Thermal insulation composite with the use of mining waste

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Abstract. The authors offer the use of environmentally friendly waste of mining plants located in the Arkhangelsk region as a binder to create a thermal insulation construction composite based on basalt fibers. This waste is the saponite-containing material (SCM) recovered from recycle water suspension produced during the enrichment of kimberlite ores from the diamond deposit named after M V Lomonosov (Arkhangelsk region). The SCM has binding properties and they depend on its dimensional characteristics and reach optimum values at an average particle size within 1-2 \(\mu\)m. The test samples of composites obtained at 1050 \(^\circ\)C with the SCM content varying in the range from 7.5\% to 25\% and the test samples of composites obtained as a result of thermal modification at up to 1200 \(^\circ\)C with the SCM content varying in the range from 15 to 25\%, were made under laboratory conditions. The raw mix for thermal insulation composite production contained the SCM as a binder with an average particle size of 1-2 \(\mu\)m, and basalt fibers with an average diameter of 3-6 \(\mu\)m as fibrous filler. Thermal modification of samples was carried out at a temperature up to 1200 \(^\circ\)C according to the temperature-time mode used in expanded clay production. As a result of tests, it was found that the composite thermal insulation capacity decreases and compressive strength increases with an increase in the SCM content. Additionally it was noted that thermal modification of thermal insulation composites considerably increases their compressive strength without any impact on the heat transfer coefficient. Thus, it is possible to obtain materials with the specified performance such as the heat transfer coefficient and compressive strength by regulating a percentage ratio of components of the thermal insulation composite based on basalt fibers – the saponite-containing material. Additionally, thermal modification of the studied composite makes it possible to increase considerably compressive strength without changing its heat transfer coefficient. The obtained thermal insulation construction composite is environmentally safe and can withstand high temperatures without breakdown. The SCM will promote the effective solution of environmental problems associated with the development of the diamond deposit named after M V Lomonosov.

1. Introduction

One of the relevant areas of construction materials science that are quickly developing now is obtaining energy saving materials and products from them. In connection with an increase in construction rates and volumes in Russia including low-rise construction, demand for new construction and thermal insulation materials as an alternative to a traditional brick, wood, foam concrete and polymers grows fast.

Building structures should be made using environmentally safe and low-power-intensive construction materials made on low-cost technologies based on the primary use of derivative products of environmentally safe industrial waste and local raw material resources.
Construction composite materials made using environmentally friendly industrial waste feature high performance with significant savings on raw materials [1, 2] and also improve the ecological situation, stabilize and lower the environmental impact.

Earlier in the paper [3] we demonstrated a possibility of using large-tonnage waste produced by mining plants in the Arkhangelsk region as a binder for mineral-wool thermal insulation. Such waste was the saponite-containing material (SCM) recovered from recycle water suspension obtained during the enrichment of kimberlite ores from the diamond deposit named after M.V. Lomonosov.

The SCM is a typical example of bentonite clays. SCM is a clay mineral, layer silicate (montmorillonite group), its solid mineral particles in suspension including 63% of saponite, 10% of dolomite, 10% of quartz, other minerals (chlorite, hematite, calcite, apatite, etc.) not exceeding 2...3% [4]. The SCM chemical composition (Table 1) determined by X-ray fluorescence spectroscopy [5,6] showed no harmful impurities. However, the fact of such chemical compounds (expressed as oxides) as SiO₂, MgO, Al₂O₃, CaO present in the pilot samples implies that hydrosilicates out of mechanically pre-activated SCM are to be formed while hydrating after SCM having been mechanically dispersed in a ball mill to an ultrafine state [7,8].

As a result of research the test sample of mineral-wool thermal insulation was obtained using the SCM-based binder and its tests proved that the material features good thermal insulation capacity and environmental friendliness, it is not affected by oxidative degradation and can withstand high temperatures (over 1000 °C) without breakdown. The SCM binding properties were evaluated [9] by the calorimetric test of the heat of hydration reaction, which showed that the specific enthalpy of hydration is 230 kJ/kg that is comparable to the hydration heat value of the basic clinker mineral. This confirms the hypothesis that the SCM, due to its chemical composition, exhibits binding properties. It is also found that the SCM binding properties depend on its dimensional characteristics and reach optimum values at an average particle size within 1-2 μm [10].

Table 1. SCM structure in terms of oxides

| Evaluated element | SiO₂ | MgO | Al₂O₃ | CaO | TiO₂ | K₂O | SO₃ | P₂O₅ | Cr₂O₃ |
|-------------------|------|-----|-------|-----|------|-----|-----|------|-------|
| Content (%)       | 51.74 | 19.40 | 9.97 | 4.19 | 1.01 | 1.69 | 0.31 | 0.66 | 0.11  |

It is known that thermal treatment of the saponite-containing material changes its properties; it is confirmed by the authors of the research [11] who carried out thermal modification of the saponite-containing material at the time and temperature modes used in expanded clay production (Figure 1) [12].

However, the thermal insulation material should also feature mechanical strength in addition to good thermal insulation properties in order to ensure wider application. Therefore, an important physical and chemical characteristic of the thermal insulation that affects material performance is bond strengths at the phase boundary of the mineral composite achieved through a quantitative combination of mineral components.

The quality of products depends on many factors and key ones include filler quality, binder type, the uniformity of binder introduction to a mat and the degree of cure. As the fiber diameter and the number of non-fibrous inclusions are reduced, the strength of mineral-wool products increases with other things being equal. According to numerous literary data [13], the fiber diameter must not exceed 5-6 μm at the minimum content of non-fibrous inclusions in order to obtain effective rigid mineral-wool products.

Thus, the purpose of this research is to obtain samples of the thermal insulation composite based on the SCM and basalt fibers and determine the functional interrelation between composite strength properties and thermal insulation capacity at various contents of mix components.
2. Methods

Test samples were produced using basalt wool as a filler obtained by induction melting with subsequent melt blowing in fibers with a diameter of 3-6 µm and the content of non-fibrous inclusions ("buttons") over 0.25 mm in size no more than 5%.

The saponite-containing material (SCM) recovered through electrolytic coagulation from recycle water suspension obtained during the enrichment of kimberlite ores from the diamond deposit named after M.V. Lomonosov was selected as a binder.

Test samples of the thermal insulation composite (basalt fibers – the saponite-containing material) were made as follows. The SCM was preliminarily reduced to its constant weight. Then, it was ground in the PM 100 planetary ball mill (manufactured by Retsch GmbH) using the dry mechanical dispersion method with the following mode parameters: rotor rotation speed – 420 rpm, grinding period – 45 minutes, 20 steel grinding balls 20 mm in diameter. SCM grinding mode parameters were selected based on previous research on the determination of the optimum SCM particle size to use it as a binder for mineral-wool thermal insulation.

Composite samples were produced using the rotor mixer. Basalt fibers with an average diameter of 3-6 µm were added batchwise to water suspensions of the saponite-containing material, and the obtained mixes were carefully stirred until smooth. Thus, the raw mix for thermal insulation production contained the SCM as a binder and basalt fibers as fibrous filler. Then the mixes were placed in molds and one portion of samples was dried up in a drying cabinet until reaching the constant weight at 105 °C, while the other portion of samples was exposed to thermal modification in the SNOL 67/1300 laboratory electric furnace with the E5CK-T digital programmable temperature controller at a temperature up to 1200 °C under the following time-temperature mode: 30 minutes – time of linear temperature rising to 600 °C, 5 minutes – time of linear temperature rising to 1200 °C, 10 minutes – sample holding time at 1200 °C.

Thus, tests were performed after preparing five samples obtained as a result of reducing to their constant weight at 105 °C with the SCM content varied in the range from 7.5 to 25% by the dry
weight, and three samples obtained as a result of thermal modification with the SCM content varied in the range from 15 to 25% by the dry weight. The lower limit of the binder content was determined by spontaneous material breakdown as a result of heat treatment.

Thermal conductivity of the studied samples was determined using the MIT-1 thermal conductivity meter by a probe method in accordance with standard method. Compressive strength was determined using the AGS-5kNX universal desktop testing machine (manufactured by Shimadzu) in accordance with standard method.

3. Result and discussion

The tests of samples as shown in Figures 2 and 3 obtained as a result of reducing to their constant weight at 105 °C, (Table 2) proved that the heat transfer coefficient (λ) changes from 0.1109 to 0.1342 W/(m·K) and compressive strength (R) changes from 0.45 to 0.93 MPa depending on the structure of composites (C – SCM content, %).

![Figure 2](image2.jpg)  
**Figure 2.** Thermal insulation composite with the following contents of components: SCM - 15%, basalt fibers - 85% obtained at 105 °C

![Figure 3](image3.jpg)  
**Figure 3.** Thermal insulation composite with the following contents of components: SCM - 20%, basalt fibers - 80% obtained as a result of thermal modification

The mathematical dependences of the heat transfer coefficient and composite strength were obtained that are characterized by the following linear equations:

\[ \lambda = 1.1 \times 10^{-3} C + 0.10 \]  \hspace{1cm} (1)

\[ P = 3.1 \times 10^{-2} C + 0.19 \]  \hspace{1cm} (2)
Approximation reliability coefficients $R^2$ for the equations (1) and (2) are equal to 0.88 and 0.85, respectively. The obtained data demonstrated that, as expected, thermal insulation capacity of the composite decreases and compressive strength increases with an increase in the SCM content.

The tests of samples obtained as a result of thermal modification (Table 3) proved that the heat transfer coefficient $(\lambda)$ changes from 0.1042 to 0.1366 $\text{W/(m·K)}$ and compressive strength $(R)$ changes from 1.60 to 3.80 $\text{MPa}$ depending on the composite structure (C – SCM content, %).

**Table 2.** Quality indicators of thermal insulation samples determined by standard methods

| No. | Basalt fibers (% by weight) | SCM (% by weight) | Heat transfer coefficient $(\text{W/(m·K)})$ | Compressive strength $(\text{MPa})$ |
|-----|---------------------------|------------------|-----------------------------------------------|----------------------------------|
| 1   | 92.5                      | 7.5              | 0.1109                                        | 0.45                             |
| 2   | 90.0                      | 10.0             | 0.1178                                        | 0.39                             |
| 3   | 85.0                      | 15.0             | 0.1184                                        | 0.80                             |
| 4   | 80.0                      | 20.0             | 0.1223                                        | 0.82                             |
| 5   | 75.0                      | 25.0             | 0.1342                                        | 0.93                             |

The analysis of test results makes it possible to conclude that the value of the heat transfer coefficient of the studied composites depends only on the mix composition, and thermal modification has no impact on this indicator. Compressive strength also depends on the composite structure, and at the same time thermal modification of the studied composites considerably increases this indicator in comparison with the composite obtained at 105 $^\circ\text{C}$.

**Table 3.** Quality indicators of thermally modified thermal insulation samples determined by standard methods

| No. | Basalt fibers (% by weight) | SCM (% by weight) | Heat transfer coefficient $(\text{W/(m·K)})$ | Compressive strength $(\text{MPa})$ |
|-----|---------------------------|------------------|-----------------------------------------------|----------------------------------|
| 1   | 85                        | 15               | 0.1042                                        | 1.60                             |
| 2   | 80                        | 20               | 0.1239                                        | 2.90                             |
| 3   | 75                        | 25               | 0.1366                                        | 3.80                             |

The comparison of the studied thermal insulation composite with the known construction thermal insulation materials according to their thermal insulation and strength properties has shown that it is comparable with gas and foam concrete blocks. It should be noted that this material is environmentally safe and withstands high temperatures without breakdown.

Thus, the obtained thermal insulation composite can be recommended not only for housing construction, but also for thermal insulation of industrial equipment and pipelines operating at high temperatures.

**4. Conclusions**

Based on the experimental data obtained, we can draw a conclusion that it is possible to obtain materials with the specified performance such as the heat transfer coefficient and compressive strength by regulating a percentage ratio of components of the thermal insulation composite based on basalt fibers – the saponite-containing material. Additionally, it is possible to increase considerably compressive strength by thermally modifying the studied composite without changing its heat transfer coefficient.

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