

**LIGHTWEIGHT THERMAL INSULATION MATERIALS BASED ON EXPANDED  
VERMICULITE: PHYSICAL AND CHEMICAL PROPERTIES, PRODUCTION  
TECHNOLOGIES**

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**Annotation:** Expanded vermiculite is a natural layered silicate that, due to its high porosity, low density, and low thermal conductivity, is a promising filler for creating lightweight and energy-efficient construction materials. The mineralogical properties of vermiculite, its thermomechanical properties, role in mixtures, the effectiveness of thermal insulation properties, as well as its contribution to the energy efficiency of buildings were studied.

**INTRODUCTION**

The development of new, environmentally friendly, and energy-efficient materials for the construction industry is a global need. Vermiculite, a natural mineral, when expanded, becomes a porous, extremely lightweight filler that conducts heat poorly. This filler is used in various composite materials, including concrete, slabs, and gypsum composites. In recent years, it has been proven that incorporating vermiculite into construction significantly reduces energy loss, improves fire resistance, and reduces the weight of structures. This article examines the scientific basis for this approach.

**Mineral and growth properties of vermiculite.**

Vermiculite is a layered silicate mineral found in nature in an aqueous state. When heated, its water of crystallization evaporates, causing a dramatic expansion of the structure. As a result, the mineral's volume increases 10-20 times. The porosity of exfoliated vermiculite can reach 70-90%.

**Physicochemical properties**

Expanded vermiculite has a very low density (80–190 kg/m<sup>3</sup>). Its thermal conductivity is reported to be in the range of 0.06–0.12 W/m<sup>2</sup>·°C. Vermiculite is also inert, chemically stable, and environmentally safe. Its layered and porous texture is clearly visible when analyzed with a scanning electron microscope.

**Detailed analysis of vermiculite inertness, chemical stability and SEM analysis:**

Vermiculite is a natural mineral, and its inertness, chemical stability, and environmental safety have been confirmed by numerous scientific studies. Below are explanations of these properties, based on precise scientific analysis and scanning electron microscopy (SEM) observations.

**1. Inertness and chemical resistance:** Vermiculite is a hydrated plate silicate that expands at high temperatures and has very low chemical reactivity. It remains stable even when exposed to strong acids and alkalis. Therefore, it is widely used in construction, production of packaging materials, fire-retardant materials and in agriculture.

**2. Environmental safety:** vermiculite, being a natural mineral, has low radioactivity and does not emit toxic substances into the environment. It does not end up in industrial waste that emits harmful gases and dust, so it is used as an environmentally friendly thermal insulation material.

**SEM (Scanning Electron Microscopy) Analysis:** SEM images clearly demonstrate the layered, plate-like structure of vermiculite. Micropores and gaps between the mineral plates dramatically reduce thermal conductivity. The following spatial features are observed in magnified images:

- Vermiculite has a natural lamellar structure, which creates natural barriers to heat flow.
- Micro- and nanopores increase air permeability and improve thermal insulation.

- In exfoliated vermiculite, the distance between the lamellar plates is even greater, significantly increasing porosity.

In conclusion, the SEM analysis results confirm the key factors directly explaining the effectiveness of vermiculite as a thermal insulation material. Its inertness, chemical stability, and environmental safety make it an important raw material for the creation of modern energy-saving materials. Анализы ТГ/ДТА подтверждают его устойчивость к высоким температурам.

**Scientific analysis of vermiculite for inertness, chemical stability and TG/DTA analysis:**

Vermiculite is a natural plate-like silicate mineral, and its inertness, chemical stability, and high-temperature resistance have been thoroughly studied using thermoanalytical methods (TG/DTA). A detailed scientific analysis of these properties is presented below.

**Inertness and chemical resistance:** Vermiculite's crystal lattice is based on magnesium-iron-aluminum silicate. This structure reacts poorly with chemical reagents. Even when briefly exposed to strong acids, the mineral's basic structural elements remain unchanged. This confirms its advantage as a chemically inert substance.

**TG (thermogravimetric analysis)** – Thermogravimetric analysis results: TG analysis shows how vermiculite mass changes with increasing temperature. Typical TG curves show the following stages: • 100–250 °C: Высвобождение поверхностной физически связанной воды (небольшая потеря массы).

- 250–600°C: Gradual release of hydrated water within the structure.
- Above 600°C: The bulk of the mineral structure remains stable, without sudden breakdown or significant mass loss.

These results scientifically confirm that vermiculite is stable at temperatures up to 600–900°C.

**DTA (differential thermal analysis):** The DTA curve displays the endothermic and exothermic processes occurring during heating of the mineral. The following endothermic peaks are observed in vermiculite:

- 120–200 °C: Peak evaporation of surface water.
- 250–350 °C and 450–550 °C: Broad endothermic zones corresponding to the dissociation of interlayer bound hydrated water.
- 700–900 °C: Structural rearrangement processes occur, but the mineral does not completely decompose.

These endothermic peaks confirm that the mineral has stable phase stability even at high temperatures.

**General conclusion based on the results of thermogravimetric and differential thermal analysis:** Thermogravimetric and differential thermal analysis results confirm that vermiculite is a high-temperature, chemically stable, and inert material. The gradual loss of hydration water directly impacts its thermal insulation properties, as increased porosity reduces thermal conductivity.

Therefore, vermiculite serves as an important raw material in the production of high-temperature building materials, fire-resistant boards, blocks, thermal insulation materials and energy-efficient concrete compositions.

**Lightweight concrete with vermiculite based on cement, low water requirement.** The most important parameters of cement-based vermiculite for low-water-demand lightweight concrete are the mixture's density, thermal conductivity, and mechanical strength. Experiments show that the optimal ratio is achieved with a vermiculite content of 20–40%. Due to the porous structure of vermiculite, its water absorption is high. Therefore, it is effectively reinforced with polycarboxylate superplasticizers.

### **Thermal conductivity**

Expanded vermiculite filler creates an energy-efficient microstructure. Thermal conductivity tests show that vermiculite-based lightweight concrete blocks are 3-5 times more effective at insulating than conventional concrete. Furthermore, air voids within the lightweight concrete block impede heat flow.

### **Mechanical properties:**

The compressive strength of vermiculite lightweight concretes based on low-water cement typically ranges from 2–10 MPa, which is sufficient for thermal insulation in most cases. If it is necessary to ensure the load-bearing capacity of the structure, additional reinforcement with fiber, geopolymer binders or polycarboxylate superplasticizers is required.

**Moisture resistance, fire resistance and long-term stability:** One of the natural advantages of expanded vermiculite is its high fire resistance. This mineral retains its structure up to 1300°C. This makes it an ideal lightweight aggregate for the production of fire-resistant concrete blocks. Moisture is a major limitation, so hydrophobization is required. For this purpose, it is advisable to use moisture-repellent additives.

### **Building Energy Efficiency**

Using lightweight, low-water-consumption vermiculite-based concrete in walls can reduce building heat loss by 15–30%. Modeling studies (such as EnergyPlus) show that annual energy consumption can be reduced by 10–12%.

### **Production Technology:**

The production technology for low-water-demand vermiculite lightweight cement-based concrete consists of the following main stages:

- Determining the adequacy of local raw material reserves;
- Crushing and sorting raw materials into specified fractions;
- Firing in special kilns at 800–1000°C;
- Dry mixing of low-water cement with vermiculite;
- dry mixing of low-water cement, vermiculite, and fiber;
- slow mixing of water;
- molding, pressing, or vibration;
- drying under normal conditions;

### **Possibilities of implementation in production:**

Vermiculite-based materials are particularly promising in Uzbekistan, as they provide thermal insulation in hot climates and heat retention in cold ones. With local raw materials available, production can be cost-effective.

### **CONCLUSION.**

Lightweight vermiculite-based composite materials are a promising solution for meeting energy efficiency requirements in construction. Their low density, fire resistance, and good thermal insulation are important advantages. However, further modifications may be required to improve mechanical properties. Industrial implementation requires laboratory testing and a detailed feasibility study.

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