick-extinguishing lime

Galina Kuznetsova\textsuperscript{1} and Nina Morozova\textsuperscript{1} [0000-0002-7867-4203]

\textsuperscript{1}Kazan State University of Architecture and Engineering, 420043 Kazan, Russia
E-mail: kuznetzova.gal@yandex.ru

Abstract. Slow-extinguishing lime is used in the production of autoclave hardening aerated concrete. If the production of aerated concrete is arranged in parallel with the production of silicate brick, then the lime will be quick-extinguishing. In this connection, the present paper considers the possibility of using quick-extinguishing lime and waste products from silicate brick. A significant content of quartz (over 75\%) in the composition of silicate brick makes it possible to use it in a ground form as an analogue of ground sand. Also, the paper has established a reduction in the setting time of cement and an increase in the strength of autoclaved concrete. However, slip-like additives reduce the mobility of the mixture and increase its water demand. The deterioration of processing characteristics is observed when ground waste is introduced into the sand slurry of aerated concrete mixture. Therefore, a complex additive based on the waste of silicate brick, plasticizer and gypsum stone has been proposed, which allows for expanding the scope of application of quick-extinguishing lime, reducing the water demand of the mixture without reducing mobility and increasing the strength of the finished product.

Key words: autoclaved aerated concrete, lime, additive, silicate brick, strength.

1 Introduction

Autoclaved aerated concrete is one of the leading structural insulations used all around the world [1-4]. Autoclaved aerated concrete in most cases is produced in Russia on the same premises as silicate brick and blocks, paving slabs and dry building mixtures.

The more modern cutting technology of aerated concrete involving a single edging comes with waste in the form of a cutting layer while in the production of hydrated lime-in unburned grains after the classifier are produced [5-9], and in the production of rusticated silicate bricks there are the crumbs of this product [10-13]. Efficiency in the use of active mineral additives in the production of autoclave materials to increase their operational properties [14-16], reduce energy costs [17, 18], and efficiency in use industrial waste in the production of aerated concrete [12, 19-21] were shown by a number of researchers.

In our opinion, the most rational option is to use waste and associated products of our own production, their processing into powders and use as additives in production [22]. Since the content of quartz in the composition of silicate bricks is not less than 75\%, it becomes possible to use it in a ground form as an analog of crushed quartz sand [23], and hydrosilicates contribute to increasing the strength due to better recrystallization of SN(I) in tobermorite [8, 24-27].

An example is the use of crushed silicate brick in the production of a lime binder. As the production of silicate brick involves a grinding site for a lime-silica binder, the issue of disposal is not difficult to solve. The chips left from rusting colored brick are not used as an additive in the binder in
the production of white silicate brick, although colored brick is the same ground silica and calcium hydrosilicates. However, in the production of white silicate brick, it changes their appearance, like the appearance of other colored waste, while also increasing the physical and mechanical properties of the finished product [28, 29].

The purpose of this paper is to develop a complex additive based on waste silicate bricks to improve the efficiency of production of cellular concrete autoclave hardening on quick-extinguishing lime. To that end, at the first stage, a comparison of the grinding capacity of silicate brick crumbs and quartz sand was performed to determine the energy consumption for obtaining powders. The second stage examines the influence of the addition of silicate brick powder on the properties of sand sludge and on the setting time of cement used as a structure-forming component in the pre-autoclave hardening period. The next step was to evaluate the effect of plasticizing additives and sulfates on the properties of lime. Then a complex organo-mineral additive was designed. Further, the technological properties of cellular concrete mix and physical and mechanical properties of autoclave-hardened aerated concrete with this additive are studied.

2 Materials and methods
This paper studies the production waste of silicate bricks of the M150 brand which comes in the form of crumbs. Since this waste features different grain sizes, the waste was ground. At the same time, the grinding capacity of silicate brick crumbs in comparison with quartz sand was evaluated to establish comparative energy consumption. An IDA-175-disc eraser was used to grind the silicate brick waste with grains of 2.5 mm being preliminarily crushed in a DLSCH-10 laboratory crusher. The other granular materials used (construction sand, quick-dried crushed lime) were crushed on an IDA-175 crusher. The true density of powders was determined using a Le Chatelier flask; their specific surface area is determined using a PSKh-12 device through the air permeability method. The powders obtained in this way (table.1) were used as an additive in the composition of cement mortar and autoclaved aerated concrete. The study used cement CEM I 42.5 N produced by LLC "Holcim" based in the city of Volsk. Ground sand (table 1) was used as a quartz component of a cellular concrete mix obtained from construction sand with a grain size of 1.4, containing dust-like and clay particles (no more than 1.5%).

| Name of material | Powder performance |   |
|------------------|--------------------|---|
|                  | true density, g/cm³|   |
| Silicate brick   | 2.57               |   |
| Quartz sand      | 2.65               |   |

The gas-forming component is the PAP-2 brand aluminum powder with an active aluminum content of 80%, a covering power of at least 1000 m²/kg on water, while sulfanol – alkylbenzenesulfonate, a mixture of isomers of sodium salts of alkylbenzenesulfonic acids in the form of an aqueous solution obtained from a free-flowing granular powder of light color, was used to prepare the suspension.

The processing parameters were evaluated via the methods envisaged by GOST 310.4 and SN 277-80. The physical and mechanical properties of cement mortar and aerated concrete were determined using standard methods under GOST 10180-2012 and GOST 12730.1-78.

3 Results and discussion
The first stage involved an assessment of the grindability of the silicate brick crumb in comparison with that of the quartz sand (figure 1).
As a result (figure 1), the grinding of quartz sand is 1.5-2 times slower than the grains of silicate bricks due to the lower strength of the grains of silicate bricks. This fact indicates lower energy consumption for the grinding process when obtaining powders.

The technology involving aerated concrete on a mixed binder sees cement as a necessary structure-forming component in the pre-autoclave curing period [30, 31]. To this end, the effect of the addition of ground brick on cement and its properties has been investigated. The results are presented in figure 2.

As can be seen from the results, the addition of ground brick in an amount of up to 10% does not affect the setting time of cement. The water demand of silicate brick powder amounted to 38.8%; its introduction into the mixture has a negative impact on the aerated concrete mix. For this, the density and water demand of sand slurry with the addition of ground brick, the characteristics of which are shown in figure 2, were studied. The criterion for evaluating the chosen diameter of the spread of sand slurry is given.

**Figure 1.** Grinding materials.

**Figure 2.** The effect of ground silicate brick on the setting time of cement.
The introduction of ground brick additives reduces the flow of sand slurry. As can be seen from figure 3, the additive in the composition of sand sludge increases water demand, but reduces its density (figure 5). A decrease in concrete density will help to increase its heat-shielding properties [33].

It is possible to solve the problem of stabilizing the viscoplastic properties of the aerated concrete mixture by controlling the rheological characteristics through the introduction of plasticizing additives [34]. The plasticizing additives and gypsum stone, as is noted by the researchers [31, 35], lead not only to liquefaction, but also to an increase in the time of lime slaking.
In figure 5, the greatest effect of slowing down the hydration of lime is achieved when using naphthalene S-3 superplasticizer and two-water gypsum (HA). The superplasticizer increases the coefficient of deceleration by 14% more than the addition of gypsum. It is also known that the addition of gypsum stone lowers the extinguishing temperature of lime two times more than the addition of the S-3 superplasticizer [30, 36]. The use of gypsum stone in concrete with waste ensures the creation of a uniform pore structure of aerated concrete [36].

Further, considering the effects obtained, a comprehensive additive KD-1 was designed and prepared above, including waste silicate brick, gypsum stone and naphthalene superplasticizer.

Initially, the effect of the KD-1 additive on the strength of a cement-sand mortar (CMR) was studied with cement to sand ratio of 1:4 by weight. All the compositions had the same mobility, which was fixed by a jolt table pursuant to the method set forth in GOST310.4. The cone spread was maintained within 110-112 cm by regulating the amount of mixing water. After that, beam samples sized 4×4×16 cm were molded from the resulting mixture. One series of samples was subjected to heat and humidity treatment at a temperature of 95 °C, the other was subjected to autoclaving at a pressure of 1.2 MPa, and the third series of samples was placed in a normal hardening chamber for 28 days. Upon completion, all samples were tested for bending and compression.

Table 2. Strength indicators of samples depending on the hardening conditions.

| Hardening conditions                                      | Strength indices of CMR samples for compression/bending, MPa, with the amount of the KD-1 additive, %, from the weight of the binder | 0 | 5  | 7,5 | 10 |
|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|---|----|-----|----|
| Normal hardening conditions after 28 days               |                                                                                                                          | 18.2/4.4 | 19.48/4.6 | 22.3/4.9 | 25.5/4.9 |
| Heat and humidity treatment at atmospheric pressure in a chamber with 95 °C |                                                                                                                          | 16.1/3.6 | 18.4/4.9 | 19.7/4.3 | 22.3/4.3 |
| Heat and moisture treatment in an autoclave at 1.2 MPa   |                                                                                                                          | 18.9/6 | 26.5/7 | 28.5/7.2 | 31/7.5 |

As can be seen from the results obtained in table 2, the additive is effective under all conditions of hardening and the efficiency is higher in those conditions where more energy is used. Autoclaved samples have a higher strength than samples after a thermal vacuum treatment and than samples hardened under normal conditions. For autoclaved samples, the increase in compressive strength relative to the non-additive composition was 40 and 64%, respectively, with the introduction of an additive in the amount of 5 and 10%. For samples hardening under normal conditions, the increase in compressive strength with respect to the non-additive composition was 7% at 5% of the additive, and 40% at 10%. For samples hardening during heat-moisture treatment, the increase in compressive strength relative to the non-additive composition was 14 and 38% with the introduction of an additive in the amount of 5 and 10% of, respectively.

Thus, the results obtained indicate the effectiveness of the developed additive KD-1 in autoclave hardening materials, which is aerated concrete on a mixed lime-cement binder.

Next, the properties of aerated concrete of the D600 brand which involves an injection molding technology with the addition of KD-1 in an amount of 5, 10, 15% by weight of sand were studied. The manufacturing technology of aerated concrete is cast. The mixing time of the mixture is 4 minutes. The developed additive KD-1 is characterized by a plasticizing effect (figure 6), the introduction of which into the aerated concrete mixture increases its mobility by 8-10% and reduces the temperature of the mixture by 5-7°C for every 5% of the additive (figure 7).
Figure 6. The effect of additives KD-1 on the mobility of the cellular concrete mixture.

Figure 7. The effect of additives KD-1 on the temperature of the concrete mixture.

Taking into account the obtained properties of the aerated concrete mixture and the requirements of SN 277-80, the mixing water temperature was adjusted for preparing the aerated concrete mixture by an injection technology with a temperature of 35 °C, from which cube samples of 10×10×10 cm were formed. After autoclaving at a pressure of 1,2 MPa, the samples were tested out pursuant to the method envisaged by GOST 10180.

Table 3. Properties of aerated concrete with the addition of KD-1.

| The amount of KD additive as % of sand mass | Concrete medium density, kg/m³ | Ultimate compression strength, MPa | Strength-density ratio (SDR) |
|--------------------------------------------|-------------------------------|----------------------------------|-------------------------------|
| 0                                          | 603                           | 1.64                             | 2.7                           |
| 5                                          | 615                           | 1.91                             | 3.1                           |
| 10                                         | 630                           | 2.25                             | 3.6                           |

As can be seen from the results of Table 3 the additive KD-1 increases the physical and mechanical properties of autoclaved aerated concrete. The increase in autoclave strength amounted to 16 to 37% with the introduction of 5 and 10% of the additive, respectively.

In order to establish the strength efficiency of the D600 grade aerated concrete according to the obtained values given in table.3, the SDR was calculated by dividing the ultimate compressive strength by its relative average density. As a result, the SDR increases by 15-33% which is achieved by increasing the strength per unit mass of the material.

4 Conclusions

The conducted experiments have established that the additive KD-1 is effective.

The developed additive allows for recycling industrial waste, arranging the production of aerated concrete on quick-extinguishing lime, reducing the water demand of a cellular concrete mixture.
without reducing its mobility and decreasing the maturation time of the batch in the pre-autoclave period.

The results of the research have enabled the development of a complex additive KD-1 based on silicate brick waste for the production of cellular concrete of autoclave hardening on quick-extinguishing lime.

It is established that the use of the comprehensive KD-1 additive in the production of autoclave-hardened aerated concrete using the injection molding technology can increase the strength by 16-37% while its own waste will be disposed of. The economic effect of using the KD-1 additive in autoclave-hardening aerated concrete technology is greatest when the production of this additive, aerated concrete and silicate bricks is located on the same premises.

References

[1] Fakhratov M, Erkenov R, Kulchaev A & Zavgorodniy A 2017 Manufacturing processes of cellular concrete products for the construction MATEC Web of Conferences, 117. doi: 10.1051/matecconf/201711700043

[2] Kazaryan R & Belyaev K 2019 The sustainable energy approach in the manufacture of cellular concrete E3S Web of Conferences, 91. doi: 10.1051/e3sconf/20199102024

[3] Vishnevsky A A, Greenfeld G I, Smirnova A S 2015 Production of autoclaved aerated concrete in Russia Building materials, No. 6, pp 52-54.

[4] Sazhnev N P 2018 The production and use of cellular concrete in the Republic of Belarus is 50 years old Building Materials, No. 5, pp 4-10.

[5] Shi C, Li Y, Zhang J, Li W, Chong L & Xie Z 2016 Performance enhancement of recycled concrete aggregate A review Journal of Cleaner Production, 112, pp 466-472.

[6] Zaetang Y, Sata V, Wongsa A & Chindaprasirt P 2016 Properties of pervious concrete containing recycled concrete block aggregate and recycled concrete aggregate Construction and Building Materials, 111, pp 15-21. doi: 10.1016/j.conbuildmat.2016.02.060

[7] Silva R V, De Brito J & Dhir R K 2016 Establishing a relationship between modulus of elasticity and compressive strength of recycled aggregate concrete Journal of Cleaner Production, 112, pp 2171-2186. doi: 10.1016/j.jclepro.2015.10.064

[8] Xuan D, Zhan B & Poon C S 2016 Assessment of mechanical properties of concrete incorporating carbonated recycled concrete aggregates Cement and Concrete Composites, 65, pp 67-74. doi: 10.1016/j.cemconcomp.2015.10.018

[9] Serres N, Braymand S & Feugeas F 2016 Environmental evaluation of concrete made from recycled concrete aggregate implementing life cycle assessment Journal of Building Engineering, 5, pp 24-33. doi: 10.1016/j.jobe.2015.11.004

[10] Qu X & Zhao X 2017 Previous and present investigations on the components, microstructure and main properties of autoclaved aerated concrete Construction and Building Materials, 135, pp 505-516. doi: 10.1016/j.conbuildmat.2016.12.208

[11] Yoon H & Yang K 2019 Optimum mixture proportioning of autoclave lightweight aerated concrete considering required foaming rate and compressive strength Journal of the Korea Concrete Institute, 31(2), pp 123-130. doi: 10.4334/JKCI.2019.31.2.123

[12] Cai L, Li X, Liu W, Ma B & Lv Y 2019 The slurry and physical-mechanical performance of autoclaved aerated concrete with high content solid wastes: Effect of grinding process Construction and Building Materials, 218, pp 28-39. doi: 10.1016/j.conbuildmat.2019.05.107

[13] Liang X, Yuan D, Li J, Wang C, Lin X & Chang N 2018 Preparation and phase characteristics of autoclaved aerated concrete using iron ore tailings Revista Romana De Materiale Roman Journal of Materials, 48(3), pp 381-387.

[14] Mukhametakhimov R, and Lukmanova L 2018 Features of the hydration process of the modified blended cement for fiber cement panels In: MATEC Web Conf. doi: 10.1051/matecconf/201817003030
[15] Lukmanova L V., Mukhametrakhimov RK, and Gilmanshin IR 2019 Investigation of mechanical properties of fiber-cement board reinforced with cellulosic fibers IOP Conf Ser Mater Sci Eng 570 doi: 10.1088/1757-899X/570/1/012113

[16] Mukhametrakhimov R and Lukmanova L 2018 The Modified Fiber Cement Panels for Civil Construction. doi: 10.1007/978-3-319-70987-1_91

[17] Mukhametrakhimov R and Lukmanova L 2018 Parametric optimization of autoclave curing for energy cost reduction of fiber cement panels In: MATEC Web Conf. doi: 10.1051/matecconf/201817003029

[18] Mukhametrakhimov R Kh and Lukmanova L V 2017 Decreasing of energy expenditures connected with production of fiber cement panels for building finish In: IOP Conf. Ser. Earth Environ. Sci. doi: 10.1088/1755-1315/90/1/012112

[19] Hustavova J, Sebestova P, Meszarosova L, Cerny V & Drochytka R 2019 Usability of waste perlite in the technology of production of autoclaved aerated concrete IOP Conference Series: Materials Science and Engineering, 549(1). doi: 10.1088/1757-899X/549/1/012027

[20] He T, Xu R, Da Y, Yang R, Chen C & Liu Y 2019 Experimental study of high-performance autoclaved aerated concrete produced with recycled wood fibre and rubber powder Journal of Cleaner Production, 234, pp 559-567. doi: 10.1016/j.jclepro.2019.06.276

[21] El-Dedamony H, Amer A A, Mohammed M S & El-Hakim M A 2019 Fabrication and properties of autoclaved aerated concrete containing agriculture and industrial solid wastes Journal of Building Engineering, 22, pp 528-538. doi: 10.1016/j.jobe.2019.01.023

[22] Sinica M, Sezemanas G, Mikulskis D, Kligys M, Česnauskas V, Zacharčenko P, Pivenj N 2019 Investigation of the composite material with inclusions of autoclaved aerated concrete chips Medziagotyra, 15(4), pp 356-362.

[23] Kuznetsova G V, Shinkarev A A, Morozova N N, Gazimov A Z 2018 Additives for direct silica brick manufacturing technology Building Materials, Nos. 9, pp 12-16.

[24] Laukaitis A A 2014 Investigation of the effect of the additive of ground wastes of cellular concrete on its properties Building Materials, No. 3, 130.

[25] Che Y & Yang H 2016 Compacted microstructure and improved mechanical properties of cement mortar by adding waste concrete dust. Cailiao Daobao Materials Review, 30, pp 162-166.

[26] Dachowski R, Kostrzewa P & Brelak S 2018 Autoclaved materials with chalcedonite addition. MATEC Web of Conferences, 174, doi: 10.1051/matecconf/201817402011

[27] Fleischhacker J, Helanova E & Drochytka R 2016 Hydrothermal synthesis of tobermorite at 170 and 190 °C from fly ash and quartz sand. doi: 10.4028/www.scientific.net/MSF.865.42

[28] Skawińska A & Owsiański Z 2017 The influence of metahalloysite addition on the properties of autoclaved aerated concrete Cement, Wapno, Beton, (1), pp 18-25.

[29] Stanescu G, Badanoiu A, Nicoara A & Voicu G 2019 Brick and glass waste valorisation in the manufacture of aerated autoclaved concrete Revista De Chimie, 70(3), pp 828-834. doi: 10.37358/RC.19.3.7015

[30] Kuznetsova G V, Morozova N N, Potapova L I, Klokov V V 2017 Integrated additive for autoclaved aerated concrete Building materials, No. 5, pp 36-39.

[31] Kaminskas R & Barauskas I 2019 Autoclaved aerated concrete waste as a micro-filler for portland cement. Revista Romana De Materiale Romanian Journal of Materials, 49(2), pp 244-250.

[32] Kuznetsova G V, Morozova N N, Yusupov I D 2018 Investigation of the effect of dispersed additives on the properties of autoclaved aerated concrete Building materials, No. 5, pp 20-23.

[33] Leontiev S V, Shamanov V A, Kurzanov K D, Golubev V A 2015 Study of the effect of plasticizing additives on the stabilization process of the cellular structure of heat-insulating aerated concrete autoclaved Basic Research, No. 11-3, pp 474-479.

[34] Bedarev A A 2013 The effect of plasticizing additives on the temperature and visco-plastic properties of a silicate mixture for the production of gas silicate Izvestija KSASU 2(24), 208 p.
[35] Helanova E, Drochytka R & Cerny V 2016 Influence of gypsum additive on the formation of tobermorite in autoclaved aerated concrete.

[36] Vishnevskiy A A & Kapustin F L 2017 Low density cellular concrete made of reftinskaya SDPP fly ash. doi: 10.4028/www.scientific.net/SSP.265.124