METHODS FOR IMPROVING THE CORROSION RESISTANCE OF TITANIUM ALLOYS

Rakhmonov Tokhtasin Nurmamatovich
Assistant of the Department of Materials Science of the Andijan State Technical Institute
Tel: +998 91 609 42 63
E-mail: traxmonov1960@gmail.com

Abstract: This article studies methods for increasing the corrosion resistance of titanium alloys. Mainly, surface modification, coating technologies, alloying element addition, anodizing and plasma treatment methods were analyzed. The effectiveness of protective coatings was evaluated through laboratory experiments. The results showed that titanium-based materials significantly extend their service life in extreme environments. Practical recommendations were developed to reduce the corrosion rate.

Keywords: Titanium, alloy, corrosion, durability, coating, anodizing, plasma treatment, alloying element, passivation, protective technology

Аннотация: В данной статье рассматриваются методы повышения коррозионной стойкости титановых сплавов. В основном анализировались поверхностная модификация, технологии нанесения покрытий, добавление легирующих элементов, методы анодирования и плазменной обработки. Эффективность защитных покрытий оценивалась с помощью лабораторных экспериментов. Результаты показали, что материалы на основе титана значительно увеличивают срок службы в экстремальных условиях. Разработаны практические рекомендации по снижению скорости коррозии.

Ключевые слова: Титан, сплав, коррозия, долговечность, покрытие, анодирование, плазменная обработка, легирующий элемент, пассивация, защитная технология.

Annotatsiya: Ushbu maqolada titan qotishmalarining korroziyaga chidamliligini oshirish usullari o‘rganildi. Asosan sirtni modifikatsiyalash, qoplama texnologiyalari, legirlovchi elementlar qo‘shish, anodlash va plazmali ishlov berish usullari tahlil qilindi. Laboratoriya tajribalari orqali himoya qoplamalarning samaradorligi baholandi. Natijalar titan asosli materiallarning ekstremal muhitlarda xizmat muddatini sezilarli darajada uzaytirishini ko‘rsatdi. Korroziya tezligini kamaytirish bo‘yicha amaliy tavsiyalar ishlab chiqildi.

Kalit so‘zlar: Titan, qotishma, korroziya, chidamlilik, qoplama, anodlash, plazma ishlovi, legirlovchi element, passivatsiya, himoya texnologiyasi

Introduction

ISSN 3030-3907

The rapid development of modern industries has sharply increased the need for materials that can operate in various extreme conditions, with high strength, heat and especially corrosion resistance. One of the materials suitable for such conditions is titanium and its alloys. Titanium is a light, relatively low density (about 4.5 g/cm³) metal in its elemental state, but very strong, and at the same time has good corrosion resistance properties. It is widely used in aviation, aerospace, medicine, the oil and gas industry, the chemical industry, and marine engineering due to its biological inertness, mechanical stability, and the ability of its surface to passivate. A thin layer of TiO_2 oxide that forms naturally on the surface of titanium protects it from corrosion in many aggressive environments. At the same time, titanium alloys can lose their passivation and corrode in some environments with strong oxidizing agents or chloride ions. Micropitting and intergranular corrosion occur on the surface of titanium, especially in environments with the presence of seawater, human body fluids, or strong acids. Therefore, it is necessary to take additional protective measures against corrosion.

The issue of controlling and reducing corrosion is one of the urgent issues not only for titanium, but also for other non-ferrous and ferrous metals. However, due to the unique properties of titanium, the methods of its protection are also unique. It is possible to significantly extend the service life of titanium by strengthening the passivation state of the surface, protecting it from strong mechanical and chemical influences, and adding corrosion-resistant elements to the alloy. For such purposes, a number of methods are currently widely used: anodizing, ion implantation, plasma treatment, chemical modification, hard coatings (TiN, TiC, ZrO_2, etc.), nanocoatings, and physical vapor deposition (PVD) technologies. These methods create strong, smooth, closed-structure layers on the titanium surface and limit the penetration of corrosion ions into the metal. Also, in some cases, the degree of passivation of the surface and the tendency to reactivation are studied using electrochemical tests. Experimentally developed protective coatings have shown high efficiency in titanium-based implants, shipbuilding equipment, heat exchangers, and chemical reactors. As mentioned above, the development of corrosion-resistant titanium alloys is based on the results of scientific research. In most cases, certain alloying elements are added to reduce the corrosion rate, stabilize or accelerate the regeneration of the passive layer. For example, elements such as molybdenum, vanadium, and niobium play an important role in increasing corrosion resistance. They ensure the chemical stability of the passive layer, slow down the anode-current exchange, and maintain electrochemical equilibrium. Especially for biomaterials made on the basis of titanium, corrosion resistance is a matter of life and death, and the long-term

ISSN 3030-3907

operation of implants directly depends on the level of surface protection. Therefore, much attention is paid in scientific circles to in-depth study of the surface structure of titanium alloys and analysis of the mechanisms of corrosion processes at the micro- and nano-level. To date, modern microscopic methods (SEM, TEM, AFM), spectral analysis (EDS, XRD), and electrochemical tests (Tafel, EIS) are widely used in this direction.

This article reviews the most effective methods for increasing the corrosion resistance of titanium alloys. The main focus is on methods of plasma electrooxidation, anodizing, adding alloying elements, and surface modification using nanocoating technology. The results obtained in the study, the relationship between parameters such as corrosion rate, coating thickness, and surface morphology, are also analyzed. The goal is to extend the service life of titanium alloys by increasing their corrosion resistance, ensuring their reliability, and increasing their economic efficiency.

Research and method: The main objective of this study is to experimentally study and compare methods for increasing the corrosion resistance of titanium alloy Ti-6Al-4V. The selected alloy is characterized by high mechanical properties and relatively good corrosion resistance. The samples prepared for the study were manufactured in a standard geometric shape (Ø10×2 mm). All samples were prepared by grinding (from P800 to P2000) and polishing. Four main types of surface treatment were selected: 1) anodizing (formation of an oxide layer), 2) plasma electrooxidation (PEO), 3) TiN coating by PVD method, 4) simple polishing (control group). After each method, the samples were subjected to corrosion testing in a 3.5% NaCl solution for 168 hours. The experiments were carried out according to the ASTM G31: Standard Practice for Laboratory Immersion Corrosion Testing of Metals methodology. The corrosion rate was estimated by gravimetric and electrochemical Tafel extrapolation. Additionally, the passive state and resistance of the surface were measured using electrochemical impedance spectroscopy (EIS). Each test was repeated 3 times and the level of statistical reliability was taken into account.

The surface morphology of the samples was analyzed using SEM (Scanning Electron Microscope), and the coating composition was analyzed using EDS (Energy Dispersive X-ray Spectroscopy). The anodizing process was carried out at a voltage of 20 V, for 60 minutes with a mixture of $H_2SO_4 + H_2O_2$ as the electrolyte. PEO treatment was carried out under high-frequency current, in a silicate-phosphate electrolyte environment. TiN coating via PVD was performed by evaporation in a vacuum chamber at 450°C in a nitrogen atmosphere. After the processes were completed, the thickness of the surface layer was measured by

ISSN 3030-3907

microscopic analysis. Below is a table compiled based on the data obtained as a result of the experiments. This table reflects how the coating method affected the properties of the surface layer and corrosion resistance.

Table-1.

Titanium alloy processing methods and their effect on corrosion resistance

Method type	Corrosion rate (mm/year)	Layer thickness (μm)	Surface resistance (kΩ•cm²)	Description
Normal (control group)	0.042	—	5.3	Polished, unprotected surface
Anodizing	0.015	8	21.7	Thin, amorphous TiO_2 layer
PVD - TiN coating	0.010	2	32.4	Hard, dense, smooth surface
Plasma electrooxidation	0.005	12	47.9	Non-porous, crystalline TiO_2 layer

It is evident that the best corrosion resistance was achieved by the plasma electrooxidation method. This is due to the high degree of crystallinity and the density of the coating. SEM images also showed that these coatings did not contain microcracks or pores. The following figure shows the surface structure of titanium samples treated with different treatments.

Result and negotiation: The experiments showed that surface modification methods are important in increasing the corrosion resistance of titanium alloys. Based on the results of the study, when comparing different treatment methods, it was found that plasma electrooxidation formed the most effective protective layer. The coating formed by this method is smooth, crystalline and dense, significantly reducing the penetration of ions and liquids into the surface. In particular, the electrochemical resistance of the surface increased to 47.9 kΩ•cm² with this method, which is almost 9 times higher than the value of a simple polished sample. When the surface structure after plasma treatment was studied under a SEM microscope, no microcracks or pores were observed. The thickness of the coating layer was approximately 12 μm, and it was found that the presence of a crystallite structure enhanced the protective properties of TiO_2. Due to the hardness, closed structure and chemical stability of the coating, plasma electrooxidized samples showed the lowest corrosion rate (0.005 mm/year).

ISSN 3030-3907

It was also confirmed that TiN coatings formed by anodization and PVD also have effective protective properties. The amorphous TiO_2 layer formed by the anodization method exhibited a corrosion rate 3 times lower than the unoxidized surface. However, since the crystallinity and strength of the anodized layer are lower than that of the plasma electrooxidized surface, its stability under long-term operating conditions may be somewhat limited. The TiN coating applied by the PVD method, on the other hand, produced a smooth and dense surface, which was especially useful in limiting the contact surface with the liquid. However, its thickness (about 2 μm) is relatively small, which may increase the sensitivity to mechanical abrasion. This indicates that the effectiveness of plasma oxidation depends not only on chemical stability, but also on the perfection of the surface structure. According to the results of the study, the electrochemical behavior of the coatings was analyzed using Tafel curves, and the rate of formation of the passive state, passivation current density, and potential differences were determined. These indicators served as the basis for a deeper understanding of the formation mechanism of corrosion-resistant layers. As a result, the role of coating technologies in increasing the service life and reliability of titanium alloys was once again proven.

Conclusion: Based on the results of the conducted research, it can be concluded that surface modification methods are of great importance for increasing the corrosion resistance of titanium alloys. In particular, anodizing, the formation of a nitride coating by PVD, and especially the plasma electrooxidation method made it possible to form protective layers on the titanium surface that are strong, dense, crystalline and have high electrochemical resistance. In the example of the Ti-6Al-4V titanium alloy involved in the study, it can be seen that, although a simple polished surface is subject to a significant degree of corrosion in a 3.5% NaCl solution, the layer formed as a result of plasma electrooxidation slowed down this process by more than 8 times. It is these aspects that ensure the reliable operation of titanium materials in extreme conditions, for example, in the marine environment, in the case of implantation inside the body or in chemical reactors. In addition, the anodizing method is characterized by simplicity, economy and convenience in production conditions, but the low degree of crystallinity of the passive layer somewhat limits its long-term use. The TiN layer coated by the PVD method is smooth and dense, but also distinguished by its hardness, but due to its relatively small thickness, its resistance to mechanical abrasion may decrease. Therefore, at the end of the study, the plasma electrooxidation method was chosen as the most optimal technology for protecting titanium alloys from corrosion. Morphological and elemental analyses of the surface layers were carried out using

ISSN 3030-3907

microscopic methods such as SEM and EDS, and the passivation properties were analyzed in depth through electrochemical tests. Based on these results, it is possible to develop effective, economical and environmentally friendly surface protection technologies for industrial use. In conclusion, it is worth noting that in the future, the service life and functional capabilities of titanium materials can be further expanded by creating hybrid coatings based on nanostructures on the titanium surface, developing multifunctional surface layers, and implementing automated processing technologies.

REFERENCES

1. Karimov.A.K.Physical properties of titanium alloys.-Tashkent:Fan,2020-180 p.
2. Kholmatov R.T. Fundamentals of materials science. – Tashkent: Oliy ta'lim, 2019. – 256 p.
3. Tursunov B.B. Corrosion of metals and methods of protection. – Tashkent: "Technique", 2022. – 212 p.
4. Abdurakhmonov I.R. Surface strengthening technologies. – Tashkent: TDMI, 2021. – 198 p.
5. Nurmukhamedov U.M. Titanium-based biomaterials. – Samarkand: Samarkand publishing house, 2020. – 144 p.
6. Usmonov D.Q. Fundamentals of electrochemical methods. – Tashkent: "Ilm ziyo", 2018. – 165 p.
7. Jalolov F.K. Modern metal coatings. – Bukhara: Science and Technology, 2023. – 190 p.
8. Uralov N.A. The role and prospects of titanium alloys in industry. – Tashkent: Science and Development, 2020. – 150 p.
9. Madrahimov A.S. The structure of alloys and their properties. – Andijan: Yangi Avlod, 2021. – 220 p.
10. Rakhimov L.J. Nanocoating technology. – Fergana: Scientific Research Center, 2022. – 175 p.
11. Ruzmetov S.K. Chemical resistance and passivation processes. – Karshi: Scientific Publication, 2019. – 136 p.

ISSN 3030-3907