MATEC Web of Conferences 117, 00149 (2017) DOI: 10.1051/matecconf/201711700149
XXVI R-S-P Seminar 2017, Theoretical Foundation of Civil Engineering

Properties of dry masonry mixtures based on hollow aluminosilicate microspheres

Vyacheslav Semenov[1] *

[1]Moscow state university of civil engineering, Yaroslavskoye shosse, 26, Moscow, Russia, 129337

Abstract. At present, there is a steady increase in the volume of housing construction in the Russian Federation. The modern trends in the field of energy and resource saving determine the need of the use of efficient building materials that ensure the safety, comfort and minimum cost of housing construction. Among the materials, often used for erecting of fencing structures, it is possible to note effective small-piece elements (ceramic and light-weight concrete units, etc.). To ensure the solidity of such structures, it is necessary to use the masonry mortars whose properties correspond to those of the main wall material. The existing dry mixes for obtaining of such mortars are expensive and often do not meet the minimum physical-and-mechanical and exploitation requirements. The solution of this problem is the usage of the hollow ceramics (aluminosilicate) microspheres as a filler for such mixes. The article presents the results of studies of the main physical-and-mechanical and exploitation characteristics of dry masonry mixes with hollow ceramics microspheres modified with various chemical additives. The effect of the compounding factors on the average density and strength of dry masonry mixes was studied. The compositions have been optimized by the methods of mathematical planning.

1 Introduction

The housing construction is one of the largest parts of the construction industry in our country and since the 2000s there has being a significant increase in the construction of residential areas. According to the data published by the Research Institute of Building Physics, in the Russian Federation the buildings consume up to 45% of the total volume of produced energy, 18 ... 45% of which are the heat losses through external walls [1]. A consequence of this is the development of rather high normative requirements for providing of thermal protection to fencing structures for the performance of which it is expedient to use the efficient building materials. An important factor in assessing the heat-shielding properties of the fencing structure is the coefficient of thermal uniformity. This coefficient takes into account the presence of thermally heterogeneous fragments in the fencing structure – the “cold bridges” [2]. Their presence leads to an increase in heat losses through the fencing structures, as well as to the risk of condensate formation in the zone of heat conducting inclusions.

* Corresponding author: science-isa@yandex.ru

A significant part of residential buildings are erected with the use of two or three-layer fencing structures made of effective small-piece elements - ceramic units, aerated concrete blocks, polystyrene concrete blocks, etc. For the construction of fencing structures made of similar materials, it is necessary to use the light-weight masonry mortars whose average density should not exceed the average density of the wall material, and the compressive strength of these mortars should be 20...25% higher than the strength of the wall material, which is the condition for ensuring the design strength of the fencing structure. For example, for masonry made of ceramic units, the grade strength of the mortar should be 5.0...15.0 MPa, for masonry made of aerated concrete blocks this value should be 5.0...7.5 MPa. At the same time, the existing dry mixes for preparation of such mortars are expensive and do not provide the required strength. Such mixes are produced by introducing into their composition the light-weight fillers: expanded perlite or vermiculite sands, foam glass or expanded polystyrene granules, etc. The mortars with expanded vermiculite and perlite sands have low strength. At an average density of 400...600 kg/m^3, the compressive strength of such mortars varies between 1...2.5 MPa, while their freeze-thaw durability is not more than 35 cycles [3-4]. The expanded pearlite and vermiculite sands have high water absorption. For perlite sand the water absorption can reach 900% by mass, for vermiculite sand it value can be up to 400%, which significantly reduces the strength, freeze-thaw durability and durability of mortars. To solve this problem, the fillers are hydrophobized by creating a thin mineral film on the surface of grains, which leads to a significant increase in the cost of aggregates (by 1.5...2.2 times). In addition, pearlite sand with a low bulk density has a strength value up to 0.1 MPa, and, due to its high brittleness, it can break down during transportation as well as during the process of mortar mixing. Vermiculite sand has a higher strength, but its cost is 3...5 times higher than the cost of perlite sand.

Also, expanded polystyrene and foamed glass granules are used as the light-weight aggregates for mortars and concretes [5]. The granules of aggregate float up at stirring and are unevenly distributed in the mortar. Such aggregates are difficult to use in masonry mortars, because the size of the granules does not allow evenly distributing the mortar with a thin and cohesive layer over the surface, which leads to the denudation of the granules and to the low strength of the mortar joint.

At present, the cement compositions using the hollow microspheres (glass, ceramic (aluminosilicate), polymeric) as a light-weight aggregate are widely developed [6-9]. The spherical shape of this aggregate granules provides for greater plasticity of the mortars and its higher compressive strength. The introduction of hollow microspheres into the dry mixes as a filler will make it possible to obtain an effective composite material with high strength and thermophysical parameters [10-12]. However, the analysis of earlier studies demonstrates a need in an integrated approach to the formation of the structure of such composites.

The aim of the research was the development and study of the properties of modified dry masonry mixes with hollow ceramics microspheres (CMS).

2 Materials and methods

In this study, the Portland cement CEM I 42.5 N (Holcim), in accordance with GOST 31108-2003 and GOST 30515-2013, was used as the binder. The most promising is the application of the hollow aluminosilicate microspheres as a filler for light-weight dry masonry mixes [15]. The aluminosilicate microspheres are a component of fly ash (mineral waste generated by flaring coal at thermal power plants) [14-16]. In this work, the hollow ceramics (aluminosilicate) microspheres with the fraction size from 1 to 500 μm (INOTEK, Siberia Kuznetskaya) were used as a filler. The hollow ceramics microspheres are a gray powder consisting of thin-walled balls. The thickness of the microsphere's wall is 0.1 to 10 μm. The coefficient of thermal conductivity of the microspheres is 0.08 W/(m·°C) at the temperature of 20°C, the softening point is over 1000°C. The composition of the gas phase inside the spheres is a mixture of CO_2 (70%) and N_2 (30%). The main properties of aluminosilicate thin-walled microspheres are given in Table 1.

Table 1. The main properties of aluminosilicate thin-walled microspheres (INOTEK, Siberia Kuznetskaya)

Parameters	Units	Parameter value
Density of the shell material	kg/m^3	2450
Bulk density	kg/m^3	370…390
Average particle size	μm	300
Minimum strength in hydrostatic compression (10% fracture)	MPa	15…28
Flotation	% of volume, type result	96

Since the subject-matter of the study is a dry mix, all chemical additives must be rapidly dispersible (the dissolution time at a water temperature of 15...30°C should not exceed 2 to 10 min), should have low hygroscopicity and a sufficient period of activity, and also be well distributed in the mixture in a process of dry mixing. To reduce the water-cement ratio of the mortar mixture, the superplasticizer PERAMIN SMF 10 was used at a dosage of 0.4% of the cement mass, the chemical composition is a sulfonate melamine powder. The air-entraining additive (AEA) ASCO 93 which is an anionic surfactant based on a high molecular weight olefin sulfonate, and the redispersible polymer powders (RPP) Vinnapas 4023 N and Vinnapas 8034 H were used as the structure modifiers. The introduction of the air-entraining additive improves the workability of the mortar, increases the freeze-thaw durability of the mortar and reduces its average density. The redispersible polymer powders increase the physical-and-mechanical properties and improve the technological properties of the mortar.

The experimental studies were carried out according to standard testing methods in accordance with GOST. The mobility of the mortar was determined from the depth of immersion of a standard cone with a mass of 300 g. For all compositions, the mobility which corresponds to the immersion value of a cone of 4 to 8 cm was adopted. The average density of mortar was determined by a steel cylindrical vessel with a capacity of 1000 cm^3, the determination of the water-retention capacity was performed with the help of the DW-RC device. The retention of the mortar was determined according to EN 1015-9: 2007 (procedure B). This parameter determines the usefulness of the masonry mortar for use (min), after which the mobility of the mortar in the standard test changes by 30 mm as compared to the initial mobility. The physical-and-mechanical characteristics of the masonry mortar were determined at the age of 28 days on samples with the dimensions of 4×4×16 cm. The moisture and water absorption of the masonry mortar were determined by standard methods. The determination of the freeze-thaw durability of the masonry mortar was carried out according to the basic method with repeated freezing and thawing on samples with the dimensions of 4×4×16 cm. The sorption humidity was determined by the desiccator method at the relative humidity of 40%, 60%, 80%, 90% and 97% (an aqueous solution of sulfuric acid was used). The coefficient of thermal conductivity of the mortar was determined in the dried state.

3 Results and discussion

Earlier, the authors in the paper [17] used the computer modeling of the structure of cement mortar with hollow ceramics microspheres for the calculation of the optimum content of aggregate (CMS) of a given granulometric composition, in which the most dense packing of particles is achieved (60% of the binder mass). In this case, theoretically, the highest specific strength of the composite should be achieved. The average density of the obtained mortar in dry state was 950 kg/m^3, the compressive strength was 17.1 MPa, and a bending strength was 2.8 MPa. The further increase of the content of CMS in the mortar does not provide an effective reduction in its average density, increasing the water requirement of the mortar, reducing its strength and causing an unnecessary increase in the cost of the dry mix. Meanwhile, for the construction of fencing structures with effective small units, it is necessary to obtain a masonry mortar with a lower average density. One of the ways to solve the aforesaid problem is to modify the structure of the mortar with an air-entraining additive at compensating the decrease in physical-and-mechanical characteristics by the introduction of the RPP.

All studies were carried out on the previously obtained optimal composition of the dry mix containing 60% of the CMS from the mass of the binder and a superplasticizer at a dosage of 0.4% of the binder mass. The consumption of AEA and RPP was varied in the range of 0.01...0.03% and of 1...5% of the mass of the binder, respectively. Two types of RPP were used. The mobility of all masonry mortars corresponds to the immersion value of a standard cone of 4 to 8 cm. The water-retention capacity for all compositions was higher than the minimum normalized value (90%), therefore the introduction of a water-retaining additive into the mortar is not required. This is due to the fact that hollow ceramics microspheres actively adsorb water, and, due to the surface forces, keep it on its surface. The retentivity of the initial mobility of the mortar was 4.5 to 5 hours, which is sufficient for the production of masonry work. The compositions and properties of dry mixes in the solidified state are given in Table 2.

Table 2. Compositions and properties of light-weight dry mixes with hollow ceramics microspheres, redispersible polymer powders and air-entraining additive

No	Composition, mass, %						W/C	Average density of mortar in dry state, kg/m^3	Strength at the age of 28 days, MPa	
	PC	CMS	SP	AEA	V 4023 N	V 8034 H			compression	bending
1	100	60	0,4	–	–	–	0,65	951	17,14	2,76
2	100	60	0,4	0,02	–	–	0,71	576	5,01	1,67
3	100	60	0,4	0,02	1	–	0,71	645	7,96	1,88
4	100	60	0,4	0,02	–	1	0,73	583	6,84	1,73
5	100	60	0,4	0,02	3	–	0,73	811	10,68	2,03
6	100	60	0,4	0,02	–	3	0,76	598	8,38	1,89
7	100	60	0,4	0,02	5	–	0,75	887	11,37	2,19
8	100	60	0,4	0,02	–	5	0,78	701	8,92	1,99

Notes: PC - Portland cement; CMS - hollow ceramics microspheres; SP - superplasticizer; AEA - air-entraining additive; V 4023 N and V 8034 H -redispersible polymer powders Vinnapas 4023 N and Vinnapas 8034 H, respectively.

From Table 2, it can be seen that the introduction of different amount of RPP into the dry mix neutralizes the effect of air entrainment. With the help of mathematical planning of the experiment and the processing of its results, two-factor mathematical models of the properties of light-weight masonry mortar with hollow ceramics microspheres, AEA and RPP were obtained, their compositions were optimized. For the production of mortar with an average density of 500 kg/m^3, the introduction of a RPP is not required, and the AEA flow rate is 0.04% of the binder mass (composition No. 2). To obtain a mortar with an average density of 600 kg/m^3, the optimum consumption of the modifying additives was 0.02% for AEA and 3% for RPP of the mass of the binder, respectively (composition No. 6).

An important exploitation parameter of the masonry mortar is water resistance characterized by a softening factor. The coefficient of softening for mortar of all compositions was in the range 0.8... 0.89, which makes it possible to classify the developed dry mixes as water resistant ones.

The coefficient of thermal conductivity of the mortar obtained from the developed light-weight dry mortar mixture depends on the content of microspheres and the porosity of the cement stone. The results of measuring of the coefficients of thermal conductivity for the control and modified compositions of mortars are presented in Table 3.

Table 3. Main exploitation properties of mortar obtained from a light-weight dry masonry mix with hollow ceramics microspheres, redispersible polymer powders and air-entraining additive

No	Average density of mortar in dry state, kg/m^3	Coefficient of thermal conductivity of the mortar in dry state, W/(m·°C)	Water absorption, %		Water absorption at capillary suction, kg/(m^2·hours^{0,5})	Freeze-thaw durability, cycles
			mass	volume		
1	951	0,244	8,1	8,1	0,3	100
2	576	0,146	13,9	13,9	0,4	50
6	598	0,152	9,2	9,2	0,2	75

From Table 3 we can see that the composition with AEA (No. 2) has the smallest coefficient of thermal conductivity. Compared with the control composition (No. 1), this parameter decreased by 40% due to the formation of a highly porous structure and a decrease in the average density. The coefficient of thermal conductivity of the mortar with AEA and RPP (No. 6) decreased by 34% compared to the control composition.

The water absorption of the mortar is provided a significant effect on its performance characteristics. From Table 3 it can be seen that the water mass absorption of the mortar with AEA increased by 72% in comparison with the control composition. Since Vinnapas 8034 H has a hydrophobizing effect, the water absorption of the composition with this RPP decreased by 51% as compared with the composition with the AEA. The sorption humidity of the developed dry mixes is in the range of 5...7% at a relative air humidity of 97% and in the range of 0.7...1% at the relative humidity of 40%.

The freeze-thaw durability is the most important parameter determining the durability of the building material. The results of the determination of the freeze-thaw durability of a mortar obtained from a light-weight dry masonry mix are shown in Table 3. According to the GOST 530-2012, the freeze-thaw durability of the face brick should not be lower than 50 cycles, therefore, taking into account that, the water absorption of mortar (by mass) did not exceed the normative value of 15%, the softening factor is not less than 0.8, the developed dry mixes can be used for facade masonry.

The composition and structure of the light-weight dry masonry mixes in the hardened state were studied. The results of microstructural and X-ray phase analysis of samples of dry masonry mixes in the solidified state with CMS, modified by the AEA and RPP are shown in Figures 1, 2.

It is established that the microstructure of the samples of the modified mortar is represented by uniformly distributed in volume microspheres and cement matrix over the solid partially crystallized calcium hydrosilicates with inclusions of low-strength needle-like calcium hydrosilicates.

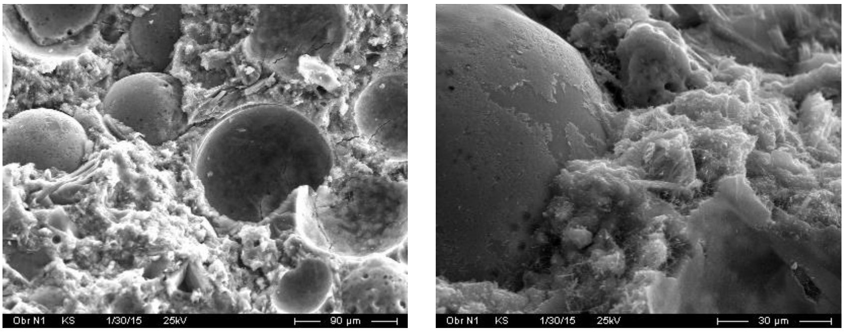

Fig. 1. Microstructure of the light-weight masonry mortar with hollow ceramics microspheres, redispersible polymer powders and air-entraining additive

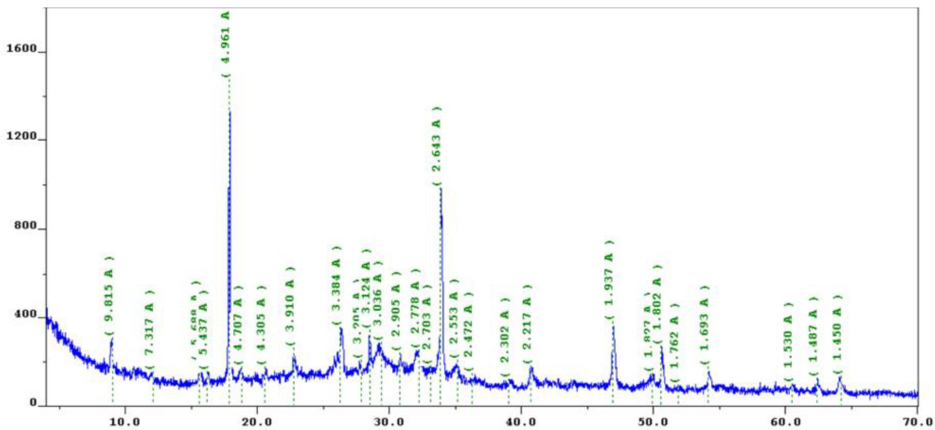

Fig. 2. X-ray diagram of the light-weight masonry mortar with hollow ceramics microspheres, redispersible polymer powders and air-entraining additive

The surface of the microspheres is covered by the products of the chemical interaction of their walls with the cement matrix, which leads to an increase in the strength of the contact zone “microsphere – cement matrix”. On the X-ray diagram the clinker minerals, the portlandite, partially crystallized calcium hydrosilicates, hydroaluminate and hydroferrite of calcium, calcite, ettringite are identified. The degree of cement hydration is 66.5% (at the age of 28 days).

5 Conclusions

As a result of the studies, the compositions of modified light-weight dry mixes for masonry work with hollow aluminosilicate microspheres with an average density of 576...608 kg/m^3, compressive strength of 5...8.38 MPa, bending tensile strength of 1.67 ... 1.89 MPa, water-retaining capacity of the mortar not less than 93%, the retainability of the initial mobility of the mortar mixture not less than 4.5 hours were obtained. The coefficient of thermal conductivity of the developed light-weight mortar is 0,146...0,162 W/(m·°C), water absorption by mass is 13,9...9,2%, softening factor is 0,8 ... 0,89, sorption humidity at relative humidity of air 97 % is 6.9...5.7%, the freeze-thaw durability is 50...75 cycles.

References

1. V.G. Gagarin, V.V. Kozlov, Vestnik MGSU, **3(1)**, 192 (2011)

2. A.S. Gorshkov, A.A. Gladkikh, Magazine of Civil Engineering, **3**, 39 (2010)
3. R. Demirboğa, İ. Örüng, R Gül, Cement and Concrete Research, **31 (11)**, 1627 (2001)
4. Yu.M. Tikhonov, V.I. Kolominetc, Bulletin of Civil Engineers, **3**, 83 (2006)
5. V. Ferrándiz-Mas, T. Bond, E. García-Alcocel, C.R. Cheeseman, Construction and Building Materials, **61**, 285 (2014)
6. V.S. Semenov, T.A. Rozovskaya, D.V. Oreshkin, Advanced Materials Research, **860–863**, 1244 (2014)
7. V.S. Semenov, T.A. Rozovskaya, IOP Conference Series: Materials Science and Engineering, **71**, 012042 (2015)
8. A.K. Suryavanshi, R.N. Swamy, Cement and Concrete Research, **32**, 1783 (2002)
9. S.P. McBride, A. Shukla, A. Bose, Journal of Materials Science, **37 (19)**, 4217 (2002)
10. Y. Wu, J.Y. Wang, P.J.M. Monteiro, M.H. Zhang, Construction and Building Materials, **87**, 100 (2015)
11. D.P. Bentz, M.A. Peltz, A. Durán-Herrera, P. Valdez, C.A. Juárez, Journal Of Building Physics, **34 (3)**, 263 (2011)
12. A.S. Inozemtcev, E.V. Korolev, V.A. Smirnov, Structural Concrete, **18(1)**, 67 (2017)
13. A.S. Inozemtcev, E.V. Korolev, Industrial and civil Engineering, **10**, 80 (2013)
14. L.Ya. Kizilshtein, Science and Life, **5**, 42 (2008)
15. A.A. Sagradyan, G.A. Zimakova, News of higher educational institutions. Construction, **2**, 43 (2012)
16. M. Żyrkowski, R. C. Neto, L. F. Santos, K. Witkowski, Fuel, **174**, 49 (2016)
17. V.A. Smirnov, T.A. Rozovskaya, V.S. Semenov, Science Review, **10-2**, 78–83 (2015)