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Investigation of the Environmental Efficiency and Thermal Insulation Properties of the Ak-7 Polymer-Mineral Composite Coating Based on Basalt Fiber and Expanded Vermiculite

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Abstract

This study is devoted to evaluating the functional properties of the Ak-7 polymer-mineral composite coating based on basalt fiber and expanded vermiculite, with the aim of improving the energy efficiency and fire safety of buildings and structures, as well as developing environmentally promising construction materials. The composite formulation consisted of acrylic-styrene copolymer (20.98%), expanded vermiculite (39.73%), calcium carbonate (13.39%), basalt fiber (7.14%), and polyvinyl alcohol (18.76%). The thermophysical properties of the material were evaluated using an XND-2-3030C laboratory apparatus, its mechanical properties were assessed through flexural strength measurements, and its resistance to combustion was determined based on the limiting oxygen index (LOI). According to the experimental results, the thermal conductivity coefficient of the Ak-7 (40%) sample was 0.090575 W/(m·K), which was 39.7% lower than that of the sample containing 30% mineral filler. The flexural strength of the base composition was 9.272 MPa, while its limiting oxygen index reached 38.5%. The porous mineral structure of expanded vermiculite provides significant potential for limiting heat transfer, whereas the reinforcing properties of basalt fiber contribute to maintaining the mechanical integrity of the composite. The thermal stability and potential environmental advantages of basalt fiber compared with certain glass fiber reinforcing materials were evaluated based on scientific literature. The obtained results indicate that the Ak-7 composite coating represents a promising solution for reducing heat loss in buildings, promoting the efficient use of energy resources, and developing multifunctional protective materials aimed at improving fire safety.

Keywords: Environmental protection, basalt fiber, expanded vermiculite, polymer-mineral composite, energy efficiency, thermal insulation, fire safety, limiting oxygen index.

Introduction

Today, the efficient use of energy resources, reduction of atmospheric pollution, and improvement of fire safety in buildings and structures are among the major objectives of environmentally sustainable development in the construction sector[1]. Heat loss in buildings may increase the energy consumption of heating and cooling systems, potentially contributing to higher greenhouse gas emissions. Therefore, the development of environmentally oriented composite materials combining high thermal insulation performance, mechanical strength, and resistance to combustion has become an important scientific and practical challenge.

In recent years, interest has increased in the use of fibers obtained from natural basalt rocks as an alternative to conventional glass fiber reinforcing materials. Basalt fiber is characterized by high mechanical strength, thermal stability, and resistance to certain aggressive environments[2-4]. Scientific studies have reported that basalt fibers may retain their functional properties more effectively under elevated-temperature conditions than certain E-glass fibers[5]. The use of natural mineral raw materials in basalt fiber production offers certain technological advantages[6]. However, its environmental superiority should be assessed by considering manufacturing energy consumption, carbon footprint, and service life[7,8].

Expanded vermiculite is a layered silicate mineral characterized by a porous structure that enables it to limit heat transfer[9]. Its incorporation into polymer compositions can reduce thermal conductivity and improve the thermal properties of the material[10]. Previous studies have demonstrated that vermiculite may positively influence the fire resistance characteristics of acrylic-based protective coatings[11]. The combined application of basalt fiber and vermiculite represents a promising approach to integrating reinforcing and thermal insulation properties within a single composite material.

The limiting oxygen index (LOI) is an important parameter for evaluating the fire performance of polymer-mineral composites, as it characterizes the minimum oxygen concentration required to sustain combustion under standardized laboratory conditions. Furthermore, a comprehensive assessment of the environmental performance of such materials requires life cycle assessment

(LCA), encompassing raw material extraction, manufacturing, service life, and end-of-life disposal stages.

The objective of this study is to experimentally evaluate the thermophysical, mechanical, and combustion resistance properties of the Ak-7 polymer-mineral composite coating developed using an acrylic-styrene copolymer, basalt fiber, and expanded vermiculite. The study analyzes the functional significance of the individual components and investigates the practical potential of the material for reducing heat loss in building structures, improving energy efficiency, and developing protective coatings intended to enhance fire safety. The obtained results provide a scientific basis for developing environmentally promising multifunctional construction materials through optimization of the proportions of mineral fillers and polymer binders.

Materials and Methods

The Ak-7 polymer-mineral composite coating, designed to improve the thermal insulation, mechanical stability, and fire safety of buildings and structures, was investigated in this study. The composite formulation consisted of AK-777 acrylic-styrene copolymer (20.98%), expanded vermiculite (39.73%), calcium carbonate (13.39%), basalt fiber (7.14%), and polyvinyl alcohol (18.76%) by mass.

To determine the thermophysical properties of the material, Ak-7 samples containing 25%, 30%, 35%, and 40% mineral filler, with nominal dimensions of 300×300×50 mm, were tested using an XND-2-3030C laboratory apparatus. The thermal conductivity coefficient (λ) and thermal resistance (R) were evaluated. The theoretical thermal resistance was calculated using the equation $R = \delta/\lambda$.

Preparation of Samples for Thermal Testing: Samples with nominal dimensions of 300×300×50 mm were used to evaluate thermal conductivity. The tests were performed using an XND-2-3030C laboratory apparatus. The source data did not provide information on the moisture content of the samples, drying and conditioning durations, hot and cold surface temperatures during measurements, criteria for achieving steady-state conditions, equipment calibration, or the number of repeated measurements. The absence of these details limits the reproducibility of the measurement results and the assessment of their statistical reliability. Therefore, the reported values were interpreted as preliminary experimental results.

The nominal test surface area was $S = 0.300 \times 0.300 = 0.090$ m², while the sample thickness was $\delta = 0.050$ m. This thickness was used to compare the thermal resistance reported by the apparatus with the calculated resistance. However, information regarding surface irregularities of the composite, sample compression conditions, and the actual measured thickness was not provided. Therefore, the calculated values serve as verification calculations and do not replace the official equipment test report.

The physical and mechanical properties of the composite were investigated using samples containing acrylic–styrene copolymer at mass fractions of 5%, 8%, 10%, 20.98%, and 30%. The evaluation was based on flexural strength, maximum load, and deformation characteristics. The flammability of the material was assessed using the limiting oxygen index (LOI). Standardized methods for determining the limiting oxygen index are described in ISO 4589-2:2017 and ASTM D2863-23[12,13]. The obtained experimental data were comparatively analyzed to investigate the influence of the composite formulation on thermal insulation, mechanical strength, fire safety, and the energy efficiency of buildings.

Results and Discussion

The results of the conducted research demonstrated that the Ak-7 composite coating developed on the basis of an acrylic-styrene copolymer is a promising material combining thermal insulation, mechanical strength, and fire safety-related properties. The incorporation of 39.73% expanded vermiculite, 20.98% acrylic–styrene copolymer, 13.39% calcium carbonate, 7.14% basalt fiber, and 18.76% polyvinyl alcohol contributes to the functional properties of the material.

An important advantage of this formulation lies in the effective combination of mineral and polymer components. In particular, the porous structure of expanded vermiculite may help limit heat transfer, while basalt fibers may contribute to improving the mechanical stability of the composite structure[2,3]. Calcium carbonate acts as a mineral filler and contributes to the formation of the composite structure.

Thus, the developed composite formulation provides a scientific and practical basis for integrating thermal insulation and structural protection functions within a single material.

Table-1: Thermal Conductivity and Thermal Resistance of Ak-7 Composite Samples.

Sample and Application Rate	λ, W/(m·K)	R, m²·K/W
Ak-7 (40%)	0.090575	0.462025
Ak-7 (35%)	0.096921	0.445156
Ak-7 (30%)	0.150195	0.287232
Ak-7 (25%)	0.134406	0.309633

The experimental results presented in Table-1 clearly demonstrated the potential of the Ak-7 coating for thermal insulation applications. Particularly noteworthy is the thermal conductivity coefficient of the sample containing 40% mineral filler, which was 0.090575 W/(m·K).

This value was approximately 39.7% lower than the 0.150195 W/ (m·K) recorded for the sample containing 30% mineral

filler, indicating that heat transfer can be significantly reduced through the targeted optimization of the composite formulation.

Furthermore, the thermal resistance recorded for the 40% sample was 0.462025m²·K/W, representing the highest value among the investigated samples. This indicates the relatively high potential of this formulation to resist heat flow.

From an environmental protection perspective, these findings are of considerable importance. The application of materials with low thermal conductivity in external building envelope structures can reduce the energy demand for heating and cooling. Consequently, reduced energy consumption may contribute to lowering greenhouse gas emissions into the atmosphere, depending on the energy source used[1].

A comparative analysis of the thermal conductivity coefficients and thermal resistance values of Ak-7 composite samples with different formulations revealed significant differences among them. In particular, the differences observed when the mineral filler content increased from 30% to 40% demonstrate the possibility of improving thermal protection properties through targeted optimization of the composite formulation. At the same time, comparison of the results obtained for samples containing 25% and 30% mineral filler indicates that changes in these parameters do not follow a simple linear relationship. From a practical perspective, the application of such low-thermal-conductivity composite coatings to building walls, roof structures, and other building envelope elements may help reduce heat loss.

The environmental significance of these findings lies in their potential to reduce energy consumption in buildings and, depending on the energy source used, decrease greenhouse gas emissions into the atmosphere[1]. The principal scientific finding of the experimental investigations is that the thermal insulation properties of the Ak-7 composite can be improved by selecting an optimal mineral filler content, as demonstrated by the experimental data.

Mechanical Properties: The results presented in Table-2 confirm that the acrylic-styrene copolymer content significantly influenced the flexural strength of the composite coating. In particular, the flexural strength of the sample containing 5% copolymer was 4.481 MPa, whereas increasing the copolymer content to 30% resulted in a flexural strength of 9.790 MPa. Consequently, the mechanical strength increased by a factor of 2.18.

A particularly noteworthy finding is that a flexural strength of 9.272 MPa was achieved at a copolymer content of 20.98%, corresponding to the base Ak-7 formulation. This value represents 94.7% of the maximum measured strength. These results demonstrate that high mechanical performance can be achieved in the developed composite formulation while maintaining a high mass fraction of mineral fillers.

From a practical perspective, this property is important for ensuring the coating's resistance to external mechanical stresses during service. Maintaining the structural integrity of the coating is one of the essential conditions for the continuous performance of the thermal protection layer and for extending its service life.

Table-2: Results Obtained from Composite Samples of the Ak-7 Acrylic–Styrene-Based Coating.

Acrylic–Styrene Copolymer %	Maximum Load at Fracture, N	Flexural Strength, MPa	Displacement at Fracture, mm	Deformation %
30	293.719	9.790	2.2	1.88
20.98	278.177	9.272	2.36	2.18
10	151.105	5.036	3.1	2.78
8	141.816	4.727	3.4	2.82
5	132.184	4.481	3.5	3.24

Significance of the Results Obtained for Fire Safety: Table-3 shows that the limiting oxygen index (LOI) of the Ak-7 composite coating is 38.5%. This result represents an important scientific parameter for evaluating the combustion resistance properties of the composite. Considering that the oxygen concentration in atmospheric air is approximately 20.9%, the determined LOI value indicates that the material requires a higher oxygen concentration than that present in normal atmospheric air to sustain combustion under standardized test conditions.

This finding is particularly promising for improving the fire safety of construction coatings. The incorporation of mineral components such as expanded vermiculite, basalt fiber, and calcium carbonate into the composite formulation is also noteworthy. Their properties under thermal exposure may contribute to the thermal stability of the material.

Thus, the limiting oxygen index of 38.5% represents a positive result, demonstrating the scientific and practical potential of the Ak-7 coating as a material intended to enhance fire safety.

Table-3: Limiting Oxygen Index (LOI) of the Ak-7 Composite.

Composition	Limiting Oxygen Index (LOI), %
Ak-7	38.5

Environmental Protection and Practical Efficiency: The environmental significance of this study lies in the integration of several functional properties within the Ak-7 composite coating. First, the application of a coating with low thermal conductivity offers the potential to reduce heat loss through building

envelopes. This may contribute to the efficient use of energy required for heating and cooling buildings. Second, the incorporation of mineral components enables the combined utilization of the properties of polymeric and mineral materials in the composite formulation. Third, the integration of mechanical strength and resistance to combustion within a single material provides an important scientific basis for the development of multifunctional protective coatings.ISO 14040:2006 and ISO 14044:2006 establish the principles and requirements for life cycle assessment (LCA)[14,15]. However, a comprehensive LCA of the Ak-7 composite coating remains a subject for future research.

The conducted experimental investigations demonstrated the possibility of simultaneously improving the thermophysical, mechanical, and combustion resistance properties of the Ak-7 polymer composite coating. The key positive findings of the study included a reduction in thermal conductivity to 0.090575 W/(m·K), an increase in flexural strength to 9.272 MPa for the base formulation, and a limiting oxygen index of 38.5%. These results substantiate the scientific and practical potential of the Ak-7 composite formulation for developing energy-efficient construction materials and protective coatings aimed at enhancing fire safety.

The principal advantage of this study is the successful integration of mineral and polymer components, enabling the development of essential functional properties, including thermal insulation, mechanical stability, and resistance to combustion, within a single composite material.

Practical Recommendations: Based on the research findings, the Ak-7 polymer-mineral composite coating based on basalt fiber and expanded vermiculite is recommended for use in construction technologies aimed at improving the thermal insulation of buildings, reducing energy consumption, and enhancing fire safety.

The porous structure of expanded vermiculite may help limit heat transfer, while the mechanical and thermal stability of basalt fiber may contribute to improving the functional performance of the protective coating. Basalt fiber is considered an environmentally promising alternative to certain glass fiber materials.

To expand the practical application of the composite, further evaluation of its long-term durability, performance under fire exposure, and environmental efficiency throughout its life cycle is recommended.

Conclusion

The research findings demonstrated that the Ak-7 polymer-mineral composite coating exhibits promising properties in terms of thermal insulation, mechanical strength, and resistance to combustion.

The thermal conductivity coefficient of the Ak-7 (40%) sample was 0.090575 W/(m·K), while the flexural strength of the base formulation reached 9.272 MPa, and the limiting oxygen index was 38.5%.

The porous structure of expanded vermiculite, together with the reinforcing and thermal properties of basalt fiber, plays an important role in determining the functional performance of the material. Basalt fiber may offer advantages in thermal stability compared with certain glass fiber materials.

Overall, the Ak-7 composite represents a promising solution for reducing energy losses in buildings, potentially lowering atmospheric emissions, and developing environmentally efficient construction materials aimed at enhancing fire safety.

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The findings of this study contribute to the development of energy-efficient, environmentally promising, and fire-safety-oriented construction materials.

References

1. United Nations Environment Programme (2026). Global Status Report for Buildings and Construction 2025–2026: Building Fast. Falling Short. UNEP.

2. Fiore V., Scalici T., Di Bella G. and Valenza A. (2015). A review on basalt fibre and its composites. Composites Part B: Engineering, 74, 74–94.

3. Dhand V., Mittal G., Rhee K.Y., Park S.J. and Hui D. (2015). A short review on basalt fiber reinforced polymer composites. Composites Part B: Engineering, 73, 166–180.

4. Chowdhury I.R., Pemberton R. and Summerscales J. (2022). Developments and Industrial Applications of Basalt Fibre Reinforced Composite Materials. *Journal of Composites Science*, 6(12), 367.

5. Farghal H.H. and Madkour T.M. (2026). Basalt Fiber Composites: Structure, Properties, Sustainability, and Life Cycle Analysis. *Journal of Composites Science*, 10(5), 253.

6. Jamshaid H. and Mishra R. (2016). A green material from rock: basalt fiber – a review. *The Journal of the Textile Institute*, 107(7), 923–937.

7. D'Andrea D., Salmeri F., Di Bella G., Totaro M. and Risitano G. (2025). Replacing Glass with Basalt in the Vacuum Infusion Process of Vinyl Ester Composite Laminates: Effect on the Mechanical Performance and Life

Cycle Assessment (LCA). *Journal of Composites Science*, 9(6), 308.

8. Pant M., Negi H. and Sharma S. (2026). Life Cycle Analysis, Cost Analysis, and Sustainability of Basalt Fiber Composites. Advances in Basalt Fibers and Their Composites, ACS Symposium Series, 459–481.

9. Rashad A.M. (2016). Vermiculite as a construction material – A short guide for Civil Engineer. *Construction and Building Materials*, 125, 53–62.

10. Guo L., Wang S., Leng Y. and Yin C. (2025). Water resistance and thermal insulation properties of modified expanded vermiculite composites. *Materials Today Communications*, 42, 111424.

11. Jiang S., Wang J., Wen S., Chen K., Zhou J., Wang H. and Deng X. (2024). The Effect of Expanded Vermiculite on the Fire Resistance of Waterborne Acrylic Coatings. *Polymers*, 16(16), 2302.

12. International Organization for Standardization (2017). Plastics–Determination of burning behaviour by oxygen index–Part 2: Ambient-temperature test. ISO 4589-2:2017.

13. ASTM International (2023). Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index). ASTM D2863-23.

14. International Organization for Standardization (2006). Environmental management–Life cycle assessment–Principles and framework. ISO 14040:2006.

15. International Organization for Standardization (2006). Environmental management – Life cycle assessment–Requirements and guidelines. ISO 14044:2006.