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MINI REVIEW

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Coatings: materials and methods

Yuri Evtushenko
Department of Polymer, Institute of Synthetic Polymer Materials, Moscow, Russia

ABSTRACT

The advancement of technology necessitates improved material properties, driving a heightened interest in coatings for diverse purposes such as decoration, heat resistance, erosion and wear protection, and corrosion resistance. Surface modification techniques can be categorized into protective coating formation processes and surface material modification techniques. Protective coatings are applied through methods like electroplating, thermal spraying, immersion in molten metal, and diffusion coating. Electroplating provides corrosion protection, strength enhancement, and aesthetic improvements. Thermal spraying methods range from flame spraying for large surfaces to plasma spraying for refractory ceramic coatings. While immersion in molten metal offers electrochemical protection, it is less economical. Additional methods include thermodiffusion coating, cladding, and polymer protective coatings, which offer corrosion protection and aesthetic appeal through various application techniques. Oxidation processes are utilized for both protection and decoration of metal surfaces, while gumming with rubber or ebonite provides defense against aggressive environments. These methods collectively emphasize the necessity for ongoing innovation and improvement in coating techniques to meet the evolving demands of modern technology and the growing utilization of diverse materials like polymers and composites. This comprehensive review underscores the significance of various coating methods in enhancing material properties and fulfilling technological requirements. It highlights the imperative for further advancements in coating techniques to accommodate the expanding use of alternative materials and to ensure continued progress in meeting the diverse needs of contemporary industries.

KEYWORDS

Coating techniques, Diffusion coating, Material diversity, Thermodiffusion coating, Diffusion coating

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Introduction

The progression of technology demands material enhancements for higher performance. Alloying elements boost strength and hardness, but can increase vulnerability to fracturing, raising costs. As a result, coatings are gaining popularity to combat these issues [1].

Coatings are applied to enhance operational properties based on specific needs. They serve different purposes like decoration, heat resistance, erosion resistance, wear resistance, friction reduction, corrosion resistance, and flame retardation. Each subclassification caters to unique operational requirements, allowing versatile applications in various industries [2].

Decorative coatings enhance visual appeal, while heat-resistant coatings withstand high temperatures. Erosion-resistant coatings protect against abrasive forces, wear-resistant coatings extend component lifespan. Antifriction coatings reduce frictional losses, corrosion-resistant coatings safeguard from degradation. Flame-retardant coatings impede flame propagation and reduce fire hazards [3].

The diverse coatings developed for specific needs are essential in today's engineering and manufacturing. Advancing material performance and function relies heavily on continually improving and refining coatings to meet evolving technological demands [2].

The mini-review identifies coatings as crucial in modern material science, categorizing them based on operational needs like heat resistance, wear resistance, and corrosion protection. Emphasizing their ongoing development, the review highlights coatings' vital role in enhancing material performance and meeting various industrial requirements.

Coating Techniques

All methods of surface modification can be divided into two large groups:

– Processes of formation of protective coatings, which include staining, application of electrolytic coatings, galvanization, deposition of coatings from the gas phase by PVD and CVD methods, laser layering, etc [4].

– Processes related to the modification of the material of existing surfaces. The most advanced techniques in this field include surface hardening using laser technology, electron beams, ion implantation, etc., and classical methods of chemical-thermal surface treatment (nitriding, boration). Methods for obtaining protective coatings on metal products differ in coating technology, and the main purpose of creation is good adhesion to the substrate and obtaining a solid, non-porous, and resistant protective layer in this environment [5].

Currently, the main methods of applying a protective coating are electroplating during electrolysis, gas-thermal spraying or metallization, thermal diffusion saturation in powder, immersion in molten metal, and cladding. According to the type of connection of the protective layer with the

***Correspondence:** Dr. Yuri Evtushenko, Department of Polymer, Institute of Synthetic Polymer Materials , Moscow, 117198, Russia, e-mail: evt-yuri@mail.ru

substrate, adhesive, and diffusion metal coatings are distinguished. Galvanization is an electrochemical method of applying a metal protective coating to protect surfaces from corrosion and oxidation, improve their strength and wear resistance, and give an aesthetic appearance. Electroplating coatings are used in aviation and mechanical engineering, radio engineering, electronics, and construction. Depending on the purpose of specific parts, protective, protective-decorative, and special electroplating coatings are applied to them. Protective ones isolate metal parts from the effects of aggressive media and prevent mechanical damage. Protective and decorative are designed to give the details an aesthetic appearance and protect them from destructive external influences. Special electroplating coatings improve the characteristics of the treated surfaces and increase their strength, wear resistance, electrical insulation properties, etc [3-5].

Flame spraying is the simplest and most inexpensive method used to protect large surface areas from corrosion and restore the geometry of parts. High-speed flame spraying is used to create dense metal-ceramic and metal coatings. Detonation spraying is used to apply protective coatings, restoring small damaged surface areas. Plasma spraying is used to create refractory ceramic coatings. Electric arc metallization is for applying anticorrosive metal coatings on large surface areas [6].

Immersion in the melt is one of the simple methods. The machined parts are dipped into the molten metal (tin, zinc, aluminum, lead). Before immersion, the surfaces are treated with a mixture of ammonium chloride (52-56%), glycerin (5-6%) and chloride of the coated metal. This allows you to protect the melt from oxidation and remove oxide and salt films. This method cannot be considered economical since the applied metal is consumed in large quantities. At the same time, the thickness of the coating is uneven, and it is not possible to apply the melt into narrow gaps and holes, for example, on the thread [7].

Thermodiffusion coating by zinc provides high electrochemical protection of steel and ferrous metals. It has high adhesion, resistance to corrosion, mechanical stress, and deformation. The thermal diffusion coating layer has the same thickness even on parts of complex shapes and does not peel off during operation. The cladding method is the application of metal in a thermomechanical way by plastic deformation and strong compression. Most often, protective, contact, or decorative coatings are created in this way on parts made of steel, aluminum, copper, and their alloys. Cladding is carried out during hot rolling, pressing, extrusion, stamping, or explosion welding [8].

Paint and varnish protective coatings include film-forming substances, fillers, pigments, plasticizers, solvents, and catalysts. Varying the composition makes it possible to obtain materials with specific properties (conductive, decorative, extra-strong, heat-resistant, etc.) and protect products in polymer protective coatings. The group of paint coatings includes varnishes, paints, primers, drying oils, and putties [9].

Emerging Trends in Coating Materials

The most common polymers that protect metals from corrosion include polystyrene, polyethylene, polypropylene, polyisobutylene, fluoroplastics, epoxy resins, etc. The polymer coating is carried out by dipping, gas-thermal, or vortex spraying with a conventional brush. When it cools down, it forms a solid protective film several millimeters thick on the surface. A variety of polymer coatings are antifriction hard-lubricating coatings. Externally, these materials have various conditions, but they also give them an aesthetic appearance [4-7].

Oxidation is a redox reaction of metals due to their interaction with oxygen, electrolyte, or special acid-base compositions. As a result of this process, a protective film is formed on metal surfaces, which increases their hardness, reduces the risk of scuffing, improves the running-in of parts, and increases their service life. Oxidation is used to obtain protective and decorative coatings and to form dielectric layers. This treatment has a chemical, anodic (electrochemical), thermal, plasma, and laser methods [8,9]. Gumming, or the creation of protective coatings made of rubber or ebonite, helps to protect pipelines, chemical apparatuses, and tanks for transporting and storing chemicals from the effects of aggressive environments. The protective coating can be formed from soft or hard rubber. The consistency is controlled by sulfur additives, in which soft contains 2 to 4% of this substance and hard contains 30 to 50% [10].

Future Innovations

Future innovations in protective coatings are poised to revolutionize various industries by harnessing the power of cutting-edge technologies such as nanomaterials and smart coatings. These advancements are geared towards enhancing performance, sustainability, and compatibility with emerging technologies [11-14].

Nanomaterials represent a promising frontier in protective coating development. By leveraging the unique properties of nanoparticles, such as their high surface area-to-volume ratio and exceptional mechanical strength, researchers are exploring novel formulations that offer superior protection against corrosion, wear, and other environmental hazards. Nanocoatings can provide ultra-thin yet robust layers of protection, enabling lightweight and efficient solutions for a wide range of applications, from aerospace to biomedical devices [15].

Smart coatings, equipped with responsive functionalities, are another area of intense research and development. These coatings possess the ability to adapt to changing environmental conditions, self-heal damage, or even provide real-time monitoring of structural integrity. By incorporating sensors, actuators, and other intelligent components, smart coatings offer unprecedented levels of performance and functionality, paving the way for safer, more resilient materials in critical applications such as infrastructure, transportation, and renewable energy [16].

Challenges and Conclusions

Balancing cost-effectiveness with performance and addressing environmental concerns remains a paramount challenge in the realm of protective coatings. While advancements have been made, achieving an optimal equilibrium between these factors is an ongoing endeavor. The pressure to minimize costs often conflicts with the need to maintain high performance standards, leading to a delicate balancing act for industries reliant on protective coatings. Additionally, growing environmental awareness necessitates

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the development of eco-friendly coating solutions that mitigate harmful impacts on the planet [14].

One persistent challenge is achieving uniform coating thickness, especially in complex geometries. Despite technological advancements, ensuring consistent coverage across intricate surfaces remains elusive. This issue poses significant hurdles in industries such as aerospace, automotive, and electronics, where precise coating application is essential for optimal performance and durability [17].

Protective coatings continue to play a vital role in advancing modern technology by enhancing material properties. From electroplating to plasma spraying, various coating methods cater to diverse applications across industries. However, there is still room for improvement and innovation in these techniques to address emerging needs and challenges [18].

Looking ahead, continued innovation in coatings will be essential for driving progress and equipping materials to meet future challenges. Research efforts are focusing on developing novel coating materials with enhanced properties such as durability, corrosion resistance, and thermal stability. Moreover, there is a growing emphasis on the development of sustainable coating solutions that reduce environmental impact without compromising performance [19].

In conclusion, while challenges persist in the realm of protective coatings, ongoing innovation and research efforts hold the promise of overcoming these obstacles. By addressing issues such as cost-effectiveness, uniform coating thickness, and environmental concerns, the coatings industry is poised to make significant strides in advancing modern technology and meeting the evolving needs of various industries.

Disclosure statement

No potential conflict of interest was reported by the author.

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