Properties of modified dry masonry mixtures for effective masonry units

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Abstract. The paper is devoted to the problem of the development of dry light-weight mixtures with hollow ceramics microspheres (CMS) for masonry works. For the one-layer fencing structures including effective masonry units, the use of "warm" masonry mortars is necessary. The used light-weight masonry mortars do not provide the brand strength and thermal uniformity of the fencing structures because of high average density. The CMS are effective light-weight aggregate for such mortars. The influence of the dosage of CMS on the physics-and-mechanics parameters and the technological properties of the masonry mortars has been studied. The optimal mixture compositions have been obtained and their main properties have been determined. The influence of an air-entraining admixture and redispersible polymer powders on the average density and physics-and-mechanics parameters of the masonry mortars have been studied. The optimal compositions of light-weight dry masonry mixtures with CMS have been suggested. It has been established that the mortars, obtained from such mixtures, have the requisite average density, the water retention capacity more than 95 %, high homogeneity and high strength characteristics. The application of the proposed mixtures enables to reduce the construction material costs and to improve the energy efficiency of the fencing structures.

1. Introduction

At present many countries, and particularly Russia, pay great attention to the question of energy efficiency. This is due to several factors such as the limited energy resources, high cost of energy and the negative environmental impact caused by the energy production. Today, according to the Institute of Building Physics, up to 45 % of the energy produced in Russia is consumed by buildings [1]. Herewith, the considerable part of energy is spent on maintenance of the required indoor climate parameters. The primary task of saving energy is to reduce heat loss, including the heat loss through the fencing structures. Studies show that during the operation of a multistory apartment building the heat loss through walls is within the range from 18 to 40 %, depending on the materials used and design solutions applied [2, 3]. The possibility of application of either type of fencing structures is caused by the necessity to provide the normative requirements for thermal protection.

The standard requirements for thermal protection of buildings in Russia are one of the highest in the world. It is confirmed by the fact that the reduced heat-resistance value, which considers the effect of thermal conductive inclusions, is standardized [4]. The fencing structures can be single- or multi-layer ones. However, the use of multilayer structures reduces the coefficient of thermal uniformity and, consequently, increases the wall thickness. In addition, multi-layer structures include thermal insulation made of mineral wool or polystyrene plates. Warranty lifetime of such thermal insulation materials is not more than 15...25 years. Thus, the single-layer fencing structures with the combination of structural and thermal protective qualities in one material, meeting the requirements for thermal protection, are the most technological ones, and they give a cost-effective solution. Such materials used for the erection of single-walled structures include foam ceramics concrete, cellular concrete, polystyrene concrete, etc. [5-7].

The use of cement and sand masonry mortars in one-layer wall structures including effective masonry units leads to the formation of structural cold bridges causing significant heat loss and condensation on interior wall surfaces. To exclude such negative effects, it is necessary to have the average density of masonry mortar not more than the average density of masonry unit. On the other hand, the masonry mortar strength should be at least by 10 to 15 % higher than the strength of the wall material to ensure the required values of the wall design strength. For example, in case of use of the foam ceramics concrete with the average density value of 900 kg/m^3 and the compression strength value of 12.5 MPa, the brand strength value of the mortar should be not less than 14 MPa. The brand strength of the light-weight dry masonry mixtures containing such light-weight fillers as expanded perlite and vermiculite sands, granulated foamed glass and foamed polystyrene does not exceed 5 MPa, while their average density values are not less than 700 kg/m^3. The most widely used foam and cellular concrete blocks have the average density of 600 kg/m^3. Thus, the light-weight masonry mortars available at the building materials market do not provide the design strength of ceramics walls and so do not guarantee the thermal uniformity of a cellular concrete block wall.

The hollow ceramics microspheres are effective light-weight aggregates for the construction and special mortars [8-19]. Previously suggested masonry mortars containing hollow glass microspheres (HGMS) [8-12]. The application of HGMS as a light-weight filler reduces the average density of the mortar down to 600 kg/m^3, but the compression strength value of such compositions is not greater than 2.5 MPa, moreover, the hollow glass microspheres are expensive. The hollow ceramics (alumosilicate) microspheres (CMS) are more effective light-weight fillers, they allow producing mortars with a high strength value and a considerably lower cost [14-19].

The purpose of this study was to develop effective light-weight dry cement mixtures with hollow ceramics microspheres for masonry work, meeting the modern requirements to masonry mortars for effective masonry units.

2. Materials and testing methods

The Portland cement CEM II/A-W 42.5 H (Holcim) with the addition of 9.8 % of granulated slag in accordance with GOST 31108–2003 was used as the binder. The hollow ceramics microspheres with the fraction of 100 to 500 μm "INOTEC Kuznetsk Siberia" were used in this study. The bulk density of the microspheres is 370 to 390 kg/m^3. The average density of the microspheres is 800 kg/m^3. The density of the microsphere wall material is 2450 kg/m^3. The thickness of the microsphere sheath is 1 to 5 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 minimum compressive strength for a hydrostatic compression (10 % destruction) is 15 to 28 MPa. The gas phase inside the spheres is a mixture of CO_2 (70 %), N_2 (30 %). The photos of CMS microstructure are shown in Figure 1.

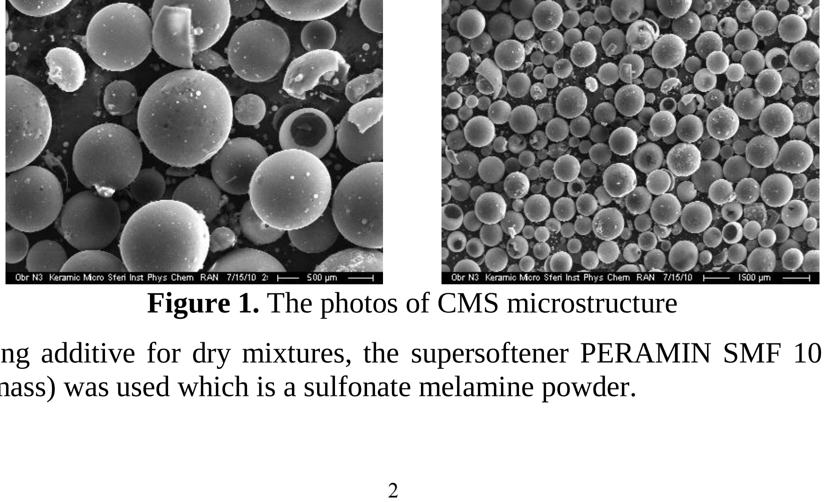

Figure 1. The photos of CMS microstructure

As a plasticizing additive for dry mixtures, the supersoftener PERAMIN SMF 10 (0.4 % of the Portland cement mass) was used which is a sulfonate melamine powder.

In this work the standard testing methods through GOST 5802-86 "Mortars. Test methods", GOST 28013-98 "Mortars. General specifications", GOST 31356-2007 "Dry cement mixtures. Test methods", GOST 31357-2007 "Dry cement mixtures. General specifications" were used. The mobility of all masonry mortars corresponds to the immersion value of a standard cone of 4 to 8 cm. The average density of mortar was determined by a steel pycnometer with the capacity of 100 cm^3. The setting time of the mortar was determined with the Vicat apparatus. The determination of the water-retention capacity of masonry mortar was performed with the help of the DW-RC device. The mortar bending and compression strength values were determined for the prismatic samples with the dimensions of 4x4x16 cm.

3. Results and discussion

The compounds of the mortars with the CMS dosage of 10 %, 20 %, 30 %, 40 %, 50 % and 60 % from the cement mass were studied. The strength of the mortar was determined at the age of 28 days under the conditions, regulated by GOST 5802-86. The compositions and properties of light-weight masonry mortars with CMS are shown in Table 1.

Table 1. The composition and properties of light-weight masonry mortars with hollow ceramics microspheres.

№	Composition, mass %				W/C	Average density of mortar, kg/m^3	Average density of dry cement stone, kg/m^3	Setting time, h-min		Strength of masonry mortar at the age of 28 days, MPa	
	PC	CMS	Water	SS				start	end	compression	bend
1	100	10	31	0,4	0,31	1728	1543	4-00	4-45	48,1	4,89
2	100	20	39	0,4	0,39	1535	1367	4-20	5-00	37,2	4,15
3	100	30	44	0,4	0,44	1386	1277	4-30	5-10	31,3	3,69
4	100	40	48	0,4	0,48	1253	1107	4-35	5-15	24,86	3,38
5	100	50	58	0,4	0,58	1195	1008	4-50	5-45	20,56	3,21
6	100	60	64	0,4	0,64	1104	837	5-15	5-55	17,14	2,84

Notes: PC = Portland cement, CMS = hollow ceramics microspheres, SS = supersoftener, W/C = water/cement ratio.

As we can see from Table 1, the average density of the mortar is 1100 to 1800 kg/m^3 depending on the dosage of the microspheres, the average density of dry mortar is 950 to 1650 kg/m^3. The compressive strength of the mortar is 17.0 to 48.0 MPa, the bend tension strength of the mortar is 2.8 to 4.9 MPa. The average density and the strength of the mortar are reduced when increasing the dosage of the microspheres (Figure 2-4). The developed compositions meet the GOST requirements. The setting time of mortar is great enough for masonry work; the water-holding capacity of mortars is over 95 % for all compositions.

The developed dry masonry mixture can be used for the foam ceramics concrete with the average density of 1000 to 1400 kg/m^3. However, for some other masonry units the average density of the dry stone should be reduced from 400 to 1000 kg/m^3. It has been found that the increase of the dosage of the ceramics microspheres in the mortar to the value of over 60 % does not provide an effective reduction of the average density of the cement stone, causing the unjustifiable rise in the cost of dry mixture [19]. Therefore, to reduce the average density of the mortar, we introduced an air-entraining admixture into the composition. In this study we used the air-entraining admixture ASCO 93 representing an anionic surfactant based on a high-molecular olefin sulfonate. The composition and properties of light-weight masonry mortars with hollow ceramics microspheres and an air-entraining admixture are shown in Table 2.

Table 2. The composition and properties of light-weight masonry mortars with hollow ceramics microspheres and air-entraining admixture.

№	Composition, mass %					W/C	Average density of mortar, kg/m³	Average density of dry cement stone, kg/m³	Strength of masonry mortar at the age of 28 days, MPa	
	PC	CMS	Water	SS	AFA				compression	bend
1	100	30	49	0,4	0,03	0,49	1093	887	8,44	2,41
2	100	40	54	0,4	0,03	0,54	965	708	7,21	2,32
3	100	50	64	0,4	0,03	0,64	892	622	6,54	2,01
4	100	60	71	0,4	0,03	0,71	802	576	5,01	1,67

Notes: AFA = air-entraining admixture.

As we can see from Table 2 and Figures 2-4, the introduction of an air-entraining admixture significantly reduces both the average density and the strength of the stone: the average density of dry stone is reduced by 30 %, the compressive strength of the mortar is by 70 to 75 % lower, and the bending strength is by 35 to 40 % lower. Therefore the introduction of the admixture enhancing the physics-and-mechanics properties of the mortar is advisable. The redispersible polymer powders (RPP) which are dry polymer powders obtained through spraying the dry latex emulsion (dispersion of polymer particles in water), belong to this category of admixtures. When mixing with water, RPP again form aqueous polymer dispersions. The RPP improve the adhesive strength with the base and both the tension strength and the bending one [20]. In this work we used admixtures Vinnapas 4023 N, (a copolymer of ethylene and vinyl acetate) and Vinnapas H 8034 (a terpolymer of ethylene, vinyl laurate, and vinyl chloride). The consumption of RPP was 3 % by mass of the Portland cement. The results are shown in Table 3 and Figures 2-4.

Table 3. The composition and properties of light-weight masonry mortars with hollow ceramics microspheres, air-entraining admixture and redispersible polymer powders.

№	Composition, mass %							W/C	Average density of mortar, kg/m³	Average density of dry cement stone, kg/m³	Strength of masonry mortar at the age of 28 days, MPa	
	PC	CMS	Water	SS	AFA	V 4023 N	V 8034 H				compres sion	bend
1	100	30	51	0,4	0,03	3	–	0,51	1233	1042	19,72	3,21
2	100	30	53	0,4	0,03	–	3	0,53	1142	951	14,95	2,91
3	100	40	56	0,4	0,03	3	–	0,56	1072	986	15,12	2,81
4	100	40	58	0,4	0,03	–	3	0,58	982	798	12,31	2,59
5	100	50	65	0,4	0,03	3	–	0,65	1003	916	12,58	2,63
6	100	50	69	0,4	0,03	–	3	0,69	928	729	10,42	2,17
7	100	60	73	0,4	0,03	3	–	0,73	907	811	10,68	2,43
8	100	60	76	0,4	0,03	–	3	0,76	831	598	8,38	1,89

Notes: V 4023N – Vinnapas 4023 N, V 8034H – Vinnapas 8034 H.

Analysis of the Table 3 shows that the introduction of RPP into the mortar essentially reduces the effect of air entrainment. However, the strength of the mortar increases, i.e. the expected effect is achieved. Thus, the addition of Vinnapas 4023 N increases the average density of the dry mortar with an air-entraining admixture by 17 to 47 %, the compressive strength becomes 1.9-fold to 2.3-fold greater and the bending strength is by 30 to 40 % higher. The addition of Vinnapas 8034 H does not significantly increase the average density of dry mortar, it is only by 4 to 17 % higher, the compressive strength is by 60 to 80 % higher, the bending strength is by 20 to 80 % higher.

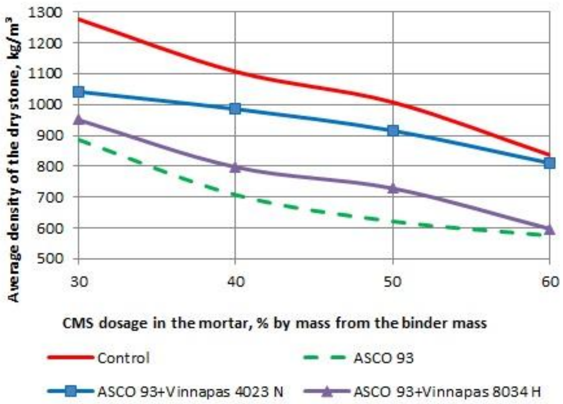

Figure 2. The average density of masonry mortars with CMS, with an air-entraining admixture and redispersible polymer powders depending on the CMS dosage

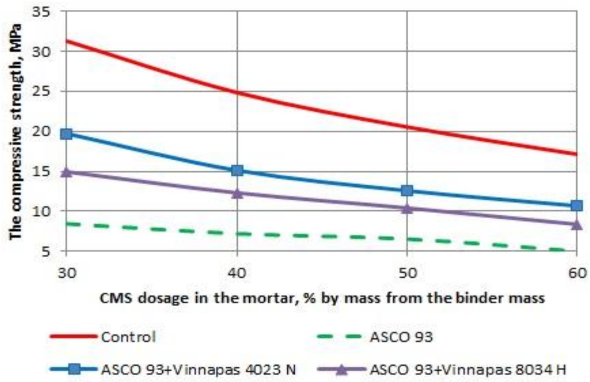

Figure 3. The compressive strength of masonry mortars with CMS, with an air-entraining admixture and redispersible polymer powders depending on the CMS dosage

The actual influence of an air-entraining admixture and redispersible polymer powders can be evaluated in terms of specific strength of the mortar (Figure 5). Thus, for the control composition with the dosage of microspheres of 30 to 60 % by mass of the binder, the specific strength is of 20 to 24 MPa, for the mortar with the air-entraining admixture it is of 8.5 to 10.5 MPa, for the mortar with the air-entraining admixture and Vinnapas 4023 N it is of 13 to 19 MPa, for the mortar with air-entraining admixture and Vinnapas 8034 H it is of 14 to 16 MPa. That is, in terms of the specific strength of the mortars, the used RPP show approximately the same results.

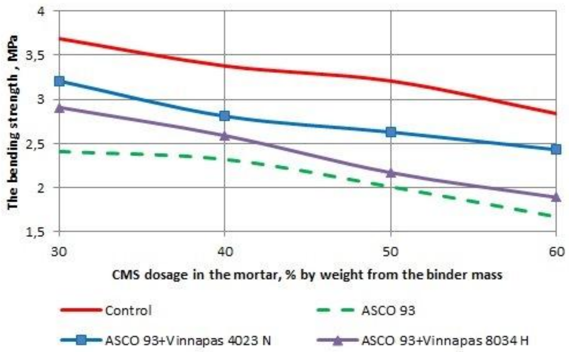

Figure 4. The bending strength of masonry mortars with CMS, with an air-entraining admixture and redispersible polymer powders depending on the CMS dosage.

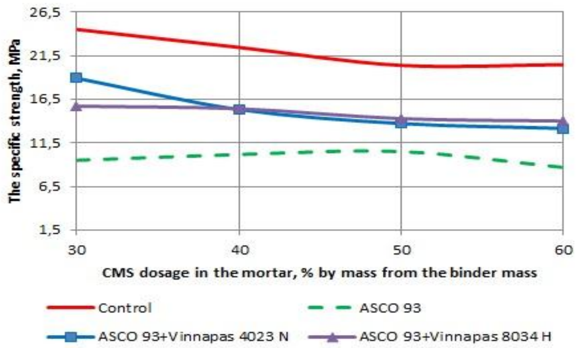

Figure 5. The specific strength of masonry mortars with CMS, with an air-entraining admixture and redispersible polymer powders depending on the CMS dosage.

4. Conclusion

Thus, the use of hollow ceramics microspheres as fillers for masonry mortars, allows producing mortars with an average density of 1000 to 1400 kg/m^3 and with the strength values of 15 MPa to 30 MPa at the dosage of CMS of 20 to 50 % by mass of the binder, designed for efficient ceramics units. Introduction of the air-entraining admixture and RPP into the dry mixture allows getting a mortar with average density of 600 to 1000 kg/m^3 and with the strength values of 5 MPa to 15 MPa for masonry works with cellular concrete blocks.

The developed dry masonry mixtures for effective masonry units provide a high thermal uniformity of the fencing structures and allow us to reduce the masonry seam thickness value to 4…5 mm. It is established that the mortars obtained from such dry mixtures have the required average density value, the water-holding capacity over 95 %, a high homogeneity and high strength parameters. The use of such mortars allows us to reduce the construction cost and to increase the energy efficiency of the fencing structures.

References

[1] Matrosov Yu 2008 The energy-saving in buildings. The problem and the ways for its solution *The Institute of Building Physics (Moscow)*
[2] Gagarin V and Dmitriev K 2013 Accounting heat engineering heterogeneities when assessing the thermal protection of enveloping structures in Russia and European Countries *Construction Materials* **6** 14–16
[3] Oparina L 2013 Results of Calculation of Energy Consumption of a Building Life Cycle *Housing Construction* **11** 50
[4] Gagarin V and Kozlov V 2011 Prospects of increase of power efficiency of residential buildings in Russia *Moscow State University of Civil Engineering Bulletin* **3 (1)** 192–200
[5] Sirazin M 2006 The warm ceramics is a promising material for residential construction in Russia *Construction Materials* **4** 18–19
[6] Gudkov U and Akhundov A 2004 Wall materials based on cellular concrete *Construction Materials* **1** 9–10
[7] Katsynel R 2013 Cellular Concrete and Energy Efficient Construction *Housing Construction* **4** 24–26
[8] Oreshkin D, Belyaev K and Semenov V 2010 High-qualitative building and plugging mortars with hollow glass microspheres *Industrial and Civil Engineering* **10** 56–58
[9] Semenov V, Oreshkin D and Rozovskaya T 2013 Properties of light-weight masonry mortars with hollow ceramics microspheres and antifreeze additives *Industrial and Civil Engineering* **11** 9–11
[10] Semenov V 2011 Efficient light-weight masonry and plugging mortars for inclement climatic conditions *Cand. of Sc. Thesis*
[11] Klochkov A, Pavlenko N, Strokova V and Belentsov Yu 2012 On the use of hollow glass microspheres in heat-insulating structural masonry mortars *Belgorod State Technical University Bulletin* **3** 64–66
[12] Oreshkin D, Belyaev K and Semenov V 2010 Thermophysical Properties, Porosity and Vapour Permeability of Light-Weight Cement Mortars *Construction Materials* **8** 51–54
[13] Oreshkin D, Belyaev K and Semenov V 2010 The overall diagram of obtaining the lightened and super-lightweight cement mortars *Construction of oil and gas wells on land and at sea* **11** 32–33
[14] Inozemtsev A and Korolev E 2013 Hollow microspheres as an effective aggregate for high-strength lightweight concretes *Industrial and Civil Engineering* **10** 80–83
[15] Korolev E, Inozemtcev A 2013 Preparation and research of the high-strength lightweight concrete based on hollow microspheres *Advanced Materials Research* **746** 285–288
[16] Blanco F, García P, Mateos P, Ayala J 2012 Characteristics and properties of lightweight concrete manufactured with cenospheres *Cement and Concrete Research* **30** 1715–1722
[17] Danilin L, Drozhzhin V, Kuvaev M, Kulikov S, Maksimova N, Malinov V, Pikulin I, Redyushev S and Khovrin A 2012 The hollow microspheres from the flue ash as a multi-functional aggregate for composition materials *Cement and its use* **4** 100–105
[18] Teryaeva T, Kostenko O, Ismagilov Z, Shikina N, Rudina N and Antipova V 2013 The physical and chemical properties of alumosilicate hollow microspheres *Kuzbass State Technical University Bulletin* **5** 86–90
[19] Semenov V and Rozovskaya T 2013 Dry masonry mixtures with ceramic hollow microspheres *Science Review* **9** 195–199
[20] 2013 Modern trends in development of the consumption market for complex and multi-functional additives for concrete. Discussions *Concrete Technologies* **7** 8-15