

Research Article

Lightweight Thermal-protective Materials Based on Foamed Vermiculite: Physical and Chemical Properties, Production Technologies

Yusupov Xamid Vaxobovich , Karimov Gafur Umurkulovich ,
Saidmurodova Sarvara Muzaffarovna* 

Department of Civil Engineering, Samarkand State Architecture and Construction University, Samarkand, Uzbekistan

Abstract

Expanded vermiculite is a natural layered silicate material that, due to its high porosity, low bulk density, and low thermal conductivity, is considered a highly promising filler for the production of lightweight and energy-efficient building materials. These unique physical and structural characteristics make vermiculite particularly suitable for applications where thermal insulation, weight reduction, and energy savings are critical requirements. This paper comprehensively examines the mineralogical composition of expanded vermiculite, its thermomechanical behavior under different temperature conditions, and its functional role when incorporated into construction mixtures. Special attention is given to evaluating the effectiveness of vermiculite as a thermal insulation component and its overall contribution to improving the energy efficiency of modern buildings. At the present stage of development, deepening economic reforms in the construction sector of our Republic is of great importance in order to achieve tangible and sustainable results. This requires the implementation of effective measures aimed at increasing economic efficiency, reducing production costs, and ensuring the wide and productive use of local raw materials in the manufacture of energy-efficient construction materials. In addition, the rational and complete recycling of waste generated by various industrial sectors is becoming an essential component of sustainable development in the construction industry. These priorities highlight the need for innovative material solutions that combine technical performance with economic and environmental benefits. One of the most pressing economic and technological challenges today is the production of high-quality building materials using energy-saving, efficient, and resource-conserving technologies during production, development, and continuous improvement processes. In this context, particular attention is paid to the development of ultra-lightweight, energy-efficient, and durable concrete products. One of the key objectives addressed in this study is the production of high-quality concrete blocks based on expanded vermiculite and low-water cement systems. Such materials have the potential to significantly reduce structural weight, enhance thermal performance, and improve overall energy efficiency, while maintaining the required strength and durability characteristics for modern construction applications.

Keywords

Expanded Vermiculite, Lightweight Concrete, Thermal Insulation, Energy-efficient Building Materials, Low Water Demand Cement, Porous Fillers, Thermomechanical Properties

*Correspondence: Saidmurodova Sarvara Muzaffarovna (habibullayevdavron1@gmail.com)

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1. Introduction

Due to the shortage of material and energy resources in the world, many studies are being carried out in the construction industry aimed at the efficient use of local raw materials and industrial waste, as well as the addition of industrial waste and reinforcing fibers to porous and lightweight concrete to improve modern compositions and increase the reliability of thermal properties. Therefore, important tasks include research aimed at increasing the durability, frost resistance, strength, thermal insulation properties and seismic resistance of building materials, reducing their cost and recycling industrial waste [1, 2].

The Republic uses innovative ideas in the development of the building materials sector, and much attention is paid to the improvement and development of the production of building materials with the wide use of natural and local raw materials, their economic efficiency at the current level, ensuring the production of building materials and products with sustainable and environmentally friendly raw materials, as well as the development of the construction industry with the wide use of local raw materials. The New Uzbekistan Development Strategy for 2022–2026 defines current objectives for “doubling the production of building materials.” In implementing these objectives, it is important to develop practical recommendations for improving the physical and mechanical properties of aerated concrete and lightweight concrete produced in Uzbekistan using industrial waste [3, 4].

The development of new, environmentally friendly, and energy-efficient materials for the construction industry is a global challenge. Vermiculite, a natural mineral, expands into a porous, extremely lightweight, and poorly conductive filler. This filler is used in various composite materials, including concrete, slabs, and gypsum composites. In recent years, vermiculite has been shown to significantly reduce energy loss, improve fire resistance, and reduce the weight of structures. This article will explore this scientific basis [5, 6].

2. Materials and Research Results

The objective of the study is to develop the composition and study the properties of lightweight, low-water-consumption vermiculite cement concrete.

Research objectives:

- 1) Development and research of technical properties of high-strength, high-quality, low-water lightweight concrete based on cement with vermiculite [7, 8].
- 2) Study of expansion of the raw material base for the production of expanded vermiculite;
- 3) Development of an optimal composition for producing low-water cement-based vermiculite lightweight concrete;
- 4) Development of an optimal composition for producing low-water cement-based vermiculite lightweight concrete;

- 5) Development of technology for the production of lightweight concrete wall blocks and intermediate wall blocks using expanded vermiculite;
- 6) The aim of the study is to obtain vermiculite lightweight concrete compositions and lightweight wall blocks based on KSTS type cement;
- 7) The subject of the study is the composition and physico-chemical, physicomechanical, technical and economic parameters of vermiculite lightweight concrete on a cement base of the KSTS type, as well as the improvement of the production technology of vermiculite lightweight concrete blocks and products based on them [9, 10].

Research methods: scientific analysis, comparison and generalization of existing scientific and technical literature, regulatory documents, foreign and domestic experience on the research topic, conducting experimental and testing work in laboratory conditions to determine the physical, mechanical and technological properties of cement compositions modified with mineral additives, analysis of the results of experimental and testing work, Based on the test results, methodological recommendations were developed for optimizing effective compositions and their practical application. In the course of the research, standardized methods were used to study the physical, mechanical and operational properties of lightweight concrete with vermiculite based on Low Water Demand Cement, modern physical and chemical analysis, theoretical calculation of thermal properties, analysis of the results of experimental and test work, mathematical modeling, as well as quality indicators and properties [10, 11].

The scientific novelty of the study is as follows:

The mechanism of structure formation as a result of a chemical reaction in a system with a high content of vermiculite, silicon carbide fiber, and calcium nitrate was established – polycarboxylate superplasticizer Glenium C 323 MIX - water, which are components of low-water cement vermiculite lightweight concrete. A process for forming a strong structure in lightweight concrete and a method for its formation for obtaining vermiculite lightweight concrete have been developed, which allows for a significant improvement in its physical and technical properties, quality indicators, durability and operational properties during hardening (No. IAP 7920).

The mechanism of structure formation in lightweight concrete as a result of a chemical reaction in the system of KSTS type cement – expanded vermiculite – superplasticizer has been established – Sand obtained from crushed granite - vermiculite sand - saponified wood pulp - polycarboxylate superplasticizer and water for the preparation of vermiculite lightweight cement-based concrete with low water consumption. A process for high-strength structure formation in lightweight concrete and the formation of its structure under hardening conditions has been developed for the preparation of vermiculite lightweight concrete with physical and technical proper-

ties, quality indicators, heat resistance, durability, and environmental friendliness (No. IAP 8038) [12, 13];

The practical results of the study are as follows:

- 1) Optimal compositions were developed based on a complex of chemical and mineral additives used in expanded vermiculite lightweight concrete technology using KSTK cement with improved performance properties;
- 2) Optimal technological parameters of methods for obtaining vermiculite lightweight concrete based on a complex of chemical and mineral additives used in the technology of expanded vermiculite lightweight concrete based on KSTK cement with improved performance properties have been determined;
- 3) Technical specifications have been developed for the production of efficient building structures and products made from vermiculite lightweight concrete based on a complex of chemical and mineral additives used in the technology of expanded vermiculite lightweight concrete based on cement with improved performance properties [14].

Mineral and growth properties of vermiculite

Vermiculite is a layered silicate mineral found in nature in a hydrous state. When heated, the crystalline water evaporates, causing the structure to expand dramatically. As a result, the mineral's volume increases 10-12 times. The porosity of exfoliated vermiculite can reach 70-90%. (Figure 1).

Vermiculite is a large aggregate belonging to the group of hydromicas (formed during the hydration of phlogopite, as well as in the biotype) and, by chemical composition, classified as an aluminosilicate. It has a layered structure. Vermiculite contains up to 35% silicon, magnesium, calcium, iron, and slightly less (up to 10%) other components. This natural insulating material is characterized by a crystalline and crusty form. However, after processing at high temperatures, it takes the form of twisted threads. If the temperature is raised to 1000 degrees Celsius or higher, a golden-colored exfoliated vermiculite can be produced. In this form, the material is highly hygroscopic (100 grams of vermiculite can absorb up to 395 ml of liquid).



Figure 1. Appearance of expanded vermiculite.

When testing lightweight concrete samples with vermiculite based on low-water-intensity cements, water absorption ranged from 16% to 26%. After 23-25 freeze-thaw cycles, the textured layer retained its integrity. The weight loss of each

sample did not exceed 0.7-2%. Vermiculite concrete is made from expanded vermiculite. Bitumen, cement, molten glass, synthetic resins, and other binders are used. Another feature of the material is its thermal insulation properties:

Vermiculite's density ranges from 80 to 330 kg/m³.

The thermal conductivity coefficient ranges from 0.15 to 0.27 W/m² °C. This value may vary slightly depending on the density of the binder and its fractions, and the thermal conductivity coefficient also varies.

Physicochemical Properties

Expanded vermiculite has a very low density (80–330 kg/m³). Its thermal conductivity, according to available data, ranges from 0.06–0.12 W/m² °C. Vermiculite is also an inert, chemically stable, and environmentally friendly material. Its layered and porous texture is clearly visible when analyzed with a scanning electron microscope.

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

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.

Inertness and chemical stability:

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, packaging, fireproofing materials, and agriculture.

Environmentally friendly: Since vermiculite is a natural mineral, it has low radioactivity and does not release toxic substances into the environment. It does not enter the industrial waste stream that emits harmful gases or dust, so it is used as an environmentally friendly thermal insulation material.

Scanning Electron Microscopy (SEM) Analysis: SEM images clearly show that vermiculite has a layered, plate-like structure. Micropores and gaps between mineral plates cause a sharp decrease in thermal conductivity. The following spatial features are visible in the enlarged images:

- 1) In nature, vermiculite forms a layered (lamellar) structure - a natural barrier that prevents the flow of heat.
- 2) Micro- and nanopores increase the air permeability area and improve thermal insulation.
- 3) In expanded vermiculite, the distance between the plates increases and the porosity increases sharply.

In conclusion, scanning electron microscopy analysis confirms the main factors that directly explain 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.

TG/DTA analyses confirm its resistance to high temperatures [15].

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

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

- 1) Inertness and chemical stability: Vermiculite's crystal lattice is based on Mg-Fe-Al silicates. This structure does not readily react 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.
- 2) TG (thermogravimetric analysis) – Thermogravimetric analysis results: TGA shows how vermiculite mass changes with increasing temperature. Typical TGA curves show the following stages:
 - a) 100–250°C: Release of water physically bound to the surface (small mass loss).
 - b) 250–600°C: Gradual release of hydrated water between structures.
 - c) Above 600°C: The bulk of the mineral structure remains stable, without abrupt disintegration or significant mass loss.

These results provide scientific evidence that vermiculite is stable up to 600–900°C.

- 3) DTA (Differential Thermal Analysis): The DTA curve allows one to determine the endothermic and exothermic processes occurring during heating of a mineral. The following endothermic peaks are observed in vermiculite:
 - a) 120–200°C: Peak evaporation of surface water.
 - b) 250–350°C и 450–550°C: Wide endothermic zones corresponding to the dissociation of interlayer hydrated water.
 - c) 700–900°C: Structural restructuring processes occur, but the mineral does not completely decompose.

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

- 4) General conclusion based on the results of TG/DTA analysis: The TG/DTA results confirm that vermiculite is a heat-resistant, chemically stable, and inert material. The gradual loss of hydration water directly impacts its thermal insulation properties, as increased porosity reduces thermal conductivity [16].

Thus, vermiculite serves as an important raw material in the production of high-temperature building materials, refractory

boards, blocks, thermal insulation materials and energy-efficient concrete compositions.

Lightweight cement-based concrete with vermiculite, requiring minimal water consumption.

The most important parameters in lightweight cement-based concrete with vermiculite, which requires minimal water consumption, are the density of the mixture, thermal conductivity and mechanical strength. Experiments show that the optimal balance is achieved with a vermiculite content of 20–40%. Due to the porous structure of vermiculite, the degree of water absorption is high. Therefore, strengthening with polycarboxylate superplasticizers is effective.

Thermal conductivity

Expanded vermiculite filler creates an energy-efficient microstructure. Thermal conductivity tests show that vermiculite-based lightweight concrete insulation blocks are 3–5 times more efficient than conventional concrete. In addition, air voids inside the lightweight concrete block impede heat transfer [17].



Figure 2. Thermal conductivity coefficient is determined using the ITS-1 device.

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 filler for the production of fire-resistant concrete blocks. Moisture is a major limitation, requiring hydrophobic modification. For this purpose, it is advisable to use moisture-wicking additives.

Mechanical properties:

The compressive strength of lightweight concrete materials based on vermiculite with low water content is typically in the range of 2–10 MPa, which is sufficient for thermal insulation in most cases. If load-bearing capacity is required, additional reinforcement with fibers, geopolymer binders, or polycarboxylate superplasticizers is necessary [18].

Table 1. Presents the compositions of low-water-consumption lightweight concrete based on vermiculite and their compressive strengths.

Raw materials							
			P.C		P	W	R
					F	%	
1	120	100	400	1,0	0,5	0,54	2,55
2	120	100	400	1,0	1,0	0,54	2,90

Raw materials			P.C		P	W	R
3	120	100	400	1,0	1,2	0,54	3,80
4	120	100	400	1,0	1,5	0,54	3,60

Table 2. The composition of lightweight concrete based on Portland cement and vermiculite, as well as its compressive strength.

Raw materials			LWDC		P	W	R
1	120	100	400	1,0	0,5	0,63	1,87
2	120	100	400	1,0	1,0	0,63	2,16
3	120	100	400	1,0	1,2	0,63	2,50
4	120	100	400	1,0	1,5	0,63	2,37

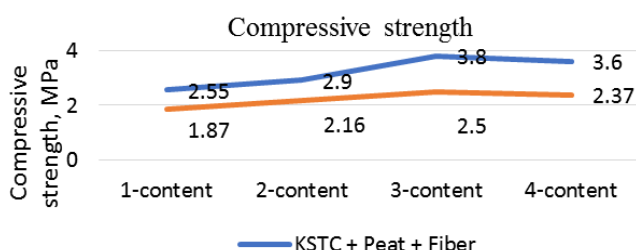


Figure 3. Graph showing the difference between low water vermiculite and portland cement based lightweight concrete formulations and their compressive strengths.

Using lightweight, low-water-content vermiculite-based concrete in walls can reduce building heat loss by 15–30%. Modeling shows a 10–12% reduction in annual energy consumption.

3. Production Technology

The technology for producing lightweight concrete materials based on vermiculite with low water content in cement includes the following main stages:

- 1) Determining the adequacy of local raw material reserves;
- 2) Crushing and sorting raw materials into specified fractions;
- 3) 800-1000°C for maximum baking temperature;
- 4) dry mixing of low-water cement with vermiculite;
- 5) dry mixing of low-water cement, vermiculite, and fiber;
- 6) slow mixing with water;

7) molding, pressing, or vibration;

8) drying under normal conditions;

Possibilities of implementation in production

Lightweight, low-water-consumption vermiculite-based concrete materials are particularly promising in Uzbekistan, as they provide thermal insulation in hot climates and heat retention in cold climates. The local raw material base is sufficient for use in construction, and production is economically viable.

4. Conclusions

Lightweight vermiculite-based concrete materials with low water consumption are a promising solution that meets energy efficiency requirements in construction. Key advantages include their low density, fire resistance, and thermal insulation. Additional modifications are used to improve their mechanical properties. The production of building materials using local raw materials and secondary products from various industries, as well as the creation of new technologies is a relevant, economically and environmentally beneficial direction for the development of the construction industry and the implementation of laws and projects, adopted in this direction. One of the most important tasks of modern housing construction is to reduce energy consumption for the production of building materials while simultaneously improving product quality. Experience in using products and structures made from vermiculite lightweight concrete in construction demonstrates their high economic efficiency.

Abbreviations

TG/DTA	Analyses Confirm Its Resistance to High Temperatures
TG	Thermogravimetric Analysis

Author Contributions

Yusupov Xamid Vaxobovich: Supervision, Project administration, Methodology, Writing – review & editing

Karimov Gafur Umurkulovich: Resources, Investigation, Validation, Writing – review & editing

Saidmurodova Sarvara Muzaffarovna: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



duties.

Yusupov Xamid Vaxobovich is an Uzbek professional known for his dedication to continuous learning and professional development. He has gained experience in his field through academic training and practical work, demonstrating strong analytical thinking and a responsible approach to his



proach to his responsibilities.

Karimov Gafur Umurkulovich is an Uzbek professional recognized for his commitment to continuous professional development and responsible work ethics. He has gained experience through education and practical activities, demonstrating strong analytical thinking and a disciplined approach to his responsibilities.



Saidmurodova Sarvara Muzaffarovna is an Uzbek professional known for her dedication to professional development and continuous learning. She has built her experience through education and practical activities, demonstrating responsibility, accuracy, and a strong work ethic.

Research Field

Yusupov Xamid Vaxobovich: Engineering and Applied Sciences, Structural Engineering, Construction Materials and Technologies, Analysis and Design of Engineering Structures, Innovative and Sustainable Construction Solutions.

Karimov Gafur Umurkulovich: Engineering and Applied Sciences, Structural Analysis and Design, Construction Materials and Technologies, Sustainable and Innovative Engineering Solutions, Safety and Reliability of Engineering Structures.

Saidmurodova Sarvara Muzaffarovna: Engineering and Applied Sciences, Construction Engineering and Management, Building Materials and Technologies, Sustainable Construction and Development, Quality Control and Safety in Construction.