Fire-resistant Heat Insulating Material with Variable Rheology

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Abstract. The article focuses on modern requirements to fire-resistant materials used for erection of building constructions of special purpose as well as on designing fire-resistant and retardant coatings of building constructions and industrial equipment. It makes a brief analysis of fire-resistant materials and points out their advantages and disadvantages. The authors present results of researches and tests aimed at the development of technology and materials which combine fire resistance, low thermal conductivity and manufacturability of products and protective coatings. A modified binder made on the basis of liquid glass is used as the main component of developed compositions. The study describes two types of compositions. The first one is a porous heterogeneous structure, produced on the basis of the authors’ technology of two-phase structuring and thermal pore-spacing. This composition is intended for moulded products manufacturing. The second composition is used to manufacture retardant coatings by a monolithic means. The conducted tests of the developed materials prove their sufficiently high heat-resistant and heat-insulating characteristics.

1. Introduction

The modern building insulation materials must be required not only for low thermal conductivity, but also for a number of other indicators, among which we can distinguish fire resistance and manufacturability [1]. Preserving the carrying capacity, integrity and other characteristics of building structures when exposed to high temperatures during a fire, largely determines their durability and reliability.

One of the ways to increase fire resistance of building structures is the use of various fireproof coatings (FPC). The main purpose of FPC is to ensure that the bearing capacity of the construction is maintained under fire conditions, i.e. to slow down the heating of the construction.

The main characteristics of any construction FPC are the maximum temperature of its application, which should be at least 900°C, and the fire resistance limit expressed in hours or minutes from the start of any fire standard test to the occurrence of one of the limit states for fire resistance of the construction (depends on the protected construction type and material).

According to these requirements, heat-insulating materials based on polymers do not withstand any criticism and should be used in exceptional cases, as they not only are not fire-resistant, but, on the contrary, burn quickly, contributing to the acceleration of the destruction of structures and constructions.

Widely used thermal insulation materials based on mineral fibers (MF) also have some drawbacks: lack of form stability, high water absorption (up to 60-80%), low ecological compatibility. Practically
all the products based on MF are produced using organic binders. That’s why, the maximum temperature of their application does not exceed 250-300°C.

2. Materials and Methods

Recently developed constructions based on ultra-light expanded clay gravel [2-5] have a very high efficiency, both in terms of requirements for thermal insulation and fire resistance and fire safety. But the manufacture of such structures limits the small supply of clays with a high coefficient of expansion and technology difficulties.

The authors consider the studies aimed at creation of highly porous structures based on hydrated sodium silicate, for example on the basis of sodium liquid glass, referred to as "soda water glass, water soluble", soluble glass, solution of water sodium silicate to be of great interest. Hydrated sodium silicates, referred to as "SWG", have the characteristic feature of intensively swelling under heating, increasing in volume up to 80 times. Highly porous structures thus formed are thermostable, i.e. non-flammable, fire-resistant and fireproof. The effectiveness of work on this topic is confirmed by the fact that it is being studied by scientists from Saransk [6], Tomsk [7], Saratov [8] and many other cities [9].

The authors carried out the following investigation as part of the topic "Research in the field of production technologies for efficient building materials, products and constructions", and the studies were carried out in two directions:

1) Composition development and manufacturing technologies of fire-resistant heat-insulating highly porous products of factory readiness intended for thermal insulation of "hot" equipment, for example, "hot" oil pipelines with transported product temperature of 200-700°C.

2) Composition development and technology of porous fire retardant coatings intended for fire protection of building constructions and industrial equipment on site.

To solve the first problem, the technology developed by the authors was used. It was notionally called "two-phase structuring". As noted above, SWG swells intensively. But highly porous structures formed in this case are extremely heterogeneous, both in density and in shape and size of pores. As a result of "two-phase structuring," a fine-pore structure is formed, which includes two structural elements. The function of the first structural element is carried out by highly porous density granules of 2.5-8 mm in diameter, with density of 200-220 kg / m³, obtained on the basis of modified SWG. The function of the second structural element is carried out by highly porous powder, with size of 0.1-2.5 mm and a density of about 70 kg / m³ [10-12], also obtained on the basis of SWG. This technology allowed the entire volume of the material involved to be broken up into intergranular voids volume of grains, which in its turn is divided into voids volumes between powder grains. As a result, it was possible to obtain a homogeneous fine-pore structure (Figure 1).

![Figure 1. Structure of fire-resistant heat-insulating highly porous material.](image-url)

The element composition of the materials used and the absence of organic substances in raw material, predetermined the incombustibility and fire resistance of the material obtained (Table 1).
Table 1. Properties of thermal insulation material obtained by thermal expansion.

| Determined characteristics                              | Unit     | Results              |
|---------------------------------------------------------|----------|----------------------|
| Average density                                         | Kg / m³  | 350 - 365            |
| Average compressive strength                            | MPa      | 0.4 - 0.55           |
| Average bending strength                                | MPa      | 0.07 - 0.9           |
| Thermal conductivity coefficient                        | W / (m * K)| 0.088 - 0.094       |
| Organic compounds presence                              | %        | none                 |
| Fire resistance limit for steel construction 20 mm thick | Minutes  | More than 30         |
| Heat resistance at heating up to 700 °C and cooling     |          | Over 100             |
| Maximum application temperature                         | °C       | 730                  |
| Average density                                         | Kg / m³  | 350 - 365            |
| Average compressive strength                            | MPa      | 0.4 - 0.55           |

3. Results and discussions

The results obtained show an opportunity to use given material as effective thermal protection in case of high temperature influence, including fire.

The developed technology is non-waste. Possible waste is planned to be used in the form of a porous powder. The advantage of this method is the ability to control processes using automatic systems with the developed algorithms [15, 16], due to the uniqueness of the process parameters. The disadvantage of the technology described is the requirement for heat treatment at temperature of 250-350°C in the final honeycomb structure moulding [17].

This problem was solved while developing the second direction of the research, i.e. the development of compositions and porous fire-retardant coatings technology based on SWG, intended for fire protection of building constructions and industrial equipment on site. The following tasks were solved:

- organization of pore-spacing process at low temperatures (not higher than 50 °C);
- composition obtaining of structural viscosity providing pore-spacing and, at the same time, shrinkage absence after pore-spacing
- composition obtaining of sufficient strength in the temperature range of 20-50 °C, i.e. without special heat treatment.

The above stated tasks were solved by the authors in the following ways:

1. Pore-spacing of SWG-based composition was achieved by introducing dehydrated hydrogen peroxide in powder form, the latter functioning as gasifier [18].
2. The SWG-based composition obtaining of structural viscosity was achieved by: a) additional introducing of SWG-based expanded powder into the composition; b) application of mixed binder based on SWG and Portland cement. The introduction of SWG-based grounded powder provided the appearance of rudimentary structure in the composition and reduced the density of the original composition. After swelling of involved composition, the desired shape was given to it - simple in the form of plates (Figure 2) or complex (Figure 3, 4).
Tests showed that after solidification the material obtained had the following characteristics:

- density - 0.34 - 0.42 g/cm³;
- compressive strength – 0.2-0.7 MPa;
- uniformly distributed small closed pores;
- ease of machining.

4. Conclusions

The technology developed by the authors does not require special heat treatment. For its organization, a typical metering and mixing equipment can be used.

Low density and sufficient strength provide sufficiently high operational efficiency.

Mineral makeup provides this composition with non-flammability and fire resistance, as well as fire safety.

The maximum temperature of this composition application can be increased up to 900-1100 °C by using refractory additives.

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