УДК 691.327.32

COMPOSITION EFFECT ON THE STRENGTH OF MODIFIED EXPANDED CLAY LIGHTWEIGHT CONCRETE

Kroviakov S.O., PhD., Assistant Professor,
Mishutin A.V., Doctor of Engineering, Professor,
Pishev O.V., engineer,
Kryzhanovskiy V.O., engineer,
Odessa State Academy of Civil Engineering and Architecture
skrovyakov@ukr.net

Abstract. The effect of modified expanded clay lightweight concrete on its strength is investigated. In the conducted on the optimal plan experiment, the four factors of the composition varied: amount of sulfate-resistant Portland cement from 500 to 600 kg/m^3, amount of silica fume from 0 to 40 kg/m^3, percentage of gravel in concrete from 650 to 700 l/m^3, polypropylene fiber from 0 to 1,2 kg/m^3. All mixtures had equal concrete-mix consistency P2, in all mixtures superplasticizer S-3 was introduced in the amount of 0,8%. It was established that the compressive strength of investigated concrete was in the range of 34 to 45 MPa and bending tension strength in the range from 5.8 to 7.2 MPa. The greatest strength of the concrete mix with the amount of silica fume 30-35 kg/m^3 and with the content of expanded clay gravel 660-680 l/m^3. Due the addition of fiber increases the bending tension strength, while the compressive strength is practically unchanged. Investigated expanded clay lightweight concrete can be recommended for thin-walled constructions of civil buildings also for transport and hydrotechnical floating structures.

Keywords: expanded clay lightweight concrete, thin-walled constructions, modifiers, fiber

ВПЛИВ СКЛАДУ НА МІЦНІСТЬ МОДИФІКОВАНОГО КЕРАМЗИТОБЕТОНУ

Кровяков С.О., к.т.н., доцент,
Мішутін А.В., д.т.н., професор,
Піщев О.В., інженер,
Крижановський В.О., інженер,
Одеська державна академія будівництва та архітектури
skrovyakov@ukr.net

Анотація. Досліджено вплив складу модифікованого керамзитобетону на його міцність. У проведеному за оптимальним планом експерименті варіювалися чотири фактори складу: кількість сульфатостійкого портландцементу від 500 до 600 кг/м^3, кількість мікрокремнезему від 0 до 40 кг/м^3, вміст гравію в бетоні від 650 до 700 л/м^3, кількість поліпропіленової фібри від 0 до 1,2 кг/м^3. Всі суміші мали рівну рухомість П2, у всі суміші вводився суперпластифікатор С-3 у кількості 0,8%. Встановлено, що міцність при стиску досліджених бетонів знаходилась у діапазоні від 34 до 45 МПа, а міцність на розтяг при згині у діапазоні від 5,8 до 7,2 МПа. Найбільшу міцність мають склади при кількості мікрокремнезему 30-35 кг/м^3 і при вмісті керамзитового гравію 660-680 л/м^3. За рахунок введення фібри зростає міцність бетонів на розтяг при згині, а міцність при стиску практично не змінюється. Досліджені керамзитобетони можна рекомендувати для тонкостінних конструкцій громадянських будівель, а також транспортних і гідротехнічних споруд, зокрема плавучих.

Ключові слова: керамзитобетон, тонкостінні конструкції, модифікатори, фібра.

ВЛИЯНИЕ СОСТАВА НА ПРОЧНОСТЬ МОДИФИЦИРОВАННОГО КЕРАМЗИТОБЕТОНА

Кровяков С.А., к.т.н., доцент,
Мишутин А.В., д.т.н., профессор,
Пищев О.В., инженер,
Крыжановский В.А., инженер,
Одесская государственная академия строительства и архитектуры
skrovyakov@ukr.net

Аннотация. Исследовано влияние состава модифицированного керамзитобетона на его прочность. В проведенном по оптимальному плану эксперименте варьировались четыре фактора состава: количество сульфатостойкого портландцемента от 500 до 600 кг/м^3, количество микрокремнезема от 0 до 40 кг/м^3, содержание гравия в бетоне от 650 до 700 л/м^3, количество полипропиленовой фибры от 0 до 1,2 кг/м^3. Все смеси имели равную подвижность П2, во все смеси вводился суперпластификатор С-3 в количестве 0,8%. Установлено, что прочность при сжатии исследованных бетонов находилась в диапазоне от 34 до 45 МПа, а прочность на растяжение при изгибе в диапазоне от 5,8 до 7,2 МПа. Наибольшую прочность имеют составы при количестве микрокремнезема 30-35 кг/м^3 и при содержании керамзитового гравия 660-680 л/м^3. За счет введения фибры возрастает прочность бетонов на растяжение при изгибе, а прочность при сжатии практически не меняется. Исследованные керамзитобетоны можно рекомендовать для тонкостенных конструкций гражданских зданий, а также транспортных и гидротехнических сооружений, в том числе плавучих.

Ключевые слова: керамзитобетон, тонкостенные конструкции, модификаторы, фибра.

Introduction. Structural lightweight concrete on porous aggregate is widely used in the building practice of developed countries. Nowadays in Ukraine plain concrete is used quite rarely, although in 70s-80s years of last century they were very common. One of the reasons for this is the inadequate use of modern building technologies in the manufacture of lightweight concrete in particular modifiers and fiber. Accordingly, the actual objective is the study of properties modified expanded clay lightweight concrete on the domestic raw material resources base.

Analysis of recent research. Properties of lightweight concrete is almost similar to the properties of heavyweight concrete – almost equal strength, high freeze resistance, water resistance and corrosion resistance. In this case, their use allows to reduce structural weight, which provides reduction of loads on foundations and supports of buildings and structures [1]. In the field of reinforced concrete shipbuilding, the use of lightweight concrete allows to increase the deadweight capacity and improve the working conditions of personnel and process environment [2]. Moreover, lightweight concrete structures have high resistance to dynamic loads and high fire resistance.

In this way structural concrete on lightweight aggregate is effective material for many types of structures, particularly in high-rise, hydrotechnical and transport construction [3]. To ensure the durability of such materials in typical working conditions of various structures it is necessary to process control their structure with allowance for properties and impact of individual components in particular lightweight aggregate and cement, also composite action of aggregate and cement matrix.

To improve the strength of lightweight concrete, technical methods which in most cases are similar to heavyweight concrete are used. It’s applying of high-grade cements and the most strength porous aggregates, design of concrete composition with low water/cement ratio, applying effective modifiers, thorough mixing and packing of concrete mixture with the preservation of its high homogeneity and creating favorable conditions for hardening of concrete [4]. Also, in some cases, preliminary preparation of a light aggregate is carried out, particularly its hydrophobization [5].

In recent decades, ultra-disperse wastes from the production of ferroalloys – silica fume is widespread used as a highly active mineral admixture [6]. It is a condensed aerosol, which is captured by gas cleaning systems filters of blast metallurgical furnaces. Today, silica fume is one of the most frequently used and perspective modifiers for high-quality composites based on Portland cement. This active mineral admixture improves the structure due to its chemical activity of the pozzolan type and the effect of the microfiller, which contributes to the elimination and reduction of microdefects number. Pozzolans bind $Ca(OH)_2$ to hydrosilicates which increase corrosion resistance and reduce the average pore size. An important manifestation of the pozzolana effect is also the improvement of the cement stone contact area quality with the aggregate. Most often it consists of $Ca(OH)_2$, which crystallized on the surface of the filler and in the adjacent cement stones. Due to the conversion of calcium hydroxide to hydrosilicates, strength increases and the porosity of the contact zone decreases. [7]. All above mentioned lead to increased strength, reduced permeability and increased durability of concrete. On the other hand, the using of silica fume requires an increasing of water cement cement ratio to its significant dispersion. Namely, the effective applying of silica fume is possible only in complex with a superplasticizer, due to which practically completely aligned the problem of increased water demand of this component [6, 8].

Research objective is to increase the strength of expanded clay lightweight concrete due to use of modifiers, fibers and optimization of its composition**.**

Subjects and methods of research. For the 18-point optimal plan, a 4-factor experiment [9] was carried out, in which the following factors of the composition of the expanded clay lightweight concrete varied:

X_1 – amount of sulphate-resistant Portland cement, from 500 to 600 kg/m^3;

X_2 – the amount of silica fume, from 0 to 40 kg/m^3;

X_3 – percentage of gravel in concrete from 650 to 700 l/m^3;

X_4 – amount of polypropylene fibers Baucon (diameter 18.7 mcm, length – 12 mm.), from 0 to 1,2 kg/m^3.

All mixtures had equal concrete-mix consistency P2 (cone slump from 6 to 8 cm), which was achieved with the selection of water amount. In all mixtures superplasticizer S-3 was introduced in the amount of 0,8 % of the mass of cement, which was taking into account the results of previous researches [10]. The amount of silica sand in the mixture was adjusted according to the quantity of other components (gravel, cement, silica fume, water, fiber) to provide the same volume of all investigated concretes. Namely, the factor X_3 actually showed the spreading action of granules of a coarse aggregate. As a coarse porous aggregate, expanded clay produced by the Odessa Keramzite factory of 5-10 mm grade with packed density of gravel 550 kg/m^3 of grade P125 was used. As a fine aggregate – the silica sand with Mcr = 2.4. As a binder – sulphate resisting Portland cement SRPC 400.

Mixing of mixtures was carried out with pre-treatment of gravel with a cement suspension, which ensured for the strengthening of the surface layer of a coarse porous aggregate and the transition zone between the filler and the soluble part of the concrete [11].

Results of researches. As noted above, all mixtures had equal concrete-mix consistency P2, respectively water requirement and W/C lightweight concrete mixtures depended on their composition. According to the data obtained at 18 experimental points, the experimental-statistical (ES) model of the 4 factors composition influence on the W/C mixture of equal mobility was created:

$$\begin{aligned} W/C = 0.340 &- 0.012x_1 + 0.008x_1^2 - 0.002\, x_1x_2 \pm 0x_1x_3 - 0.002\, x_1x_4 \\ &+ 0.003x_2 \pm 0x_2^2 + 0.003x_2x_3 \pm 0x_2x_4 \\ &\pm 0x_3 + 0.008x_3^2 + 0.003\, x_3x_4 \\ &+ 0.002x_4 \pm 0x_4^2 \end{aligned} \tag{1}$$

It has been established that as the amount of fibers of disperse reinforcement W/C increases, the mixture increases linearly, but this increase, when even using the maximum amount of fibers (1.2 kg/m^3), does not exceed 4%. The diagram was drawn in Fig. 1 in the form of a cube, for the analysis of the Portland cement amount influence, silica fume and gravel content in concrete on the

W/C lightweight concrete mixtures for (1). On the diagram the amount of polypropylene fiber was fixed at an average of 0.6 kg/m^3 (x_4=0).

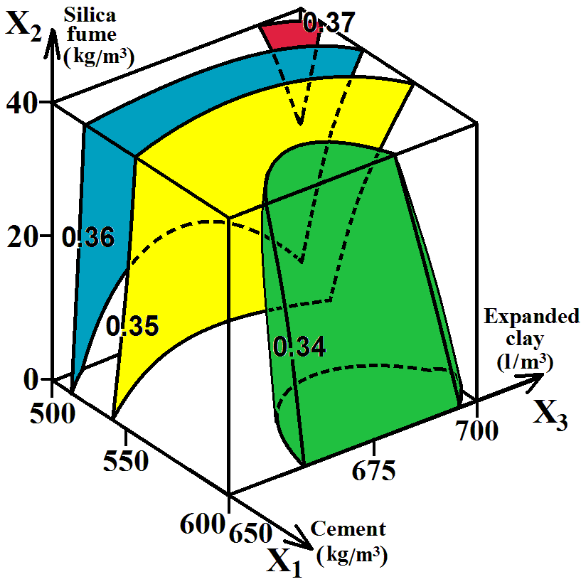

Fig. 1. Effect of Portland cement, silica fume and gravel content in concrete on W/C of lightweight concrete mixtures of equal mobility

As can be seen from the diagram, with average content of gravel (660-680 l/m^3) water requirement and the W/C of investigated mixtures was the smallest. This is explained by the fact that when the content of expanded clay gravel changed, the amount of quartz sand in the concrete changed proportionally to provide the necessary volume of material. That is, with the increased content of expanded clay gravel in the mixture, the separation of gravel decreased due to the decrease in the amount of sand and, accordingly, the soluble component. On W/C mixture of equal mobility naturally affects the amount of porous gravel and sand in this mixture, as well as the ability of its components to move during the placing. Accordingly, for the investigated mixtures with average gravel content, it has the best ability to move the components, which in turn allows us to rely on a mushier structure of such composites and their best mechanical and physical properties. With an increase the amount Portland cement W/C of lightweight concrete mix is expected to decrease. In this case, the nature of this effect is nonlinear and the W/C is more significantly reduced when changing the amount of binder from 500 to 550 kg/m^3. With the addition of silica fume, the W/C mixture is insignificantly increased. In general, all investigated mixtures in this experiment had a rather low level of W/C (0.37 and below) due to the use of a rational amount of superplasticizer S-3 – 0.8% of the binder weight.

The analysis of the concrete composition influence on compressive strength showed that for the investigated concrete this index was in the range of 34 to 45 MPa. On the compressive strength compression of modified expanded clay lightweight concrete, the amount of polypropylene fibers practically does not affect and when changing the factor x_4 within the factor space of the experiment, the value of $f_{ck.cube}$ will change no more than 1 MPa. The effect of low impact of fiber reinforcement on the strength of concrete compression is well known in building material science, however, the main purpose of fiber use is to improve other composite quality indicators. To analyze the influence of the Portland cement amount, silica fume and gravel content in concrete on its strength under compression using the ES-model, similar to (1), a diagram in the form of a cube was drawn in Fig. 2. On the diagram the amount of polypropylene fiber was fixed at an average of 0.6 kg/m^3 (x_4=0).

The analysis of this diagram shows that as the Portland cement increases, the strength of expanded clay concrete naturally increases. The addition of silica fume in the amount of 35-38 kg/m^3 increases the strength of lightweight concrete by 2-2,5 MPa. Due to the variation of the gravel consist, the strength of the investigated lightweight concrete varies by up to 1.5 MPa. The greatest strength has mixtures with a gravel content of 660-680 kg/m^3, which corresponds to a lower W/C mixture.

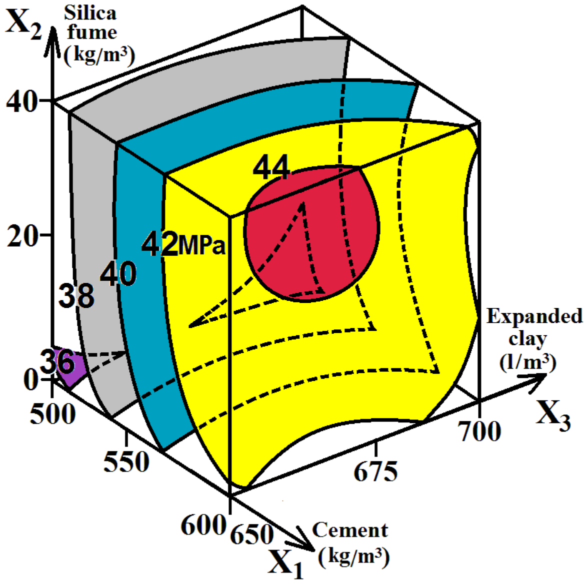

Fig. 2. Effect of Portland cement, silica fume and gravel content on the compressive strength of expanded clay lightweight concrete

The influence of the varied factors of the modified expanded clay concrete on its bending tension strength is described by the following ES-model:

$$\begin{array}{llll} f_{ctk}\,(\mathrm{MPa}) = 6.76 & + 0.47x_1 - 0.17x_1^2 & - 0.03x_1x_2 + 0.03x_1x_3 - 0.02x_1x_4 & \\ & + 0.06x_2 - 0.07x_2^2 & - 0.02x_2x_3 + 0.04x_2x_4 & \\ & \pm x_3 \quad - 0.02x_3^2 & - 0.04x_3x_4 & \\ & + 0.10x_4 - 0.02x_4^2 & & (2) \end{array}$$

The analysis of ES-model shows that within the framework of a multivariate experiment, the gravel content, that is, the removal of grains of the porous aggregate, practically does not affect the bending tensile strength of the investigated expanded clay lightweight concrete. This can be explained by the ability to withstand the tension stresses of the soluble part of the concrete and porous gravel. Accordingly, for a more detailed analysis, the effect of the Portland cement amount, silica fume and polypropylene fibers on tensile bending tension of the investigated expanded clay lightweight concrete for (2) was drawn in Fig. 3, the diagram is in the form of a cube. When it was drawn, the gravel content in concrete was fixed at the average ($x_3 = 0$).

The analysis of the diagram shows that, as the Portland cement increases, the tensile strength of the bending of the expanded clay lightweight concrete naturally increases, although this effect has a nonlinear appearance. The addition of silica fume in the amount of 30-35 kg/m^3 is insignificant, at 0,2-0,3 MPa, increases the strength of lightweight concrete to extension. Due to the use of disperse reinforcement, the value of f_{ctk} of investigated concrete increases by about 0.3 MPa, which can be considered as a positive, but rather limited result. The effect of increased tensile strength of expanded clay lightweight concrete in the use of fibers can be attributed to the rather good work of composites on porous fillers in tension. This is due, first of all, to the good adhesion of the cement paste (soluble component) to the filler. Accordingly, additional techniques, in particular, fiber reinforcement, in comparison with heavyweight concrete, have a lower effect to increase the strength of lightweight concrete in tension. Though in general, the positive effect of fiber remains.

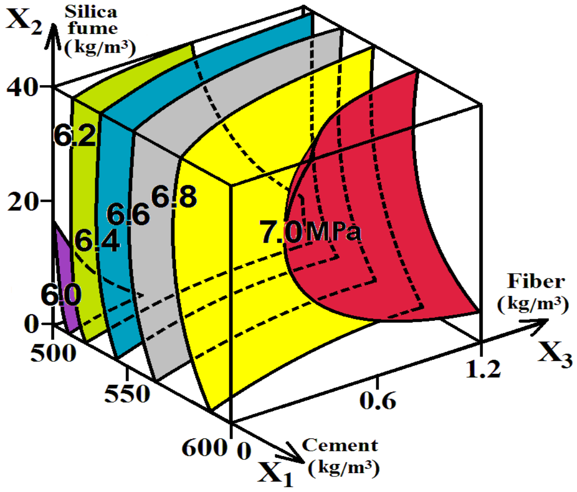

Fig. 3. Effect of Portland cement, silica fume and polypropylene fiber on the tensile strength of expanded clay lightweight concrete

Conclusions. The strength of the investigated expanded clay lightweight concretes at compressive strength and bending tension allows to recommend such materials for thin-walled constructions of civil buildings also transport and hydrotechnical floating structures.

Concrete compositions with the maximum amount of silica fume is 30-35 kg/m^3, are of the greatest strength. Modified expanded clay lightweight concrete has a high tensile strength, which allows better resistance to loads of different types, which are typical for thin-walled structures.

References

1. Structural lightweight aggregate concrete / Edited by Dr. J. L. Clarke. Blackie academic & professional, 1993. 161 p.

2. Gerwick B. C. Jr. Construction of marine and offshore structures, Third Edition. Baton Rouge:Taylor & Francis, 2005. 840 p.

3. Babich E.M. Constructions made of lightweight concrete on porous aggregates. Kiev: Vishcha shkola, 1988. 208 p. (in Russian)

4. Chandra S., Berntsson L. Lightweight aggregate concrete. Elsevier Science, 2008. 450 p.

5. Kucherenko A.A. On the mechanism of hydrophobization of concrete. Bulletin of the Odessa state academy of civil engineering and architecture. №35. Odessa: Zovnisreklamservice, 2009. P. 207-213. (in Russian).

6. High-strength fast-hardening concrete and fiber reinforced concrete. L.Y. Dvorkin, Ye.M. Babich, V.V. Zhitkovsky and others. Rivne: NUWEE, 2017. 332 p. (in Ukrainian)

7. Zotkin A.G. Concretes with effective additives. Moscow: Infra-Engineering, 2014. 160 p. (in Russian)

8. Caprielov S.S. Sheynfeld A.V. Concretes of a new generation with high operational properties / Materials of the international conference «Durability and protection of structures from corrosion», Moscow, 1999. P.191-196. (in Russian)

9. Lyashenko T.V., Voznesensky V.A. Composition-process fields methodology in computational building materials science. Odessa: Astroprint, 2017. 168 p. (in Russian)

10. Mishutn A., Kroviakov S., Pishev O., Soldo B. Modified expanded clay light weight concretes for thin-walled reinforced concrete floating structures. Tehnički glasnik 11, 3 (2017). (Technical Journal, Vol.11 No.3) P. 121-124.

11. Kroviakov S.O., Mishutin A.V. Increasing the durability of lightweight structural concrete for hydraulic engineering and transport structures by treating the surface of a porous aggregate. – Science and construction, 2017, №3. P. 50-58 (in Ukrainian)

Стаття надійшла 6.04.2018