Magazine of Civil Engineering. 2024. 17(1). Article No. 12507

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 691.3

DOI: 10.34910/MCE.125.7

Enhancing lightweight concrete strength through modified zeolite-alkaline porous aggregate: composition optimization and structural application

***O.I. Matveeva*[1], *N.K. Baishev*[2], *A.I. Makarov*[2], *A.L. Popov*[2,3] ✉, *I.R. Pavlyukova*[4], *N.A. Grigoriev*[2]**

[1] *YakutPNIS-Commercial Center, Yakutsk, Russian Federation*

[2] *North-Eastern Federal University named after M. K. Ammosov, Yakutsk, Russian Federation*

[3] *Institute of Problems of Oil and Gas of the Siberian Branch of the Russian Academy of Sciences, Yakutsk, Russian Federation*

[4] *JSC Yakutsk State Design, Research Institute of Construction, Yakutsk, Russian Federation*

✉ *surrukin@gmail.com*

Keywords: lightweight concrete, porous aggregate, modified zeolite, strength characteristics, structural application, composition optimization

Abstract. The work is aimed at research of technology of lightweight concrete with porous aggregate with improved strength characteristics to expand the field of its application in reinforced concrete structures. The lack of demand for lightweight concrete in structural construction is due to its low reliability in view of the increased ultimate deformation of compression and tension. However, as recent studies show, when taking into account the ultimate compressive strain of lightweight concrete, it is quite possible to ensure the reliability of such structures. In order to expand the scope of application of light concretes in bearing layers of multilayered enclosing and bearing reinforced concrete structures, our purpose was to determine the features of the lightweight concrete composition selection technique with improved characteristics using a porous aggregate of modified zeolite-alkaline charge. Empirical equations of dependence of lightweight concrete strength on concrete density and aggregate density as well as dependence of lightweight concrete strength on coarse aggregate volume concentration and aggregate strength were established to determine rational compositions of lightweight concrete. The possibility of producing structural lightweight concrete of strength classes B15 to B27.5, with the frost-resistance mark F_1 150 with the use of porous aggregate modified zeolite-alkaline batch is shown.

Citation: Matveeva, O.I., Baishev, N.K., Makarov, A.I., Popov, A.L., Pavlyukova, I.R., Grigoriev, N.A. Enhancing lightweight concrete strength through modified zeolite-alkaline porous aggregate: composition optimization and structural application. Magazine of Civil Engineering. 2024. 17(1). Article no. 12507. DOI: 10.34910/MCE.125.7

1. *Introduction*

Currently, a large volume of experimental and theoretical studies devoted to the study of physical-mechanical and thermal properties of lightweight concretes on glassy porous aggregates has been accumulated [1–3]. Analysis of the works indicates that researchers have developed effective aggregates for light concretes with increased content of glassy phase, which open up new possibilities of improving the whole complex of properties of light concretes and structures from them. Promising glassy aggregates with partially or completely amorphous grain structure include: granulated foam glass, granulated foam glass ceramics and other similar aggregates with a closed cellular structure and bulk density of less than 250 kg/m^3, on the basis of which it is possible to obtain light concrete with a density grade D600-D800 and with a strength class up to B2.5. [4, 5]. Major research is aimed at obtaining lightweight high-strength concrete with expanded areas of application using alternative aggregates, including waste glass sand (WGS), municipal solid waste incineration bottom ash (MSWI-BA), recycled coarse aggregates (RCA), fly ash (FA), waste rubber (WR), steel waste (SW), and waste plastic (WP), etc. [6–8].

We have made an attempt to develop compositions of light structural zeolite concretes for the manufacture of load-bearing layers of multilayer enclosing, load-bearing reinforced concrete structures (wall panels) and load-bearing reinforced concrete structures for low-rise construction (walls, lintels, floor slabs and overlaps) with specified properties: B15; D1600, $F_1$100. For this purpose, previous studies have produced pilot batch of foam-zeolite porous aggregate on the production base of LLC "Suntarzeolit" with bulk density of 680–740 kg/m^3 (bulk density mark M700-800) and a strength of 2.45–2.63 MPa (grade of strength P100-P125).

However, when selecting the composition of concrete, we encountered low verification of the actual properties of concrete with the calculated ones. This fact is due to the fact that the existing methods of selection are suitable either for heavy concretes with a density of 2200–2800 kg/m^3 [9, 10] or for light concretes with a density of less than 800 kg/m^3 [11]. The inefficiency of concretes with a density of 1000–1800 kg/m^3 is due to intermediate values of the properties of lightweight concrete, which does not allow their use in energy-efficient construction as a heat insulating material due to insufficiently low thermal conductivity and in structural engineering because of low reliability in view of the increased ultimate deformation of compression and tension. As one of the options for combining such concretes, scientists from Beirut Arab University considered the option of a reinforced concrete beam with lightweight concrete in the tension zone. However, the presence of lightweight aggregate in the tension zone tends to cause brittle failure of the beam [12]. To increase the relevance of the use of lightweight intermediate density concretes, researchers from the University of the West of England, Bristol, describe the ultimate compressive strain of lightweight concrete by a linear dependence on the ultimate compressive strain of heavyweight concrete, described by the coefficient η:

$$\eta = 0.4 + 0.6\frac{\rho}{2200}. \qquad (1)$$

If you take into account this figure it is possible to calculate a reinforced concrete beam of lightweight concrete with ultimate compressive strain of 2.18 % and a reduction in reinforcement to 47 % [13]. Also, scientists from Anhui Jianzhu University, China, who were able to simulate the fatigue life of lightweight concrete on porous aggregate using the Weibull distribution, are studying the reliability of lightweight concrete in reinforced concrete structures [14]. Increasing the durability of lightweight concrete on porous aggregates is related to water absorption and porosity of lightweight aggregates, and as the team of authors from Republic of Korea, Germany, Poland and Egypt emphasize, the aggregate used should either be artificially treated to close open pores or artificial porous aggregate with closed surface pores should be used [15]. Alternatively, cold granulation aggregates with closed porosity have been proposed, which uses cement as a binder and filler in the form of fly ash [16] or aggregates from industrial wastes such as POS [17].

Thus, the development of technology of lightweight concrete with porous aggregate with improved durability characteristics to expand its application in the load-bearing layers of multilayer enclosing, load-bearing reinforced concrete structures (wall panels) and load-bearing reinforced concrete structures for low-rise construction (walls, lintels, roof slabs and floor slabs) is relevant.

The aim of the study is to establish the technology and peculiarities of selecting the composition of lightweight concrete using porous aggregate from modified zeolite-alkaline charge that improves its properties. As the first step towards achieving this goal, the task was set to clarify the method for selecting the composition of lightweight concrete by deriving new dependencies for the influence of the quantitative and qualitative composition of components on the strength and density of concrete. The method was also tested.

2. Materials and Methods

When selecting the composition of lightweight concrete, the following components were used: as a binder, Portland cement grade CEM I 32,5B by Interstate Standard 31108-2016, produced by JSC PA Yakutcement with the characteristics indicated in Table 1; river sand was used as a fine dense aggregate from the Lena River floodplain (Table 2); porous aggregate of the pilot batch manufactured by Suntarzeolite LLC is used as a coarse aggregate (Table 3); as the plasticizing additive used was an additive for concrete and mortars produced by JSC Polyplast (LLC Polyplast-UralSib) – Superplasticizer SP-1.

Table 1. Properties of used Portland cement.

No.	Cement quality index	Unit.	Value
1	Cement strength class	MPa	32.5
2	Flexural/compression strength at 2 days of age	MPa	3.8 / 16.8
3	Compressive strength after steaming	MPa	27.1
4	Uniformity of volume change	mm	0.0
5	Normal cement density	%	26.5
6	Mass fraction of sulfur oxide (VI) SO_3	%	2.55
7	Mass fraction of chloride ion	%	0.026
8	Initial setting time	min	135
9	Information about clinker:		
	- $C_3S + C_2S$	%	76.55
	- CaO/SiO_2	-	3.09
	- MgO	-	2.12
10	Signs of a false setting	-	no

Table 2. Grain composition of used sand.

No.	Indicator name	Unit.	Requirements of Interstate Standard 8736-2014	Actual value
1	2	3	4	5
1.	Bulk density	kg/m^3	not regulated	1444
2.	Total residue on sieve with mesh No. 063, % by mass	%	up to 10	0.06
3.	The content of grains smaller than 0.16 mm	%	no more than 20	4.84
4.	Modulus of grain size	Mod.	from 1.0 to 1.5 for the "very fine" group	1.09
5.	The content of grains in coarseness, by mass:	%		
	more than 10 mm.		not more than 0.5	0.10
	more than 5 mm.		not more than 10	0.00
6.	Content of dusty and clayey particles	%	not more than 5 for class II sand	0.25
7.	Clay content in clumps	%	not more than 0.5 for class II sand	0.00
8.	True density	g/cm^3	2.0 to 2.8	2.62
9.	The content of organic impurities	standard	lighter than the standard	lighter
10.	Hollowness	%	not regulated	44.89

Experimental studies of the initial materials (fine and coarse aggregates) were carried out in accordance with the following regulatory documents:

- Interstate Standard 9758-2012 "Non-organic porous aggregates for construction work. Test methods". Controllable characteristics of foam-zeolite.
- Interstate Standard 8735-88 "Sand for construction work. Testing methods". Controllable characteristics of dense sand.

Concrete mixtures and concretes were tested in accordance with the following standards:

- Interstate Standard 10181-2000 "Concrete mixtures. Methods of testing". Controllable characteristics of concrete mixtures;
- Interstate Standard 10180-2012 "Concretes. Methods for strength determination using reference specimens";
- Interstate Standard 12730.1-78 "Concretes. Methods of determination of density";
- Interstate Standard 12730.2-78 "Concretes. Method of determination of moisture content";
- Interstate Standard 10060-2012 "Concretes. Methods for determination of frost-resistance";

– Interstate Standard 7076-99 "Building materials and products. Method of determination of steady-state thermal conductivity and thermal resistance".

Table 3. Physical and mechanical properties of the experimental batch of foam-zeolite.

No.	Name of indicators	Requirements of Interstate Standard 32496-2013	Actual value
1	2	3	4
1.	Bulk density, kg/m^3		
	fr. 5 -10 (screening)	600 to 700 for M700	696
	fr. 10-20	700 to 800 for M800	733
2.	Crushing strength of foam-zeolite in a cylinder, MPa		
	fr. 5 -10 (screening)	2.0 to 2.5 for P100	2.31
	fr. 10-20	2.5 to 3.3 for P125	2.53
3.	True density, g/cm^3		2.40
4.	Average density, g/cm^3		
	fr. 5 -10 (screening)	Not rationed	1.12
	fr. 10-20		1.25
5.	Resistance against silicate decay, %		
	fr. 5 -10 (screening)	No more than 5	1.93
	fr. 10-20		1.77
6.	Resistance to ferrous decay, %		
	fr. 5 -10 (screening)	No more than 5	1.56
	fr. 10-20		1.32
7.	Mass loss on ignition, %	No more than 3	1.20
8.	Mass loss by boiling, %		
	fr. 5 -10 (screening)	No more than 5	2.87
	fr. 10-20		2.53
9.	Softening coefficient		
	fr. 5 -10 (screening)	At least 0.75	0.77
	fr. 10-20		0.85
10.	Grain shape coefficient		
	fr. 5 -10 (screening)	No more than 1.5	1.21
	fr. 10-20		1.37
11.	Water absorption, %		
	fr. 5 -10 (screening)	No more than 20	15.04
	fr. 10-20		13.86
12.	Frost resistance grade (weight loss after 3 cycles of testing in sodium sulfate solution, %)		
	fr. 5 -10 (screening)	F15 (No more than 8)	F15 (4.38)
	fr. 10-20		F15 (5.65)

The calculation of the composition of lightweight concrete with porous aggregate is based on Interstate Standard 27006, reference book "Artificial porous aggregates and lightweight concrete on their basis" [18], normative and industrial edition "Recommendations on the selection of lightweight concrete compositions (for Interstate Standard 27006-86)" [11].

The average strength of the class when making selections is assigned equal to the strength of the concrete with a coefficient of variation V_n = 13.5 %. To do this, the specified concrete class is multiplied by the specified strength coefficient K_T equal to the specified coefficient of variation.

$$R = B \cdot K_T, \tag{2}$$

where B is the strength value corresponding to the adopted class of concrete, MPa; K_T is coefficient of specified strength.

According to the reference manual "Artificial porous aggregates and lightweight concretes based on them". [18], the ultimate strength of concrete can be achieved depending on the mass strength of the coarse aggregate and is calculated by the following formula:

$$R = 2R_{ag.}\frac{1-\varphi}{0.5}, \tag{3}$$

where $R_{ag.}$ is the grade strength of coarse aggregate; φ – volumetric concentration of coarse aggregate.

Immediately, you can calculate the consumption of coarse aggregate K:

$$K = 1000 \cdot \varphi \cdot \rho_{ag.}, \tag{4}$$

$\rho_{ag.}$ is average aggregate density, g/cm^3.

The dependence of cement consumption on the density of concrete is described by the formula:

$$\rho_{con.} = 0.97\rho_{ag.} + C\left(1.15 - 0.4\rho_{ag.}\right), \tag{5}$$

where $\rho_{ag.}$ is the average density of the aggregate, g/cm^3; $\rho_{con.}$ is average density of concrete, g/cm^3.

Then the cement consumption (C) can be found according to the derived formula, g/cm^3:

$$C = \frac{\rho_{con.} - 0.97\rho_{ag.}}{1.15 - 0.4\rho_{ag.}}. \tag{6}$$

Next, the amount of fine aggregate required is calculated by the formula:

$$V_P = \left(1000 - \left(C/\rho_{cs}\right) - \varphi \cdot 1000\right) \cdot \alpha, \tag{7}$$

where ρ_{cs} is the true density of cement stone, kg/l; α is coefficient of grain separation equal to 1.12.

The amount of fine aggregate (P) in the absolute volume of aggregates is calculated by the formula:

$$P = V_S \cdot \rho_b, \tag{8}$$

where ρ_b is the bulk density of the sand used, kg/l.

The water flow rate is calculated by the formula:

$$B = B_0 + B_1 + B_2, \tag{9}$$

where B_0 is the initial consumption of water, taken according to the methodological manual for the grade of workability P1 with the use of plasticizer equal to 165 liters per cubic meter.

B_1 and B_2 are correction for water consumption of fine and coarse aggregate, determined by the following formulas:

$$B_1 = 0.025\frac{P}{\rho_P}\left(W_P - 7\right), \tag{10}$$

$$B_2 = \frac{0.75\left(B_0 + B_1\right)}{C} \cdot \frac{\left(W_K - 15\right)}{100} \times K. \tag{11}$$

The optimal amount of additives, if any, is determined by the manufacturer's recommendations.

According to the provisions of doctoral dissertation of A.N. Davidyuk for aggregates grade P15-50 an updated formula (12) is proposed for formula (3), calculated on the basis of experimental data [19, 20].

$$R = 1.1 \cdot R_{ag.} \cdot e^{\left(1.8 \cdot \frac{1-\varphi}{0.5}\right)}. \quad (12)$$

This formula with exponential growth of the influence of the volumetric concentration of coarse aggregate is more correct. Further calculation of the composition of lightweight concrete continues by formulas 4–11.

In this work, our task was to derive experimental formulas for the ultimate strength of concrete depending on the strength of coarse aggregate, which will make it possible to predict the physical and mechanical properties of concrete on the basis of non-standard properties of foam-zeolite on the basis of modified charge from the experimental batch.

3. Results and Discussion

An analysis of empirical data from early studies and tests of lightweight concretes on porous aggregates has been carried out and equations with exponential growth of strength depending on concrete density and aggregate density have been derived (Table 4, Fig. 1). According to sources, the minimum voids content of materials of the same fraction varies from 33 % to 47.7 % depending on the topology [21, 22]. Then when grouping aggregate by density when using it in cement stone with a true density of 2.65 g/cm^3, it is possible with a step that will be equal to the difference of the minimum hollowness multiplied by the true density of the cement stone, which is approximately 300 kg/m^3.

If the task of selecting the composition of lightweight concrete satisfies the dependencies shown in the figure, you can carry out further calculations according to this methodology.

From the empirical data of earlier studies (Table 5), formula 12 is corrected for porous aggregates of different grades of strength with a grouped step of 2.2–2.5 MPa (formulas 13–15).

Table 4. Properties of lightweight concrete depending on the density of aggregates usedю

Density grade of aggregate	Concrete density		Concrete strength	
From M150 to M450	---*			
From M500 to M800	1100	1600	5.9	25
	1185	1150	7.8	7
	1100	1150	6.5	8.3
	1500	1000	17	5
From M900 to M1200	1672	1916	19	26.4
	1708	1919	17.8	33.2
	1975	1610	28.6	11.5
	1944	1637	25.9	11.9
	1958	1649	33	16.8
	1929		35.6	

* For a given aggregate grade, the equation of dependence is taken according to the source [20].

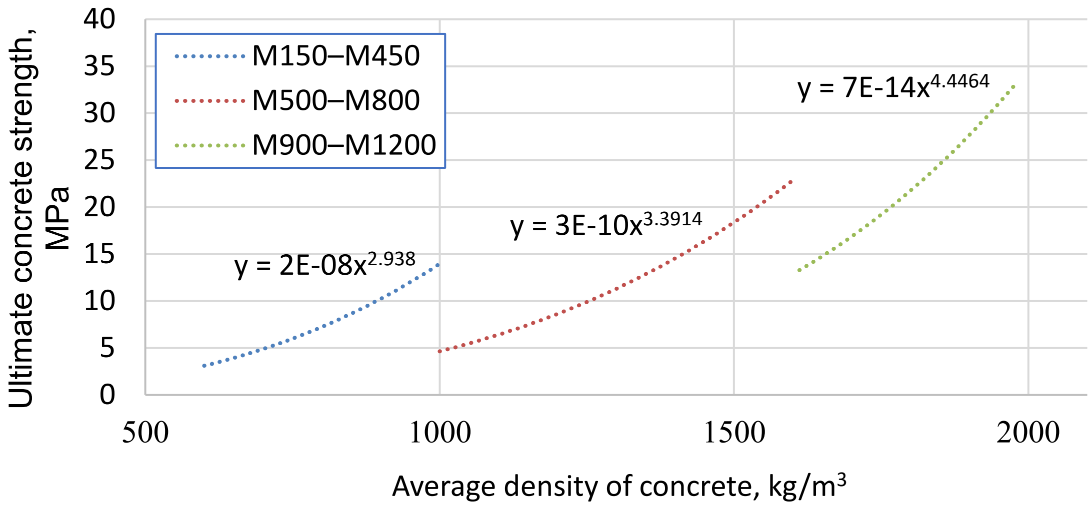

Figure 1. Experimental equations for the dependence of concrete strength on concrete density and aggregate density.

Table 5. Properties of lightweight concrete depending on the strength of the aggregates used.

Strength grade of the aggregate	Volume concentration of coarse aggregate	Concrete strength
P15–50 $\left(R_{ag.} = 0.8\right)$	---*	
P75–125 $\left(R_{ag.} = 3.3\right)$	0.4 0.5 0.6	13 11 9
P150–250 $\left(R_{ag.} = 5.5\right)$	0.4 0.54 0.57	19.5 19.5 25
P300–400 $\left(R_{ag.} = 8\right)$	0.4 0.5 0.6	28 26 23

* For a given aggregate grade, the equation of dependence is taken according to the source [20].

For aggregate grade P75-125:

$$R = 1.03 \cdot R_{ag.} \cdot e^{\left(1.14 \cdot \frac{1-\varphi}{0.5}\right)}. \quad (13)$$

For aggregate grade P150–250:

$$R = -2.5 \cdot \left(\frac{1-\varphi}{0.5}\right)^2 + 18.5 \cdot \frac{1-\varphi}{0.5} + 0.98 \cdot R_{ag.}. \quad (14)$$

For aggregate grade P300–400:

$$R = -5.3 \cdot \left(\frac{1-\varphi}{0.5}\right)^2 + 23.2 \cdot \frac{1-\varphi}{0.5} + 0.94 \cdot R_{ag.}. \quad (15)$$

A graphical representation of the dependence of concrete strength on the volumetric concentration of coarse aggregate was also obtained (Fig. 2). The dependence for stronger aggregates is described by a quadratic function, and for less strong aggregates by an exponential function. As a confirmation in the work of the authors from Nanjing University of Aeronautics and Astronautics, China, the effect of coarse aggregate volume concentration with an aggregate strength of 10 MPa, is also described by a quadratic function. However, in their case, an increase in aggregate fraction greater than 0.61 is accompanied by an increase in concrete strength, which we cannot agree with [23].

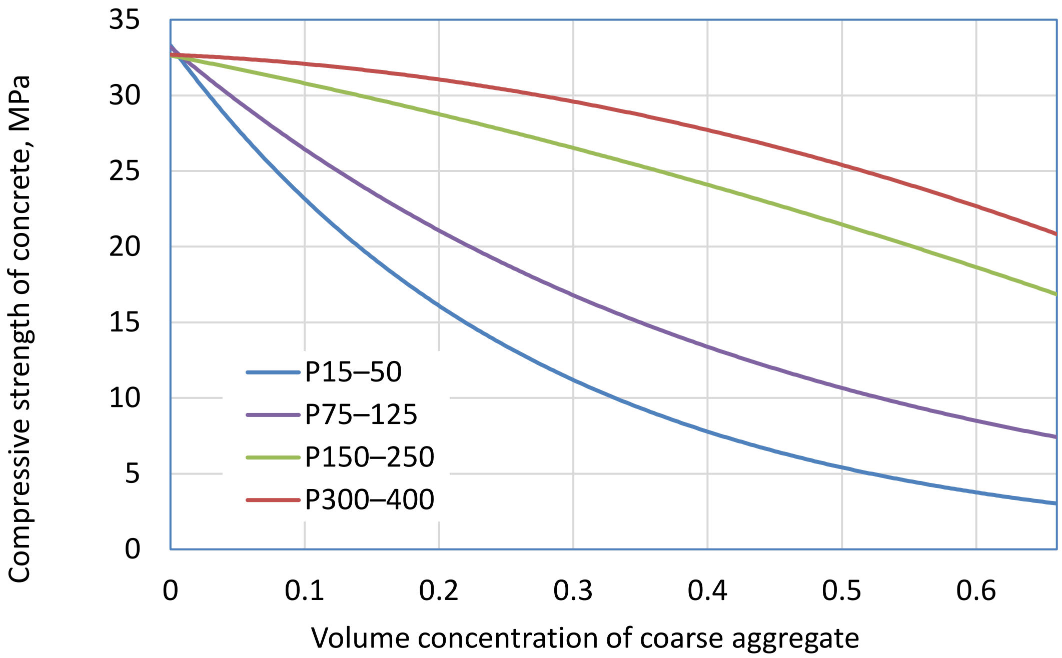

Figure 2. The dependence of the strength limit of concrete on the volume concentration of coarse aggregate of different grades of compressive strength in the cylinder.

From the formulas you can calculate the required volume concentration of aggregate to achieve a given strength, depending on the initial.

For aggregate grade P15-50:

$$\varphi = 1 - 0.28 \cdot \ln\left(\frac{R}{1.1 \cdot R_{ag.}}\right). \quad (16)$$

For aggregate grade P75-125:

$$\varphi = 1 - 0.44 \cdot \ln\left(\frac{R}{1.03 \cdot R_{ag.}}\right). \quad (17)$$

For aggregate grade P150-250:

$$\varphi = 1 - \left(\frac{R_{ag.}}{110}\right) \times \left(37 - 2.24 \cdot \sqrt{317 - 8 \cdot R}\right). \quad (18)$$

For aggregate grade P300-400:

$$\varphi = 1 - \left(\frac{R_{ag.}}{848}\right) \times \left(116 - \sqrt{17431 - 530 * R}\right). \quad (19)$$

Further calculation of the composition of lightweight concrete can continue with the formulas 4–11.

A selection task was made to test the porous filler and the methodology (Table 6).

According to the methodology, the concrete compositions shown in Table 7 were calculated. The nominal composition (0) was obtained, according to the calculation, and was adjusted to obtain the density of concrete according to the selection card of the composition.

In additional compositions (1–3) varied the consumption of cement downward. According to the developed compositions of concrete mixtures cone slump and density of concrete mixtures were determined for compliance with the brand for workability and density control (Table 8). The actual consumption of concrete mixes was determined according to Interstate Standard 27006-2019 "Concretes. Rules for mix proposing". The average discrepancy between the components of the calculated composition and the actual – 9.1 %.

Table 6. Task for selection of lightweight concrete.

Indicator	Defined properties and characteristics of starting materials
Compressive strength class	B15
Density grade	D1500
Grade of workability	P1
Frost resistance grade	$F_1$150
Terms of manufacture of products and structures:	
- molding	Vibrocompacting
- solidification	Steaming at 80° C
Raw materials:	
Binder	
Strength class	CEM I 32.5B Yakutcement, JSC PA
Fine aggregate	River sand from the Lena River floodplain
Grain modulus of sand, Mod.	1.09
Bulk density, kg/m3	1444
True density, g/cm3	2.62
Water consumption, %	10
Coarse aggregate	LLC Suntarzeolite
Foam-zeolite fractions 5-10	
Bulk density grade	M700 (696 kg/m^3)
Strength grade	P100 (2.31 MPa)

Indicator	Defined properties and characteristics of starting materials
Water absorption, %	15.04
Foam-zeolite fractions 10-20	
Bulk density grade	M800 (733 kg/m^3)
Strength grade	P125 (2.53 MPa)
Water absorption, %	13.86
Chemical additive	SP-1

Table 7. Concrete compositions.

Component	Consumption per 1 m^3, kg											
	0			1			2			3		
	Calc.	Actual	Δ, %	Calc.	Actual	Δ, %	Calc.	Actual	Δ, %	Calc.	Actual	Δ, %
PCG 10-20	375	413	9.2	254	279	9.0	254	279	9.0	254	279	9.0
PCG 5-10	386	425	9.2	508	559	9.1	508	559	9.1	508	559	9.1
Cement	442	486	9.1	400	440	9.1	350	385	9.1	300	330	9.1
Sand	421	463	9.1	238	262	9.2	300	330	9.1	363	399	9.0
Water	195	215	9.3	197	217	9.2	204	224	8.9	213	234	9.0
SP-1 0,5%	2.21	2.4	7.9	2	2.2	9.1	1.75	1.9	7.9	1.5	1.7	11.8

Table 8. Properties of concrete mixes.

Indicator, unit	Composition number			
	0	1	2	3
Cone draft, cm	0	0	1	0
Density, kg/m^3	1730	1620	1510	1580

The results of checking the properties of light concretes are given in Table 9. The results obtained showed compliance of properties of zeolite concretes of the selected compositions with the requirements of Interstate Standard 25820, the task of selecting lightweight concrete composition with a large margin of safety factor and are comparable to the characteristics of lightweight concretes developed by various leading researches [24, 25] and accepted in structural calculations [26].

Table 9. Established grades of zeolite concretes in accordance with the requirements of Interstate Standard 25820-2121 "Lightweight concretes. Specifications".

Number (marking) of composition	Mark of lightweight concrete by average density D	Compressive strength class of lightweight concrete B	Lightweight concrete frost resistance grade F_1	Heat-water coefficient, W/ (m*° C)	Classification of concrete according to its main purpose
Composition No. 0 of 05.09.2022	D1700	B27.5	$F_1$150	0.52	Structural
Composition No. 1 08.09.22	D1600	B25	-	0.52	Structural and thermal insulation
Composition No. 2 08.09.22	D1500	B15	-	0.53	Structural and thermal insulation
Composition No. 3 08.09.22	D1550	B20	$F_1$150	0.50	Structural and thermal insulation

4. Conclusion

The research performed to establish the technology and peculiarities of selecting the composition of lightweight concrete using porous aggregate from modified zeolite-alkaline charge, which improves its properties, has determined the following:

1. The empirical equations for the dependence of lightweight concrete strength on concrete density and aggregate density and the dependence of lightweight concrete strength on the volumetric concentration of coarse aggregate and aggregate strength have an exponential trend.
2. In the derived dependencies, the average discrepancy between the components of the calculated composition of lightweight concrete with the actual is 9.1 %, but the margin of assured strength in the samples obtained suggests the need for further work to clarify the methods of calculation of lightweight concrete composition.
3. It is shown that the porous aggregate – M700-M800, P100-P125 foam-zeolite can produce structural lightweight concrete of strength classes from B15 to B27.5, with $F_1$150 freeze-thaw-resistance grades. The developed compositions of concretes expand the scope of their use for load-bearing structures, including elements of the framework of buildings and structures.

Thus, the possibility of improving the characteristics of lightweight concrete by obtaining a more refined methodology for selecting the composition is shown. Further research should be aimed at obtaining the dependences of concrete characteristics on the quantitative and qualitative composition of components using numerical modeling methods and mutual verification with experimental data to obtain the most reliable method for selecting the composition of lightweight concrete on porous aggregate.

References

1. Ting, T.Z.H., Rahman, M.E., Lau, H.H., Ting, M.Z.Y. Recent development and perspective of lightweight aggregates based self-compacting concrete. Construction and Building Materials. 2019. 201. Pp. 763–777. DOI: 10.1016/J.CONBUILDMAT.2018.12.128
2. Hong, S.H., Choi, J.S., Yuan, T.F., Yoon, Y.S. A review on concrete creep characteristics and its evaluation on high-strength lightweight concrete. Journal of Materials Research and Technology. 2023. 22. Pp. 230–251. DOI: 10.1016/J.JMRT.2022.11.125
3. Tanyıldızı, M., Gökalp, İ. Utilization of pumice as aggregate in the concrete: A state of art. Construction and Building Materials. 2023. 377. 131102. DOI: 10.1016/J.CONBUILDMAT.2023.131102
4. Baishev, N., Matveeva, O., Popov, P., Semenov, K. Otsenka energoeffektivnosti zhilogo doma s razlichnymi variantami konstruktsii sten s primeneniem stenovykh blokov iz legkogo tseolitobetona [Assessment of the energy efficiency of a residential building with different variants of wall construction using wall blocks of lightweight zeolite concrete]. Sovremennye problemy stroitel'stva i zhizneobespecheniia: bezopasnost', kachestvo, energo- i resursosberezhenie [Modern problems of construction and life support: safety, quality, energy and resource saving]. 2022. Pp. 15–20.
5. Mestnikov, A.E., Pavlov, D.G. Vozmozhnosti proizvodstva granulirovannogo penostekliannogo materiala v usloviiakh Iakutii. [Possibilities of production of granulated foam-glass material in the conditions of Yakutia]. Sovremennye tendentsii razvitiia nauki i tekhnologii [Modern trends in the development of science and technology]. 2016. 1–8. Pp. 32–35.
6. Jahami, A., Issa, C.A. Exploring the use of mixed waste materials (MWM) in concrete for sustainable Construction: A review. Construction and Building Materials, 2023. 398. 132476.
7. Jahami, A., Khatib, J., Raydan, R. Production of Low-Cost, High-Strength Concrete with Waste Glass as Fine Aggregates Replacement. Buildings 2022. 12. 2168.
8. Khatib, J., Jahami, A., El Kordi, A., Sonebi, M., Malek, Z., Elchamaa, R., Dakkour, S. Effect of municipal solid waste incineration bottom ash (MSWI-BA) on the structural performance of reinforced concrete (RC) beams. Journal of Engineering, Design and Technology. 2023. 21(3). Pp. 862–882.
9. Rekomendatsii po podboru sostavov tyazhelykh i melkozernistykh betonov [Recommendations for the selection of heavy and fine-grained concrete compositions]. Moscow: Minstroj Rossii, 2016.
10. Standard practice for selecting proportions for normal, heavyweight, and mass concrete. 211.1–91. Michigan, American Concrete Institute (ACI), 2009.
11. Rekomendatsii po podboru sostavov legkikh betonov (k GOST 27006-86) [Recommendations for the selection of heavy and fine-grained concrete compositions]. Moscow: Gosstroj SSSR, 1990.
12. Khatib, J., Jahami, A., Baalbaki, O. Flexural Characteristics of Reinforced Concrete Beams Containing Lightweight Aggregate in the Tensile Zone. SSRN Electronic Journal. 2019. DOI: 10.2139/ssrn.3523048
13. Nukah, P.D., Abbey, S.J., Booth, C.A., Nounu, G. Development of a Lytag-silica fume based lightweight concrete and corresponding design equation for pure bending. Case Studies in Construction Materials. 2023. 18. e01970. DOI: 10.1016/J.CSCM.2023.E01970
14. Dengke, W., Gaozhan, Z., Yang, L., Qingjun, D. Experimental investigation and reliability prediction of high performance concrete based on lightweight aggregate under 4-point bending loading. Case Studies in Construction Materials. 2023. 18. e01804. DOI: 10.1016/J.CSCM.2022.E01804
15. Chung, S.Y., Sikora, P., Kim, D.J., El Madawy, M.E., Abd Elrahman, M. Effect of different expanded aggregates on durability-related characteristics of lightweight aggregate concrete. Materials Characterization. 2021. 173. 110907. DOI: 10.1016/J.MATCHAR.2021.110907
16. Shaiksha Vali, K., Bala Murugan, S. Impact of manufactured fiber aggregate in the production of lightweight concrete. Materials Today: Proceedings. 2022. 65. Pp. 1690–1696. DOI: 10.1016/J.MATPR.2022.04.712
17. Tale Masoule, M.S., Bahrami, N., Karimzadeh, M., Mohasanati, B., Shoaei, P., Ameri, F., Ozbakkaloglu, T. Lightweight geopolymer concrete: A critical review on the feasibility, mixture design, durability properties, and microstructure. Ceramics International. 2022. 48(8). Pp. 10347–10371. DOI: 10.1016/J.CERAMINT.2022.01.298
18. Gorlov, Yu.P. Ed. Iskusstvennye poristye zapolniteli i legkie betony na ikh osnove. Spravochnoe posobie [Artificial porous aggregates and light concretes based on them. Reference Guide]. Moscow: Stroiizdat, 1987. 304 p.
19. Davidiuk, A.N. Legkie betony na steklogranuliatakh [Lightweight concretes on glass granulates]. Stroitel'nye materialy. 2007. 7. Pp. 6–7.

20. Davidiuk, A.N., Davidiuk, A.A. Prochnostnye svoistva legkikh betonov na steklovidnykh zapolniteliakh dlia mnogosloinykh ograzhdaiushchikh konstruktsii [Strength properties of light concretes on glassy aggregates for multilayer enclosing structures]. Beton i zhelezobeton. 2008. 6. Pp. 9–13.
21. Zimakova, G.A., Sharko, P.V., Rublev, D.S., Shestakova, S.S. Optimizatsiia granulometricheskogo sostava kak metod povysheniia strukturno-prochnostnykh kharakteristik betona [Optimization of granulometric composition as a method of increasing the structural-strength characteristics of concrete]. Arkhitekturno-stroitel'nyy i dorozhno-transportnyy kompleksy: problemy, perspektivy, innovatsii [Architectural and Construction and Road-Transport Complexes: Problems, Prospects, Innovations]. Omsk: SibADI, 2020. Pp. 655–660.
22. Belov, V.V., Obraztsov, I.V. Optimizatsiia struktury melkozernistogo karbonatnogo betona s primeneniem komp'iuternogo modelirovaniia [Optimization of fine-grained carbonate concrete structure using computer modeling]. Vestnik Volgogradskogo gosudarstvennogo arkhitekturno-stroitel'nogo universiteta. Seriia: Stroitel'stvo i arkhitektura. 2013. 31–2 (50). Pp. 555–562.
23. Wu, Z., Zhang, J., Yu, H., Ma, H., Fang, Q. 3D mesoscopic analysis on the compressive behavior of coral aggregate concrete accounting for coarse aggregate volume and maximum aggregate size. Composite Structures. 2021. 273. Pp. 114271. DOI: 10.1016/J.COMPSTRUCT.2021.114271
24. Jia, Z., Aguiar, J., de Jesus, C., Castro, F., Cunha, S. Physical and mechanical properties of lightweight concrete with incorporation of ceramic mold casting waste. Materialia. 2023. 28. 101765. DOI: 10.1016/J.MTLA.2023.101765
25. Sujatha, A., Deepa Balakrishnan, S. Properties of high strength lightweight concrete incorporating crushed coconut shells as coarse aggregate. Materials Today: Proceedings. 2023. DOI: 10.1016/J.MATPR.2023.03.201
26. Im, C.R., Yang, K.H., Kim, S., Mun, J.H. Flexural performance of lightweight aggregate concrete columns. Engineering Structures. 2022. 251. 113545. DOI: 10.1016/J.ENGSTRUCT.2021.113545

Contacts:

Olga Matveeva, *PhD in Technical Sciences*
E-mail: matveeva_oi@mail.ru

Nikolay Baishev,
E-mail: nbaishev@gmail.com

Andrey Makarov,
ORCID: https://orcid.org/0000-0001-7226-9859
E-mail: andrmakarov16@mail.ru

Aleksandr Popov, *PhD in Technical Sciences*
ORCID: https://orcid.org/0000-0002-7829-6839
E-mail: surrukin@gmail.com

Irina Pavlyukova,
E-mail: pavlyukova-irina@mail.ru

Nikolay Grigoriev,
E-mail: matsugauser@mail.ru

Received 20.04.2023. Approved after reviewing 12.01.2024. Accepted 19.01.2024.