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Heat-insulating Finishing Composition of the Optimal Structure with Microspheres

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Abstract. As fillers in most heat-insulating finishing compounds, various highly porous materials with high open microporosity and moisture capacity are used - expanded vermiculite sand and expanded perlite sand. In composites based on such compositions in the pore structure, open pores predominate, which is why the performance properties deteriorate, the strength and water resistance of the resulting coatings decrease. Of great interest is the use as fillers of materials with closed microporosity - glass hollow microspheres and ash microspheres of aluminosilicate. The aim of the work is the development of a model for the heat-insulating composite of the optimal structure, which allows to minimize the consumption of the binding agent by achieving the maximally dense packing of the microspheres. On the basis of the developed model, the optimal content of hollow glass microspheres and ash microspheres of aluminosilicate, in the case of cement and lime as binding agent, was calculated in heat-insulating composites. The average density of composites of the optimal structure for each pair of "binder-filler" is predicted. It has been established that the composites of the optimal structure obtained with the use as binder of lime will have a lower density in comparison with composites obtained using binder cement. As a result of the conducted studies, the possibility of effective use of lime as a binder in heat-insulating composites obtained with the use of microspheres was identified. When it is used, it is possible to significantly reduce the density of the resulting thermal insulation coatings, thereby increasing their thermal insulation properties and vapour permeability.

1. Introduction

Due to the use of effective high-porosity fillers in heat-insulating plaster solutions, it is possible to achieve high vapour permeability, low density and thermal conductivity of the resulting finishing coatings. Currently, the most common mineral fillers for heat-insulating dry construction mixtures (DBM) are expanded vermiculite sand and expanded perlite sand [1,2]. These fillers have a high open microporosity, which 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.

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 [3,4]. The use of microspheres as a filler for DBM makes it possible to increase the water resistance of the resulting solution composites by reducing the volume of open pores in them [5,6]. Applying glass hollow microspheres and aluminosilicate ash microspheres as fillers in the DBM, one should strive to obtain the optimal structure of the solution



composite. For materials of thermal insulation type, the structure at which the composite is filled with light particles of microspheres is optimal. In this case, the binder acts as a binder component, creating a material of a conglomerate structure.

2. Methodology

The shape of microspheres and a large range of diameters provide the most compact packing due to the minimum ratio of the surface area to the occupied volume. 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 [7,8], which make it possible to achieve the maximum percentage of occupied space in the composite by microspheres. For lattices of hexagonal and face-centered cubic type, the packing density is $\eta = 0.7405$.

Consider a model of a composite consisting of an astringent and microspheres. This model is based on the following: binder particles have the same dimensions, 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 solution, because of the high pozzolanic activity of the microspheres, the transfer of particles of the microspheres to the walls will be observed [9]. The model of the composite in question is shown in figure 1.

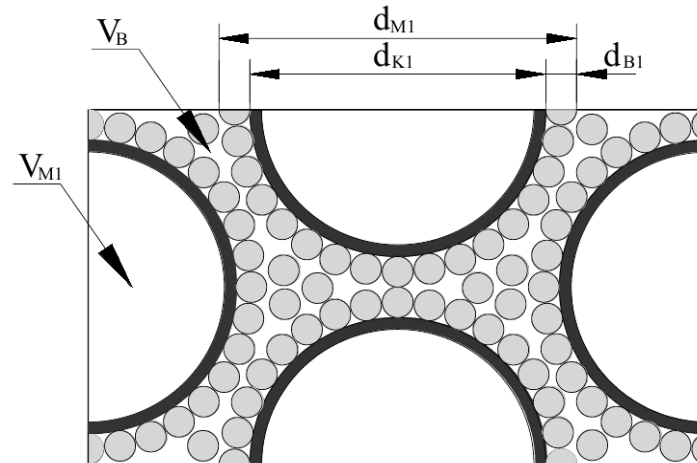


Figure 1. Diagram of the model of the composite: where d_{M1} is the diameter of the microsphere, d_{B1} is the diameter of 1 binder particle, d_{K1} is the diameter of 1 microsphere with the binder layer, V_{M1} is the volume of 1 microspheres, V_B is the volume of the binder.

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

$$V = V_M + V_B \quad (1)$$

where:

- V is composite volume (m^3)
- V_B is volume of binder (m^3)
- V_M is volume of microspheres (m^3)

$$V_M = N_M \cdot V_{M1} \quad (2)$$

where:

- N_M is number of microspheres in the volume of the composite in question (pieces)
- V_{M1} is 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 layer of binder mixture V_{K1} , m^3 , the following equation was used:

$$V_{K1} = \frac{\pi \cdot d_{K1}^3}{6} = V_{CM1} + V_{M1} = V_{M1} \cdot \frac{d_{K1}^3 - d_{M1}^3}{d_{M1}^3} + V_{M1} \quad (3)$$

where:

- V_{CM1} is volume of the binder layer around 1 microsphere (m^3)
- d_{K1} is diameter of 1 microsphere with interlayer of binder (m)
- d_{M1} is 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:

$$V_B = N_M \cdot V_{CM1} + 0,2595 \cdot V \quad (5)$$

To determine the optimal content of microspheres $M\%$ of the binder mass by formula:

$$M\% = \frac{V_M \cdot \rho_M}{V_B \cdot \rho_B \cdot \eta_B} \quad (6)$$

where:

- ρ_B is the true density ρ_M (kg / m^3)
- ρ_M is the true density (kg / m^3)
- η is packing density of binder particles

3. Results and discussions

On the basis of the obtained dependences, 4 different materials of thermal insulation composite were compared in their work:

- Option 1: filler - glass hollow microspheres; binder - lime;
- Option 2: filler - glass hollow microspheres; binder - cement;
- Option 3: filler - ash microspheres aluminosilicate; binder - lime;
- Option 4: filler - ash microspheres aluminosilicate; binder - cement.

The initial data for the calculations are presented in table 1 and table 2.

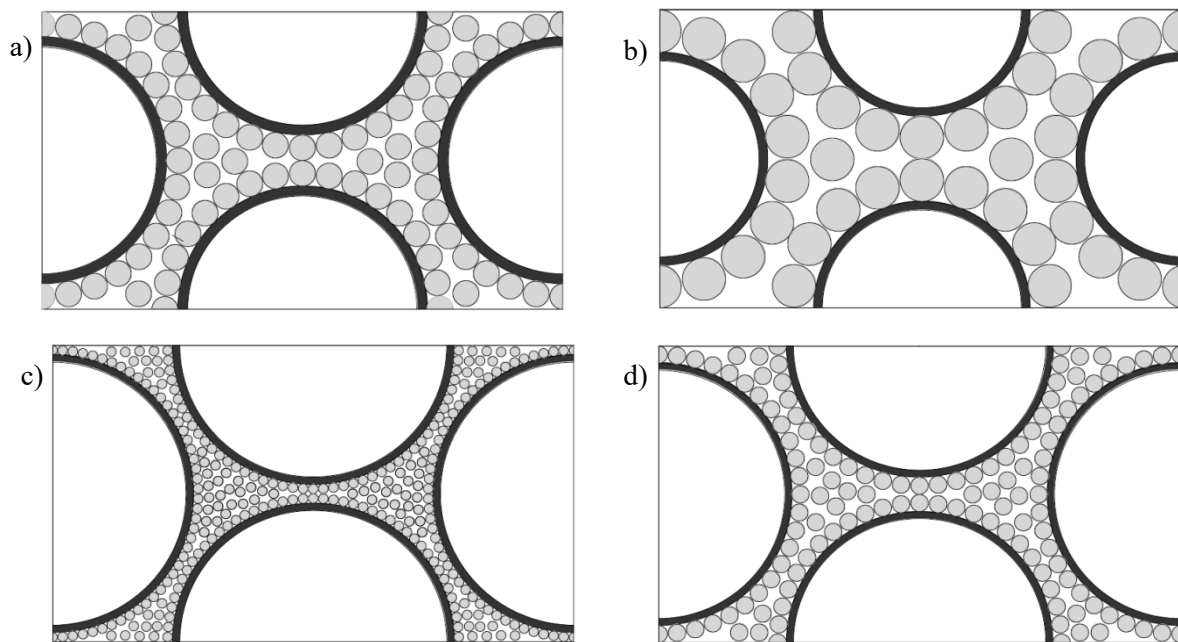
Table 1. Calculated characteristics of filler

| Material | Diameter 1 microspheres d_{M1} , μm | True density ρ_M , kg / m^3 |
|----------------------------------|--|------------------------------------|
| Glass hollow microspheres | 25.00 | 350 |
| Ash microspheres aluminosilicate | 76.28 | 450 |

Table 2. Calculated characteristics of binder

| Material | Diameter 1 of binder particle d_{B1} , μm | True density ρ_M , kg / m^3 | Packing density of binder particles η |
|----------|--|--|--|
| Lime | 2.67 | 2150 | 0.474 |
| Cement | 5.00 | 3000 | 0.733 |

Schemes of arrangement of particles of binder and filler in the compared composites are shown in figure 2.

**Figure 2.** Arrangement schemes for particles of binder and filler in composites: a - 1 option; b - 2 option; c - 3 option; g - 4 option.

The results of the calculations are presented in Table 3.

Table 3. Calculation characteristics of composites

| Option | 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 $V_{PP}, \%$ | Optimum content of microspheres from the mass of binder $M^%, \%$ | Density composite $\rho_M, \text{kg} / \text{m}^3$ |
|--------|---|--|---|---|--|
| 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 |

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 the interlayer around V_{BM} microspheres. Increasing the diameter of 1 microsphere d_{M1} by 3.05 times with the replacement of glass hollow microspheres in the composite by silica microspheres aluminosilicate, reduces the volume of calcareous binder V_B in the

composite from 58.57% to 39.55%, reduces the volume of cement binder V_B in the composite from 73.01% to 48.83%.

It has also been found that with increasing binder particle diameter, the amount of binder in the composite V_B increases due to the increase in the volume of the interlayer around the microspheres. Increasing the diameter of 1 binder particle d_{B1} by 1.87 times with the replacement of the cement binder in the composite cement, increases the binder V_B in the composite, filled with glass hollow microspheres, from 58.57% to 73.01%, increases the volume of binder V_B in the composite filled with ash microspheres of aluminosilicate, from 39.55% to 48.83%.

4. Conclusions

Due to the lower density of the calcareous binder and the smaller particle diameter d_{B1} , it is possible to reduce, in comparison with cement, the density of the resulting heat-insulating composites, thereby increasing their thermal insulation properties and vapour permeability.

Comparing the obtained data, it can be concluded that the use of lime-litter for use as a binder in heat-insulating composites obtained with the use of microspheres as a filler is a high efficiency.

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