International Journal of Engineering & Technology, 7 (4) (2018) 4341-4344

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10393
Research paper

Substantiation of selection of components at creation of thermal insulating dry building mixtures

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Abstract

The possibility of reducing the thermal conductivity of heat-insulating finishing coatings using as a filler ash microspheres of aluminosilicate and glass hollow microspheres is substantiated. A mechanism of heat transfer through heat-insulating composites is considered, depending on the type of filler used. It is revealed that the ability of the finishing coat to reflect heat does not depend on the type of filler used. It is established that the convective component of heat transfer does not significantly influence the heat-shielding qualities of the finishing coatings under consideration.

Keywords: *Heat-Insulating Dry Construction Mixtures; Fillers; Activity; Thermal Conductivity Coefficient; Packing Density.*

1. Introduction

Currently, the most common mineral fillers for heat-insulating dry construction mixtures (DCM) are expanded vermiculite sand and expanded perlitic sand [1 - 4]. However, these fillers have a high open microporosity. It leads to an increase in the water demand of the finishing compounds. A consequence of this is the delamination of the finishing compounds, the reduction of the water resistance and the strength of the composites based on them. A decrease in the strength of composites is also caused by an uneven distribution of stress concentrations around the filler particles because of their complex isometric shape. In this regard it is promising to use fillers with closed porosity, which will ensure a low water demand for plaster finishing compounds with their use. These fillers include glass hollow microspheres and ash microspheres aluminosilicate [5 - 7]. The use of microspheres as a filler for DCM makes it possible to increase the water resistance of composites by reducing the volume of open pores in them. The resulting composites are also characterized by increased strength due to the absence of an uneven distribution of stress concentrations around microsphere particles.

The disadvantage of the currently existing heat-insulating DCM dased on the microsphere is the low vapor permeability of coatings [8]. This drawback limits the use of cement DCM on the basis of microspheres. This is connected with the fact, that in order to minimize the amount of condensing moisture in the wall thickness, each subsequent layer in the fence design in the direction from the inner surface to the outer one should have less thermal conductivity and greater vapor permeability in comparison with the previous one. For example, in the case of cement mortars based on microspheres for external finishing of aerated concrete of grades D400-D600, the thermal conductivity of such coatings may be lower or close to the thermal conductivity of aerated concrete, but the vapor permeability of these coatings will be several times lower than the vapor permeability of aerated concrete. As a result, during the winter season, in aerated concrete enclosing structure , finished with cement DCM based on microspheres, moisture may collect under the surface of the finishing coat, which can cause detachment of its fragments and the appearance of a grid of small cracks on it [9], [10].

Increase the vapor permeability of heat-insulating DCM is possible due to the replacement of cement with lime. Mortar composites based on calcareous binder have a significantly higher vapor permeability. Also, the lower density of the calcareous binder in comparison with cement, will reduce the density of the resulting heat-insulating composites, thereby increasing their thermal insulation properties. To improve water resistance, additives based on synthesized hydrosilicates, amorphous aluminosilicates [11 - 13] are proposed.

We conducted comparative tests of the use of certain fillers in the composition of heat-insulating DCM. For the selection of the most effective filler, the process of heat transfer through the finishing coating was investigated. Heat through the finishing layer of the exterior walls of buildings is transmitted in 3 ways: radiation, heat conduction, convection. In the voids inside the plaster layer and near the surface of the outer fence, heat transfer predominates through convection and radiation [14,15]. In the material of the plaster coating itself, the heat is mainly transferred through thermal conductivity [16]. Considering that the thermal conductivity of the plaster coatings depends to a large extent on their pore structure, studies have been made of the change in the structure of the pore space of the composites.

2. The research methods

The expanded vermiculite and expanded perlitic sand were used, as well as hollow glass microspheres and ash microspheres of aluminosilicate. For assess the ability of plaster coatings to resist heat transfer due to thermal radiation, were determined the radiation coefficients of the investigated composites with using the Testo 882 thermal imager and the TEN-5 electronic thermometer [19].

The pozzolanic activity of the 4 high-porosity fillers was evaluated. The amount of absorbed Ca $(OH)_2$ by various fillers was de-

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termined from the lime solution, depending on the time of the experiment,

3. The results of research

When using expanded vermiculite sand and expanded perlitic sand, the total porosity of the composites is 80.2% and 72.4% respectively. The increase in the total porosity in these composites occurs mainly due to the increase in the number of open pores. The open porosity of the composites based on expanded vercmiculite sand increases from 40.7% to 53.1%, based on expanded perlite sand, from 40.7% to 47.7%. The growth of closed porosity is less significant and is due to the high microporosity of these fillers. The composite on the basis of hollow glass microspheres has a total porosity of 81.0%, and on the basis of ash microspheres of aluminosilicate – 67.2%. The growth of total porosity in the use of microspheres is due to an increase in the closed porosity due to the hollow structure of these fillers. The closed porosity of composites based on hollow glass microspheres is 56.9%, composites based on ash microspheres of aluminosilicate – 40.0%. In further studies all fillers were taken in an amount of 40% of the weight of the lime.

It has been found, that composites based on hollow glass microspheres have a lower thermal conductivity than composites based on other fillers. The thermal conductivity in the dry state of composites based on glass hollow microspheres is $\lambda = 0.105$ W/m • K, based on expanded vermiculite sand - $\lambda = 0.140$ W/m • K, based on expanded perlite sand – $\lambda = 0.155$ W/m•K, based on microspheres of aluminosilicate – $\lambda = 0.165$ W/m•K.

The degree of pore closure and pore size affect the convective component of heat transfer in the building material. In communicating with each other large pores, air flows arise that increase the convective component of heat transfer and impair the thermal insulation properties of the material. According to [17], the convective component of heat transfer in a porous material begins to significantly affect its heat-shielding properties at a critical value of the Rayleigh criterion $Ra_{cr} > 40$. It was shown in [18] that during the exploitation of materials in the wall the real Rayleigh criterion Ra_{cr} is much lower than 40. This means that the convective component of heat transfer does not have a significant effect on the heat-shielding qualities of the composites under consideration and it can be ignored. It is established, that the emissivity ε, and, consequently, the ability of the composites to reflect heat, does not depend on the filler used. For all investigated composites, the radiation coefficient was $\varepsilon = 0.93$.

Pozzolanic activity is one of the characteristics, that allow to evaluate the effectiveness of the use of fillers in the DCM. The action of the pozzolanic effect in calcareous DCM is manifested in the chemical interaction of amorphous silica (contained in the filler) with lime. In this case, low-basic calcium hydrosilicates are formed in the resulting coatings, strengthening the composites.

The high pozzolanic activity of glass hollow microspheres, 313.0 mg/g, is caused by a high content of SiO_2 in this filler - 73.0%. Significant part of SiO_2 contained in the walls of microspheres in amorphous silica [20], [21]. Less, than that of glass hollow microspheres, the pozzolanic activity of silica-alumina silica microspheres of 68.2 mg / g is explained by the lower content of SiO2 in this filler-55.0% and the smaller specific surface area of the particles of this filler. The specific surface area of the hollow glass microspheres is 1142.9 m^2/kg, the specific surface area of the ash silica-alumina microspheres is 131.1 m^2/kg. Expanded pearlite sand is characterized by a rather high pozzolanic activity – 147.7 mg/g, which is caused by a high SiO_2 content of 73.9%. The low pozzolanic activity of the verkmiculite sand 35.6 mg/g is explained by a low SiO_2 content of 40.6%.

An experiment to determine the pozzolanic activity of glass hollow microspheres was continued until the amount of calcium hydroxide absorbed by the filler did not cease to change. Glass hollow microspheres continued to actively absorb $Ca(OH)_2$ up to 70 days, then the absorption rate slowed down and by 90 days activity reached 480.5 mg/g. To study possible neoplasms on the surface of glass hollow microspheres, their electron microscopic images were taken with the help of the electron microscope VEGA3 TESCAN before and after the experiments (Fig.1).

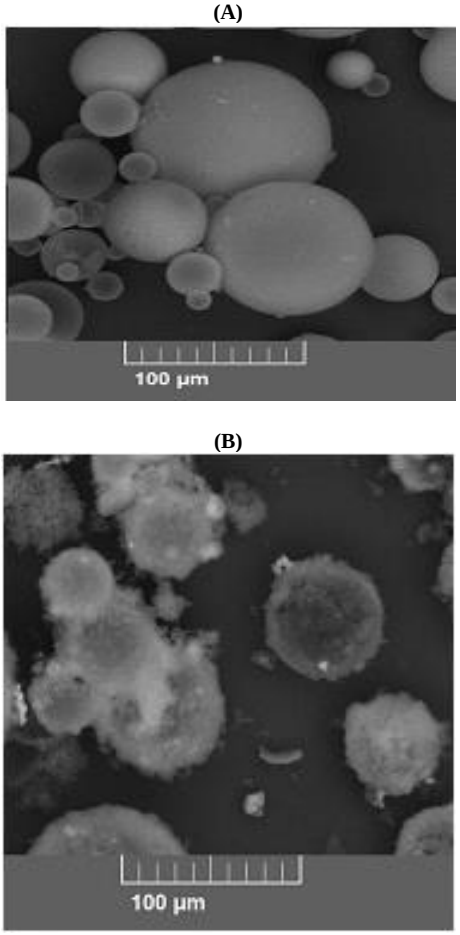


Fig. 1: Electron Microscopic Image of Glass Hollow Microspheres: A - Before the Experiment to Determine the Activity of Fillers; B - After The Experiment to Determine the Activity of Fillers.

As is known, glass hollow microspheres are closed gas-filled balls of various diameters of practically ideal spherical shape. These balls have clearly defined boundaries. In the photo of the filler, made after the experiment on determination of pozzolanic activity, there is no clear boundary in the glass microspheres. Neoplasms on the surface of microspheres are presumably calcium hydrosilicates.

To determine the optimum filler content, it is necessary to solve the geometric problem of the maximum filling of space with spheres of microspheres. Two solutions were proposed in [22], which make it possible to achieve the maximum percentage of occupied space. For lattices of hexagonal and face-centered cubic type, the packing density is equal to $\eta 1 = 0.7405$. Consider a model of a composite, consisting of an astringent and microspheres. The model considered is based on the following proposition: the particles of the binder have the same dimensions, the microspheres have the same dimensions and are separated by a layer of astringent constant thickness. In this case the thickness of the binder interlayer between microspheres is equal to 2 diameters of astringent dCC1 particles, and each individual microsphere is covered with a layer of binder with the thickness dCC1. Such a structure of composites will be formed due to the fact, that at the initial moment of the structure formation in the mortar , because of the high pozzolanic activity of the microspheres, the transfer of particles of the binder to the walls of the microspheres will be observed. Let us determine the number of lime particles that can interact with 1 glass hollow microsphere and with 1 silica-alumina microsphere. The volume of 1 glass hollow microsphere is $8.177 \cdot 10^{-15}$ m^3, the mass of 1 microsphere is $-1.717 \cdot 10^{-12}$ kg. The activity of glass

hollow microspheres is 313.0 mg/g, therefore, $0.537 \cdot 10^{-12}$ kg of lime enters the interaction with 1 microsphere. The volume of 1 particle of lime is $6.5 \cdot 10^{-17}$ m^3, the mass of 1 particle of lime is $1.398 \cdot 10^{-13}$ kg of lime. Thus, with a glass hollow microsphere, the binder will come into contact in an amount equal to 4 particles of lime. Volume of 1 ash microsphere of aluminosilicate $2{,}323 \cdot 10^{-13}$ m^3, weight of 1 microsphere $-1{,}394 \cdot 10^{-10}$ kg. The activity of the microspheres is 68.2 mg/g, therefore, with 9 microsphere, $9{,}507 \cdot 10^{-12}$kg of lime enters the interaction. Thus, with an ash microsphere of aluminosilicate, the binder will enter into the interaction in an amount equal to 41 lime particles. In the model under consideration, the proportion of microspheres in the volume of the composite is maximal, and the binder acts as a binder component, creating a material of a conglomerate structure. The model is shown in Fig. 2.

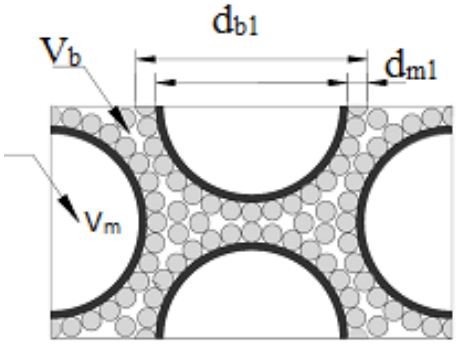


Fig. 2: Diagram of the Composite Model: Where D_{m1} Is the Diameter of the Microsphere, D_{b1} Is the Diameter of 1 Binder Particle, D_{k1} Is the Diameter of 1 Microsphere with the Binder Layer, V_{m1} Is the Volume of 1 Microspheres, V_b Is the Volume of the Binder.

For the studied composite of any volume, the following equality holds:

$$V = V_m + V_b; \quad (1)$$

Where V is the volume of the composite, m^3; V_b - volume of binder, m^3; V_m - volume of microspheres, m^3.

$$V_m = N_m \cdot V_{ml}; \quad (2)$$

Where N_m is the number of microspheres in the volume of the composite under consideration, pcs; V_{m1} - average volume of 1 microsphere, m^3.

In the composite under consideration, the scaffold is microspheres coated with an interlayer having a thickness of 1 particle of the binder d_{b1}. To determine the volume of 1 microsphere with a layer of binder mixture V_{K1}, m^3, the following equation was used:

$$V_{k1} = \frac{\pi \cdot d_{k1}^3}{6} = V_{Cml} + V_{ml} = V_{ml} \cdot \frac{d_{k1}^3 - d_{ml}^3}{d_{ml}^3} + V_{ml}; \quad (3)$$

Where V_{bm1} is the volume of the binder layer around 1 microsphere, m^3; d_{k1} - diameter of 1 microsphere with interlayer of binder, m; d_{m1} - diameter of 1 microsphere, m.

For lattices of hexagonal and face-centered cubic type, for any volume of the composite under consideration the following equality holds:

$$N_m \cdot V_{k1} = 0{,}7405 \cdot V; \quad (4)$$

Thus, the total volume of binder for any volume of the composite under consideration V_b can be calculated by the formula:

$$V_b = N_m \cdot V_{Cml} + 0{,}2595 \cdot V; \quad (5)$$

To determine the optimal content of microspheres M% by weight of the binder, the following formula was used:

$$M^{\%} = \frac{V_m \cdot \rho_m}{V_b \cdot \rho_b \cdot \eta_m} \quad (6)$$

Where ρ_b is the true density of the binder, kg / m^3; ρ_m - true density of microspheres, kg / m^3; η is the packing density of the particles of the binder.

To calculate the packing density of binder particles, the formula was used:

$$\eta_b = \frac{m_b}{\rho_b \cdot V_m} \quad (7)$$

Where m_b is the mass of the binder, kg; V_m is the volume of the mortar composite, m^3.

On the basis of the dependencies obtained, four different materials of the composite were compared:

1) Variant: filler - glass hollow microspheres; binder - hydrated lime;
2) Variant: filler - glass hollow microspheres; binder - cement;
3) Variant: filler - ash microspheres aluminosilicate; binder - hydrated lime ;
4) Variant: filler - ash microspheres aluminosilkatnye; binder - cement.

The initial data for the calculations are presented in Table. 1.

Table1: Estimated Characteristics of Binder

Material	Diameter 1 of the binder mixture particle d_{b1}, m	The true density of the astringent ρ_b, kg/m^3	Packing density of binder particles η
hydrated lime	$2{,}67 \cdot 10^{-6}$	2150	0,474
cement	$5{,}00 \cdot 10^{-6}$	3000	0,733

The results of the calculations are given in Table. 2

It is established that with increasing diameter of microspheres the volume of binder in composite V_b decreases due to decrease in the volume of interlayer around V_{bm} microspheres . The increase in the diameter of 1 microsphere d_{m1} by 3.05 times when the glass hollow microspheres in the composite are replaced by aluminosilicate ash microspheres reduces the volume of the calcareous binder V_b in composite from 58.57% to 39.55%, reduces the volume of cement binder VB in the composite from 73.01% to 48.83%. It was also found that with increasing binder particle diameter, the amount of binder in the V_{cc} composite increases due to an increase in the volume of the interlayer around the V_{cm} microspheres. The increase in the diameter of 1 binder particle d_{b1} by 1.87 times at the replacement of the lime on cement increases the binder volume V_b in the composite based on glass hollow microspheres from 58.57% to 73.01%, in the composite based on ash microspheres of aluminosilicate – from 39.55% to 48.83%.

Table 2: Calculation Characteristics of Composites

Composite variant	The volume of microspheres in the composite V_m, %	Volume of binder in composite V_b layer around the microspheres V_{bm},%	filling of space between microspheres, V_{pp}, %	The optimum content of microspheres from the mass of binder M%,%	Composite density ρ, kg/m^3
1	41,43	32,62	25,95	17,3	684
2	26,99	47,06	25,95	3,5	1663
3	60,45	13,60	25,95	89,9	766
4	51,17	22,88	25,95	28,6	1381

4. Conclusions

The possibility of lowering the thermal conductivity of heat-insulating finishing coatings using ash-microspheres of aluminosilicate and glass hollow microspheres as filler, and lime as an astringent is substantiated.

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