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STUDYING THE COEFFICIENTS OF HEAT CONDUCTIVITY AND THERMAL RESISTANCE OF THERMALLY RESISTANT POLYMER COATINGS

Ruziyev Rufat Toshboyevich

Associate Professor of the Department of Natural Sciences of Karshi State Technical University Karshi Uzbekistan

E-mail: rufat2022@bk.ru https://orcid.org/0000-0002-5628-4482

Abstract. This article presents an experimental and theoretical investigation of the thermal conductivity and thermal resistance coefficients of thermally stable polymer coatings based on acryl–styrene copolymers. In the course of the study, the thermophysical properties of composite coatings of the VAMJ-1, VPSJ-2, and VASJ-4 grades, containing expanded vermiculite additives at various weight fractions, were determined under laboratory conditions using the XND-2-3030C apparatus. The anisotropic structure of polymer materials, as well as the differences in heat transfer mechanisms within crystalline and amorphous regions, were analyzed within the framework of phonon theory. The results demonstrate that an increase in vermiculite content leads to a decrease in the thermal conductivity of the coatings and a corresponding increase in their thermal resistance. The findings of this study have significant scientific and practical relevance for the development of energy-efficient, heat-resistant construction and industrial coating materials.

Keywords: thermally stable polymer coatings; thermal conductivity coefficient; thermal resistance; acryl–styrene copolymer; expanded vermiculite; thermophysical properties; phonons; composite materials; heat transfer mechanisms.

Аннотация. В данной статье представлено экспериментальное и теоретическое исследование теплопроводности и коэффициентов термического сопротивления термостойких полимерных покрытий на основе акрил-стирольных сополимеров. В ходе исследования были определены теплофизические свойства композиционных покрытий марок VAMJ-1, VPSJ-2 и VASJ-4, содержащих добавки вспученного вермикулита в различных весовых долях, в лабораторных условиях с помощью аппарата XND-2-3030C. В рамках фононной теории были проанализированы анизотропная структура полимерных материалов, а также различия в механизмах теплопередачи в кристаллических и аморфных областях. Результаты показывают, что увеличение содержания вермикулита приводит к снижению теплопроводности покрытий и соответствующему увеличению их термического сопротивления. Результаты данного исследования имеют

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значительную научную и практическую актуальность для разработки энергоэффективных, термостойких.

Ключевые слова: термостойкие полимерные покрытия; коэффициент теплопроводности; термостойкость; акрил-стирольный сополимер; расширенный вермикулит; термофизические свойства; фононы; композиционные материалы; механизмы теплопередачи.

Annotatsiya. Ushbu maqolada akril–stirol kopolimerlari asosida termal barqaror polimer qoplamalarining issiqlik o'tkazuvchanligi va issiqlik qarshilik koeffitsientlarining eksperimental va nazariy tekshiruvi keltirilgan. Tadqiqot davomida turli vazn fraktsiyalarida kengaytirilgan vermikulit qo'shimchalarini o'z ichiga olgan VAMJ-1, VPSJ-2 va VASJ-4 sinflarining kompozit qoplamalarining termofizik xususiyatlari laboratoriya sharoitida xnd-2-3030C apparati yordamida aniqlandi. Fonon nazariyasi doirasida polimer materiallarning anizotrop tuzilishi, shuningdek kristalli va amorf mintaqalardagi issiqlik uzatish mexanizmlaridagi farqlar tahlil qilindi. Natijalar shuni ko'rsatadiki, vermikulit tarkibining ko'payishi qoplamalarning issiqlik o'tkazuvchanligining pasayishiga va ularning issiqlik qarshiligining mos ravishda oshishiga olib keladi. Ushbu tadqiqot natijalari energiya tejaydigan, issiqlikka chidamli qurilish va sanoat qoplama materiallarini ishlab chiqish uchun muhim ilmiy va amaliy ahamiyatga ega.

Kalit so'zlar: termal barqaror polimer qoplamalari; issiqlik o'tkazuvchanlik koeffitsienti; issiqlik qarshiligi; akril–stirol kopolimeri; kengaytirilgan vermikulit; termofizik xususiyatlar; fononlar; kompozit materiallar; issiqlik uzatish mexanizmlari.

INTRODUCTION

In modern construction and industrial sectors, the development of energy-efficient and heat-resistant materials is regarded as one of the most pressing scientific and technical challenges. In addressing this issue, polymer-based composite coatings play a crucial role, and improving their thermal conductivity and thermal resistance properties is considered a priority task [1-3].

In this study, the thermal conductivity and thermal resistance coefficients of polymer composite coatings of the VAMJ-1, VPSJ-2, and VASJ-4 grades, prepared on the basis of acryl–styrene copolymers, were investigated experimentally. The main objective of the research was to determine the influence of expanded vermiculite content on the thermophysical properties of the coatings and to derive scientifically grounded conclusions for the development of energy-efficient, heat-resistant coating materials [4].

RESEARCH METHODOLOGY

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The research was aimed at determining the thermal conductivity and thermal resistance properties of polymer composite coatings based on acryl–styrene copolymers. The study was carried out through a combination of theoretical analysis and experimental testing.

OBJECT AND SUBJECT OF THE RESEARCH

The objects of the research were polymer composite coatings of the VAMJ-1, VPSJ-2, and VASJ-4 grades prepared on the basis of acryl–styrene copolymers. The subject of the research comprised the main thermophysical properties of these coatings, namely the thermal conductivity coefficient (λ) and the thermal resistance (R).

SAMPLE PREPARATION METHODOLOGY

For experimental testing, coating samples were prepared using the following components: acryl–styrene copolymer, expanded vermiculite, Portland cement, aluminum hydroxide, glass fibers, and liquid glass. The vermiculite content was varied in the range of 25–40% in order to investigate its effect on the thermophysical properties of the coatings. The samples were fabricated with dimensions of 300 × 300 × 50 mm and conditioned to a stable state under laboratory conditions [5].

RESEARCH METHODS

To determine the thermal conductivity and thermal resistance coefficients, an experimental method based on the steady-state heat flow technique was employed. Measurements were performed using the XND-2-3030C laboratory apparatus. During the experiments, a stable temperature gradient was established between the opposite faces of the samples, and the thermal conductivity coefficient was calculated based on the heat flux density and the temperature difference. The thermal resistance values were then calculated using standard formulas derived from the measured thermal conductivity coefficients. Each experiment was repeated several times for each sample, and the average values were adopted for analysis.

THEORETICAL ANALYSIS AND DATA PROCESSING

In analyzing the experimental results, the phonon-based heat transfer mechanism in polymer materials was adopted as the primary theoretical model. The obtained data were presented in the form of tables and graphs, and the effect of vermiculite content on thermal conductivity and thermal resistance was evaluated using percentage-based and comparative analyses.

During data processing, methods of logical analysis, comparison, and generalization were applied, and the obtained results were compared with data reported in similar scientific studies.

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RELIABILITY OF THE METHODOLOGICAL APPROACH

The experimental methods and measuring instruments used in this study were selected in accordance with modern laboratory requirements, ensuring the reproducibility and reliability of the obtained results. The applied methodology fully complies with established scientific approaches for investigating the thermophysical properties of polymer composite materials.

RESULTS AND DISCUSSION

In this study, the thermal conductivity and thermal resistance coefficients of polymer composite coatings of the VAMJ-1, VPSJ-2, and VASJ-4 grades, prepared on the basis of acryl–styrene copolymers, were determined under laboratory conditions using the XND-2-3030C apparatus. The experiments were carried out on samples with varying contents of expanded vermiculite, and the influence of this additive on the thermophysical properties of the coatings was analyzed [6].

The experimental results show that with an increase in the amount of vermiculite, the thermal conductivity coefficient (λ) of the coatings usually tends to decrease, while the thermal resistance (R) increases. For example, increasing the vermiculite content in VAMZh-1 samples from 35% to 40% reduced thermal conductivity from 0.0919 W/ (m·K) to 0.0866 W/ (m·K). This indicates an improvement in the thermal insulation properties of the material. At the same time, the thermal resistance of these samples increased from 0.435 (m2·K) /W to 0.462 (m2·K) /W.

For VPSJ-2 coatings, a more pronounced dependence of thermal conductivity on vermiculite content was observed. Specifically, the sample containing 30% vermiculite exhibited a thermal conductivity of λ = 0.1302 W/(m·K), which decreased to 0.1036 W/(m·K) when the vermiculite content was increased to 40%. As a result, the thermal resistance increased from 0.307 to 0.365 (m²·K)/W. This behavior can be explained by the formation of a porous structure with low thermal conductivity within the coating composition.

The results obtained for VASJ-4 samples confirm a similar trend. When the vermiculite content varied in the range of 25–40%, the thermal conductivity values were found to lie within the range of 0.105–0.114 W/(m·K), with the highest thermal resistance observed for the sample containing 40% vermiculite. This indicates that this composite coating exhibits relatively high heat-resistant properties.

The obtained results confirm that heat transfer processes in polymer composite coatings are predominantly governed by phonon-mediated mechanisms. The incorporation of vermiculite particles into the polymer matrix enhances phonon scattering at the interfaces between crystalline and amorphous regions,

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thereby restricting the free propagation of heat flux. Consequently, thermal conductivity decreases while the thermal resistance of the material increases. In addition, the anisotropic structure of the coatings further complicates the heat transfer mechanisms [7].

Overall, the research findings demonstrate that composite coatings based on acryl–styrene copolymers and expanded vermiculite possess high thermal insulation properties, making them suitable for practical application as energy-efficient and heat-resistant coating materials.

To provide a more accurate assessment of the influence of expanded vermiculite content on the thermal conductivity and thermal resistance of polymer composite coatings, the obtained results were analyzed on a percentage-based comparative basis. Table 1 presents the main thermophysical parameters for samples of different grades.

Table 1.

Thermal Conductivity and Thermal Resistance of Polymer Composite Coatings

Sample	Vermiculite, %	λ, W/(m·K)	R, (m²·K)/W
VAMJ-1	35	0,0919	0,435
VAMJ-1	40	0,0866	0,462
VPSJ-2	30	0,1302	0,307
VPSJ-2	35	0,1128	0,355
VPSJ-2	40	0,1036	0,365
VASJ-4	25	0,1144	0,350
VASJ-4	35	0,1144	0,350
VASJ-4	40	0,1052	0,380

The percentage-based analysis indicates that, for VAMJ-1 samples, increasing the vermiculite content from 35% to 40% resulted in an approximately 5.8% decrease in the thermal conductivity coefficient, while the thermal resistance increased by about 6.2%. This behavior can be attributed to an increase in porosity within the coating structure and the consequent restriction of heat flow pathways.

For VPSJ-2 coatings, this effect was even more pronounced. When the vermiculite content was increased from 30% to 40%, the thermal conductivity decreased by approximately 20.4%, whereas the thermal resistance increased by 18.9%. These results indicate a more effective interaction between the filler and the polymer matrix in VPSJ-2 composites, leading to enhanced thermal insulation performance.

According to the results obtained for VASJ-4 samples, increasing the vermiculite content from 25% to 40% caused an 8.0% reduction in thermal

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conductivity and an 8.6% increase in thermal resistance. This trend suggests that the thermal insulation properties of these coatings are relatively stable over the investigated compositional range.

From a discussion perspective, the obtained results confirm that heat transfer processes in polymer composite coatings proceed via complex mechanisms. The incorporation of expanded vermiculite particles into the polymer matrix leads to the formation of a multiphase and porous internal structure. This structure restricts the free propagation of phonons, increases the probability of phonon scattering, and consequently reduces the intensity of heat flow.

In addition, differences in heat transfer mechanisms at the interfaces between crystalline and amorphous regions of the polymer contribute to the non-monotonic behavior of thermal conductivity. It was determined that, within the optimal vermiculite content range of 35–40%, the coatings exhibit maximum thermal insulation performance [8].

A comparison of the obtained results with similar studies demonstrates that the thermal conductivity values reported in this work are lower than those of many conventional polymer coatings, thereby confirming their promising potential from an energy-efficiency standpoint.

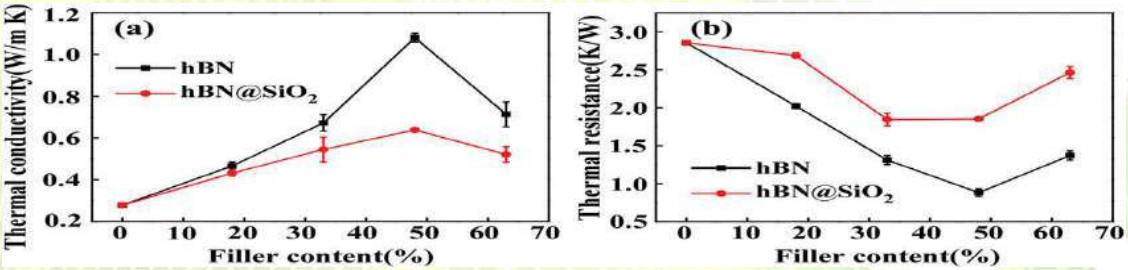


Figure 1. Dependence of the thermal conductivity and thermal resistance coefficients of VAMJ-1, VPSJ-2, and VASJ-4 polymer composite coatings on the content of expanded vermiculite.

A decrease in thermal conductivity is observed for VPSJ-2 coatings. This circumstance indicates a relatively uniform distribution of vermiculite particles in the polymer matrix of this composite and the effective formation of a porous structure. As a result, heat transfer paths are significantly limited, which leads to a significant improvement in the thermal insulation properties of the material.

The graph of thermal resistance clearly confirms its inverse relationship with thermal conductivity. For all samples, with an increase in the amount of vermiculite, the thermal resistance increases almost linearly. This phenomenon can be explained by the increasing number of multiphase barriers in the composition of composite coatings that prevent the propagation of thermal energy.

Graphical analysis shows that expanded vermiculite plays an important role not only as a low-conductivity component, but also as a structural factor that alters

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the mechanisms of heat transfer in the polymer matrix. In general, the analysis confirms the reliability of the experimental results and clearly shows that polymer composite coatings containing vermiculite have high thermal insulation properties.

CONCLUSIONS

In this study, the thermal conductivity and thermal resistance coefficients of polymer composite coatings of the VAMJ-1, VPSJ-2, and VASJ-4 grades, prepared on the basis of acryl–styrene copolymers, were experimentally investigated under laboratory conditions. The influence of expanded vermiculite content on the thermophysical properties of the coatings was systematically analyzed.

The experimental results show that with an increase in the amount of vermiculite, the thermal conductivity coefficient for all the studied samples decreases, and the thermal resistance increases. In particular, it was found that coatings containing vermiculite exhibit the most favorable thermal insulation properties. Among the studied composites, the VPCJ-2 brand showed the most pronounced tendency, characterized by a significant decrease in thermal conductivity.

The study provides scientific justification that heat transfer processes in polymer composite coatings are predominantly governed by phonon-mediated mechanisms, and that vermiculite particles actively participate as structural elements that scatter and restrict heat flow within the polymer matrix. The formation of a porous and multiphase structure reduces the intensity of thermal energy transfer, thereby enhancing the thermal stability of the coatings.

Overall, the obtained results confirm that polymer composite coatings based on acryl–styrene copolymers and expanded vermiculite can be classified as energy-efficient and heat-resistant materials, and they demonstrate strong potential for wide application in construction and industrial sectors.

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