JOURNAL OF MULTIDISCIPLINARY SCIENCES AND INNOVATIONS
GERMAN INTERNATIONAL JOURNALS COMPANY
ISSN: 2751-4390
IMPACT FACTOR (RESEARCH BIB) : 9,08. Academic research index

THERMAL STABLE POLYMER COATINGS AND THEIR APPLICATIONS

Ruziev Rufat Toshboevich

Associate Professor, Karshi State Technical University Karshi Uzbekistan

E-mail: ruziyev.2022@bk.ru tel:+998993315018

Rakhmankulov Alikul Amirkulovich

Professor, Karshi State Technical University Karshi Uzbekistan;

E-mail: raxmankulovalicul@gmail.com

Khaydarov Tuymurod Zoyirovich

Associate Professor, Karshi State Technical University Karshi Uzbekistan;
E-mail: tuymurodxaydarov228@gmail.com

Abstract: The article analyzes the types of modern thermal insulation packages and their operating mechanisms. In particular, the physical properties, active operating principles of radiation, composite, vacuum, transparent and intelligent thermal insulation coatings, as well as the nanomaterials and functional compounds used in them (Fe_2O_3, TiO_2, VO_2, etc.) were studied. Particular emphasis is placed on the release of radiant energy through the infrared "window" of the atmosphere and the role of radiation screens in the effective organization of this process. The energy-saving properties of vacuum and nanoporous coatings, the prospects for using thermochromic, photochromic and electrochromic effects in intelligent coatings are covered.
Keywords: Thermal insulation, radiation coating, transparent coating, vacuum insulation, nanoporous materials, intelligent coating, VO_2, TiO_2, infrared radiation, energy barrier, thermochromism, aerogel, composite coating.

Introduction

Recently, composite materials based on high-molecular compounds have replaced metals, and this field is rapidly improving. Important research is being conducted on their wide-scale application in all areas of the chemical industry. At the same time, the purposeful modification of high-molecular compounds, the study of the composition, physical-mechanical, thermodynamic properties of polymer-bound composites, and their modification in accordance with a predetermined goal remain the main problems of the polymer industry. [1, 2, 3].

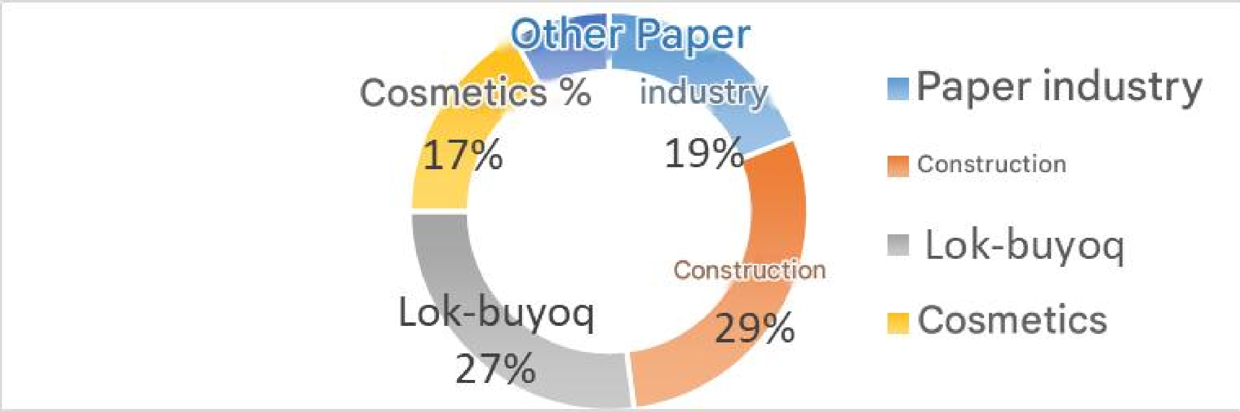

Figure 1. Global application areas of heat-resistant copolymer coatings.

Most of the epoxy composites that were initially developed were designed to operate in the temperature range from -60 to +150oC, and were successfully used mainly in engine mechanism parts. Currently, polymers are being modified to improve the heat-resistant properties of polymeric materials and are being used in all industries (Figure 1) [1, 2, 3]

In this regard, according to industry experts, more than 50% of materials obtained from nature are used to construct various types of buildings and their auxiliary structures, and at least 50% of the energy generated in the world is spent on these buildings and structures [4].

According to the theory of heat transfer, radiation from the sun is mainly received by an object or subject as heat, therefore, when the surface of the object absorbs energy, heat is transferred from the surface to the interior of the object. As a result, the temperature of the object increases accordingly. But if the surface of the object is covered with thermal insulation coatings, most of the additional heat from sunlight will remain in the insulation coatings before passing to the surface of the object (Figure 1). [4].

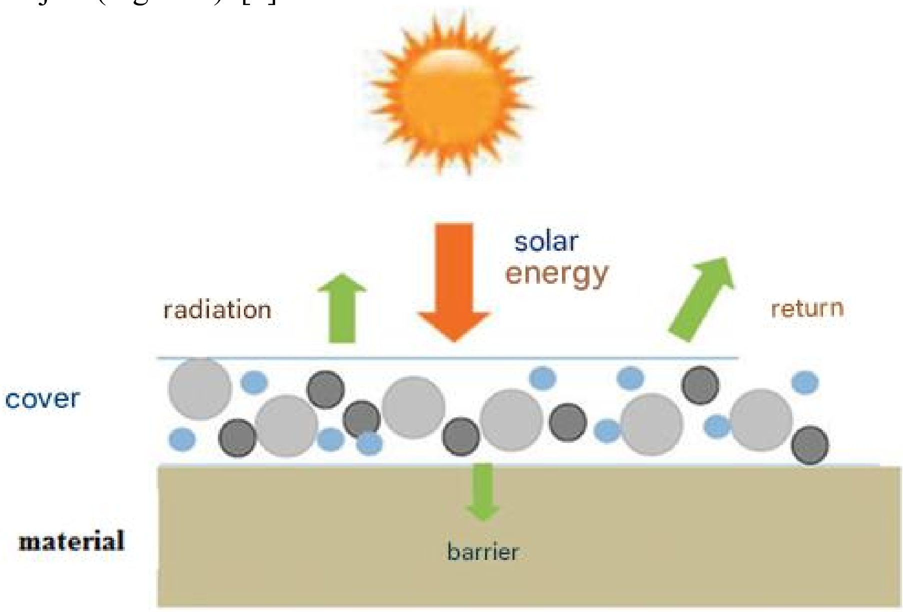

Figure 2. Schematic diagram of the mechanism of thermal insulation between the material and the thermal insulation.

Heat transfer is the result of a combination of thermal conductivity, thermal convection and thermal radiation. Accordingly, there are three types of thermal insulation modules: obstructive, reflective and radiative. Thermal insulation using coatings can be divided into four types: obstructive, reflective, radiative and composite thermal insulation coatings [4].

Research Methods Obstructive thermal insulation coatings. This coating exhibits the characteristics of a passive thermal insulation coating by resisting heat transfer. The composition of this type of coating consists of fillers, additives and solvents. For the heat-resistant performance of the film, not only the thermal conductivity of the coating materials, but also other materials are very important [5, 6].

In general, pigments, coating materials, additives and film-forming materials with low thermal conductivity are selected for the production of obstructive thermal insulation coatings. Among the obtained starting products, coating materials with very low thermal conductivity, called thermal insulation functional coatings, ensure the achievement of excellent thermal insulation performance of the film [5, 6].

With the help of coatings, the low thermal conductivity of the film creates excellent heat resistance indicators. At this point, most of the obstructive thermal insulating coating materials create a general thermal insulation at the expense of the cavity. Materials and substances with a hollow structure, such as inorganic silicate-based materials, asbestos fibers, diatoms, etc., can be included as coating materials. The closely packed hollow particles in these coatings form a gas layer that acts as a barrier to heat and blocks the "thermal bridge" (Figure 2). [5, 6].

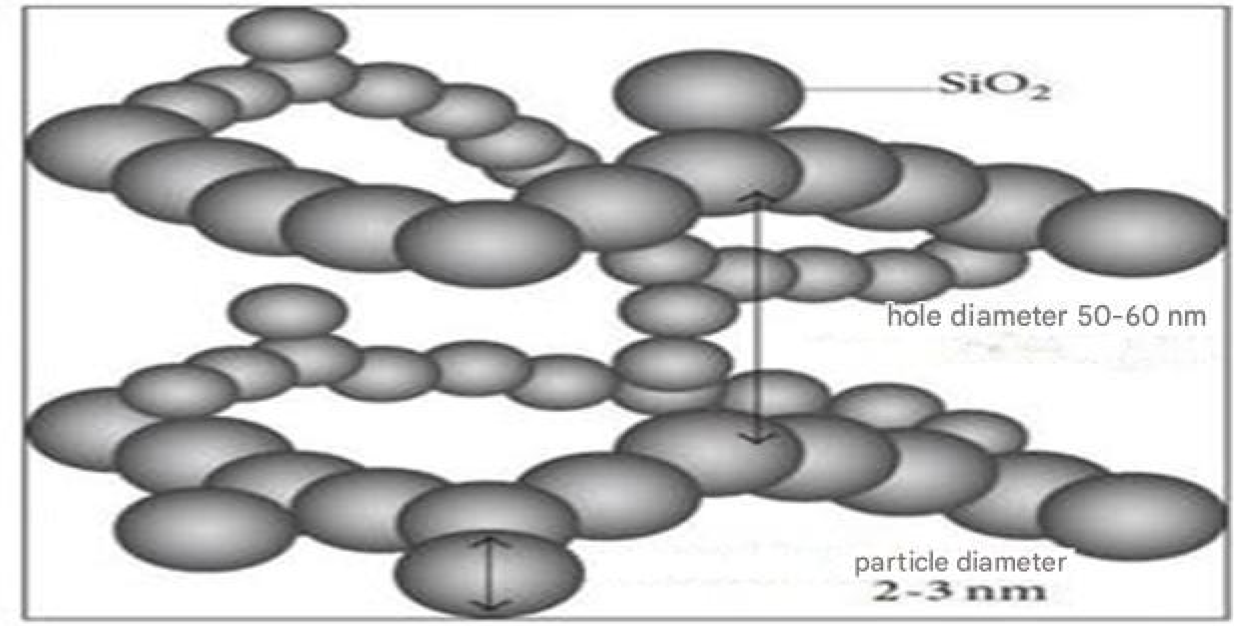

Figure 3. Scheme of the molecular structure of a heat-resistant coating.

The thickness of the film, as indicated in practical applications, always affects its thermal insulation properties. When the coating sample is thick, it reduces the thermal conductivity and ensures the effectiveness of the thermal insulation indicators of the sample. Many studies have been conducted to create samples of heat-insulating obstructive coatings with a thickness of 5-20 mm. At the same time, the thickness of the coating film in the sample also exhibits negative properties, such as poor impact resistance, significant dry shrinkage and high moisture absorption [5, 6].

Reflective thermal insulation coatings. Reflective thermal insulation coatings reflect energy instead of absorbing or resisting it. Typically, energy reflectance is the ratio of the energy reflected by a given material, expressed as a percentage. For example, certain materials absorb 25% of the available energy and reflect 75% of the energy. Theoretically, any material reflects more or less energy. [7, 8].

In general, this type of coating material is characterized by its visible color, and the coating material exhibits a specific color due to its selective reflection and absorption of the visible spectrum. For example, a white coating material reflects almost all of the visible spectrum from 400 to 720 nm. Black, on the other hand, absorbs almost all of the visible spectrum, and red means that the coating mainly reflects the spectrum from 650 to 700 nm, but absorbs other spectra [7, 8].

Accordingly, white is the best color for infrared reflective coatings, because white coatings can reflect almost all the spectrum in the visible range. For example, white titanium-based coatings can reflect more than 75% of the energy. On the contrary, black coatings are hardly suitable for thermal insulation, because they absorb almost all the energy, up to 95-97% [7, 8].

Radiant thermal insulation coatings. Any object exposed to sunlight can simultaneously absorb solar energy. If an object absorbs more energy from the sun than it radiates to the outside, the temperature of the object increases. On the other hand, if an object radiates more energy than it absorbs, the temperature of the object decreases. In this study, radiant energy is emitted in the form of invisible infrared light and electromagnetic waves of longer wavelengths. This radiation, which arises from molecular and atomic thermal motion, is called thermal radiation [9, 10, 11, 12, 13]. Theoretically, thermal radiation exists between any practical object. This means that when any object emits energy to the environment, the environment simultaneously returns energy to the object. Although these two processes always occur simultaneously, the temperature of the object is higher than the environment. If the temperature between the object and the environment is the same, there is no temperature change for the object after thermal radiation. [9, 10, 11, 12, 13].

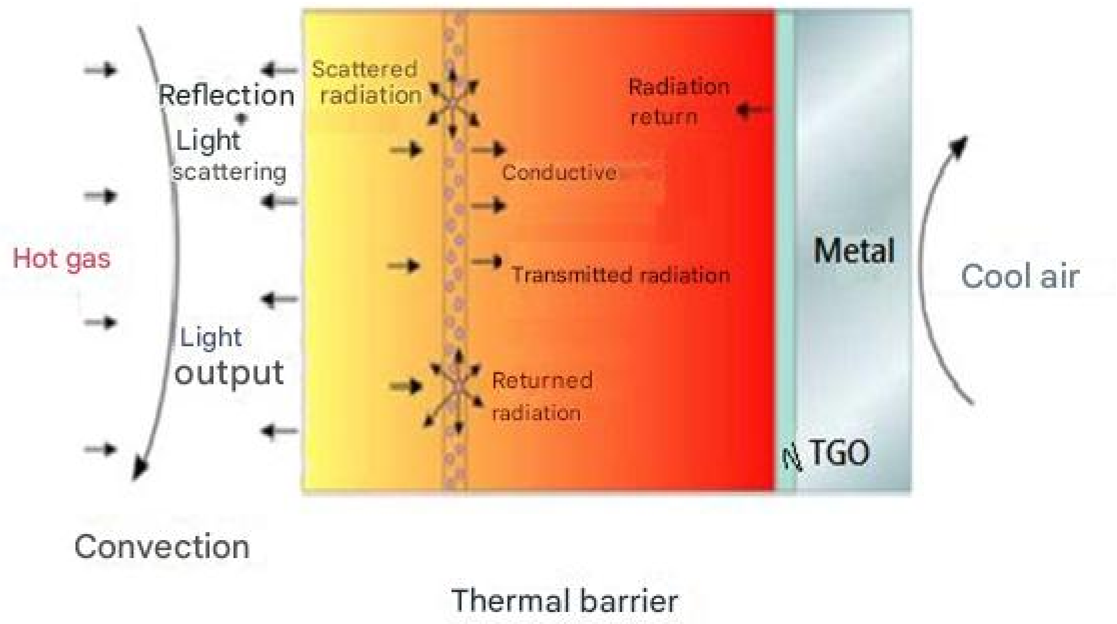

Fig. 4 Thermal barrier protecting against radiation heat

Atmospheric air consists mainly of water vapor and carbon dioxide, these two substances 8-13μm shows a weak dust absorption capacity in the dioxide spectrum. That is, the atmosphere has a high permeability in the range of 8-13 μm. Radiative thermal insulation coatings are systems with special coating materials that can convert the absorbed energy into molecular vibrational and rotational energy [9, 10, 11, 12, 13].

Therefore, the absorbed energy can be transmitted to the external environment in the form of thermal radiation. Accordingly, an object covered with a thermal radiation film emits more energy to the external environment than it absorbs from the sun at a given wavelength [9, 10, 11, 12, 13].

As a result, a radiative thermal insulation film can actively cool the enclosed object. The mechanism of this thermal insulation in radiative coatings is quite different from the obstructive and reflective coatings mentioned above. As with obstructive or reflective coatings, the film can only passively block additional energy, but with a radiative coating, the film can actively radiate additional energy into the environment. Based on the above, radiative coating materials exhibit excellent thermal radiation capabilities when used as a “window” to the Earth’s outer atmosphere. Studies by experts have shown that adding a certain amount of far-infrared coating materials to the coating system can significantly increase the infrared radiation capabilities of the film. In particular, Fe_2O_3, MnO_2, Cr_2O_3, TiO_2, CuO_2, Al_2O_3 compounds are usually used in thermal radiation functional coatings [14, 15, 16].

In short, radiation coating materials are the main factor in achieving perfect thermal radiation, and therefore, the development of new radiation coating materials in recent years has increased the thermal insulation performance of coatings, but the thermal radiation performance of coating materials is affected by many factors such as concentration, diameter size, surface characteristics (roughness/periodicity) of the coating materials. Therefore, the main problem in radiation coatings is that coating materials with stable and perfect thermal insulation performance have high economic performance [14, 15, 16].

Composite thermal insulation coatings. Since the heat transfer of an object is a combination of thermal conductivity, convection and radiation, an ideal thermal insulation coating can resist heat transfer, actively reflect and radiate its energy. Although the above-mentioned obstructive, reflective or radiative thermal insulation coatings have their own advantages in thermal insulation, the thermal insulation performance of only one mechanism cannot meet the comprehensive thermal insulation requirements.

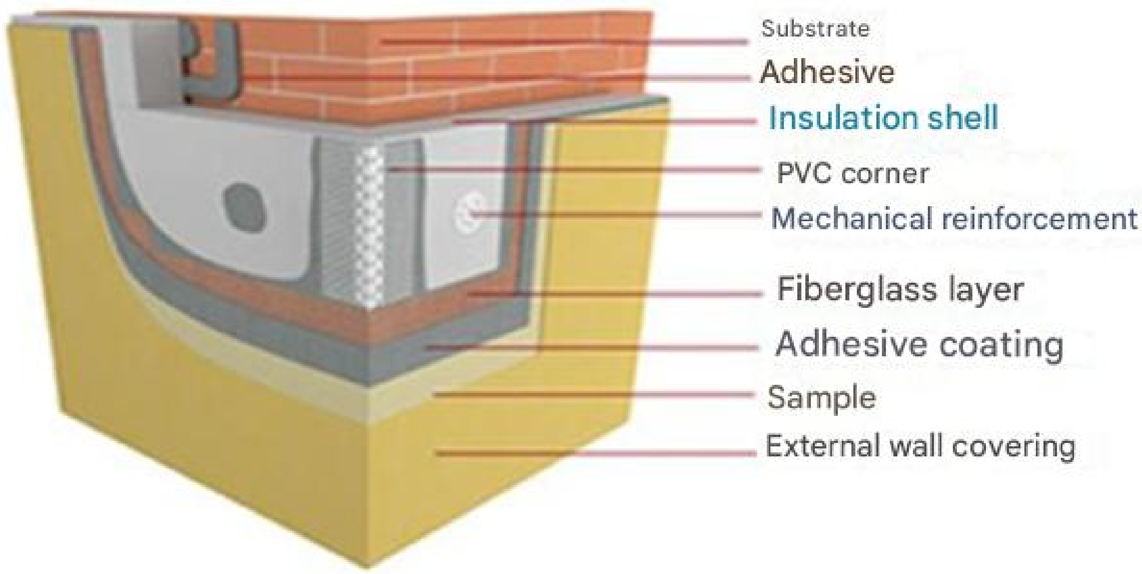

Figure 5. External heat insulation and composite systems

Therefore, in this context, composite thermal insulation coatings are designed to achieve thermal insulation with obstructive, reflective, etc. For example, hollow beads modified with nanotitanium oxide are used as functional fillers; due to the high reflectivity of titanium oxide and the low thermal conductivity of hollow beads at the same time, they exhibit excellent thermal insulation performance.

Research results. Thermal insulation coatings. Transparent thermal insulation coatings for marking can be used for windows, thermal insulation and anti-corrosion coatings for aluminum profiles, etc. Therefore, based on practical application, multifunctional coatings with thermal insulation and other special functions are the development trend of thermal insulation coatings.

Transparent thermal insulation coatings. Transparent thermal insulation coating is transparent in the visible light range with a semiconductor powder. Materials with good transmittance in the visible spectrum and high infrared transmittance can be used as functional coatings. Including antimony oxide (ATO), nano-indium tin oxide (ITO), etc. Therefore, the film with these coating materials can show excellent thermal insulation performance when transparent. Due to the unique size effect, localized field effect, quantum effect and other unique characteristics, nanoparticles can improve both the thermal insulation and anti-aging properties of the film. Transparent thermal insulation coatings can be widely used in glass doors and windows in modern buildings, automobile windows and so on. In fact, transparent thermal insulation coatings can be used on almost any substrate with specific requirements for both conductivity and thermal insulation.

A transparent thermal insulation coating with nano-ATO as a filler was prepared and tested. The results showed that the coatings showed good transparency and thermal insulation performance due to the use of nano-ATO. In addition, the weight of the film is an important indicator for the thermal insulation effect. The test results showed that the transparent thermal insulation coatings had good artificial rapid radiation resistance.

Vacuum thermal insulation coatings. Since the thermal conductivity caused by molecular vibration and convection is completely eliminated in a vacuum, the film can be formed in a vacuum or near-vacuum structure, and the thermal insulation performance of the film will be good. In addition, the data show that the film can achieve thermal insulation of up to 95%. The coatings used in buildings and structures can reduce energy consumption by 30-60%. This means that due to its special structure, vacuum thermal insulation coatings have good thermal insulation and comprehensive performance. And it is one of the most effective energy-saving materials with a promising future.

Nanoporous thermal insulation coatings. As mentioned above, vacuum aerogel shows ideal thermal insulation when used as a coating. However, in many cases, it is not easy to obtain a complete vacuum state. In this situation, researchers have tried to use aerogel as a coating. Aerogel is mainly composed of ultrafine particles and a gaseous dispersion medium. Usually, the particles are filled in the pores of the network structure of the medium. It has been found that aerogels can exhibit very good thermal insulation effects when the pores in the network are less than 50 nm. In fact, the ideal thermal conductivity of the bulk material can even approach zero. Thus, it is possible to obtain a coating with a relatively small thermal conductivity value for the bulk material with static air.
Aerogels are low-density solid materials with nanoporous network structures. The aperture of SiO2 aerogel is about 2-50 nm and the pore size is as high as 99.8%, and the thermal conductivity of SiO2 aerogel is relatively low at room temperature.

Smart thermal insulation coatings. Smart thermal insulation coatings, which can insulate heat when the outside temperature is very high and release heat when the outside temperature is very high, have attracted attention in recent years. Because such coatings have both energy storage and thermal insulation functions. Thermochromic, photochromic, electrochromic and gasochromic films are presented as various types of thermal insulation coatings for energy saving. For example, only by obtaining thermochromic films, thermochromic materials can change their optical properties under the influence of heat. Due to the phase transition, the transmittance and reflectance can change significantly. Metal oxides such as lower oxides of vanadium, titanium, and iron can be used as coatings. With a lower transition temperature and sharp transition characteristics, vanadium dioxide VO2-based smart coatings have attracted great attention in recent years.

Based on the tuning of the coating system, smart thermal insulation coatings are receiving more and more attention from researchers. Therefore, it is one of the urgent tasks to conduct research on the widespread application of smart thermal insulation coatings in the future.

Conclusion

The results of the study indicate that composite coatings that simultaneously use several mechanisms (reflection, absorption, radiation and blocking) are of great importance in achieving high-efficiency thermal insulation. In particular, radiative and smart coatings can be widely used in modern architecture, transport and aerospace industries, since they allow for active control of energy exchange with the external environment. Transparent and vacuum coatings are considered promising solutions for energy-efficient buildings. In the future, by further improving the nanostructural and intellectual properties of these coatings, their performance and economic feasibility can be increased.

References:

1. Alqadi S. et al. Energy demand reduction in two case studies based on the same residential studio: Mediterranean and Hot Climates //WILL CITIES SURVIVE? The future of sustainable buildings and urbanism in the age of emergency. BOOK OF PROCEEDINGS VOL 2 PLEA 2023. – 2023. – T. 2. – C. 802-806.

2. Irshad A. S., Noori A. G. Evaluating the effects of passive cooling and heating techniques on building energy consumption in Kandahar using CLTD method //Materials Today: Proceedings. – 2022. – T. 57. – C. 595-602.

3. Uemoto KL, Sato NMN, John VM. Estimating thermal performance of cool colored paints. Energy and Buildings. 2010;42(1):17-22

4. Bao Y et al. Monodisperse hollow TiO2 spheres for thermal insulation materials: Template-free synthesis, characterization and properties. Ceramics International. 2017;43(12):8596-8602

5. Ozel M. Thermal performance and optimum insulation thickness of building walls with different structure materials. Applied Thermal Engineering. 2011;31(17):3854-3863.

6. Cernuschi F., Bison P. Thirty Years of Thermal Barrier Coatings (TBC), Photothermal and thermographic techniques: Best practices and lessons learned //Journal of Thermal Spray Technology. – 2022. – T. 31. – №. 4. – C. 716-744.

7. Levinson R et al. Methods of creating solar-reflective nonwhite surfaces and their application to residential roofing materials. Solar Energy Materials and Solar Cells. 2007;91(4):304-314.

8. Levinson R, Akbari H, Reilly JC. Cooler tile-roofed buildings with near-infrared-reflective non-white coatings. Building and Environment. 2007;42(7):2591-2605.

9. Zhang H. et al. Ca-Mn co-doping LaCrO3 coating with high emissivity and good mechanical property for enhancing high-temperature radiant heat dissipation //Journal of the European Ceramic Society. – 2022. – T. 42. – №. 15. – C. 7288-7299.

10. Tan W, Petorak CA, Trice RW. Rare-earth modified zirconium diboride high emissivity

coatings for hypersonic applications. Journal of the European Ceramic Society. 2014;34(1):1-11.

11. Azzali N. et al. Spectral emittance of ceramics for high temperature solar receivers //Solar Energy. – 2021. – T. 222. – C. 74-83.

12. Huang J et al. Enhanced spectral emissivity of CeO_2 coating with cauliflower-like microstructure. Applied Surface Science. 2012;259:301-305.

13. Dan Z et al. Microstructure and properties of high emissivity coatings. Journal of University of Science and Technology Beijing, Mineral, Metallurgy, Material. 2008;15(5):627-632.

14. Li H. et al. High temperature conductive stability of indium tin oxide films //Frontiers in Materials. – 2020. – T. 7. – C. 113.

15. Wang X et al. Effect of antimony doped tin oxide on behaviors of waterborne polyurethane acrylate nanocomposite coatings. Surface and Coatings Technology. 2010;205(7):1864-1869.

16. Chen S. et al. Mg_2SiO_4 as a novel thermal barrier coating material for gas turbine applications //Journal of the European Ceramic Society. – 2019. – T. 39. – №. 7. – C. 2397-2408.