Original Research Article

The effect of chemical oxidation treatment on the corrosion resistance of metal materials

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Abstract: In the wide application of metal materials, corrosion resistance is an important indicator for evaluating their performance, which directly affects the service life, safety, and economy of the material. Chemical oxidation treatment, as a key means of surface modification of metal materials, can improve their corrosion resistance by forming an oxide film layer on the metal surface. This article summarizes the basic principles of chemical oxidation treatment, the changes in corrosion resistance of different types of metal materials after chemical oxidation treatment, and the key factors affecting the corrosion resistance of chemical oxidation film layers. Finally, effective methods to improve the corrosion resistance of chemical oxidation film layers are discussed.

Keywords: Chemical oxidation treatment; Metallic materials; Corrosion resistance

1. Introduction

Metal materials are widely used in various fields due to their excellent conductivity, thermal conductivity, mechanical properties, etc. However, metals are prone to oxidation and corrosion in the atmosphere, water, or other corrosive media, seriously affecting their service life and performance. Chemical oxidation treatment, as an effective surface modification technique, improves the corrosion resistance of metals by generating a dense oxide film layer on the metal surface. Therefore, it is necessary to explore the mechanism of the influence of chemical oxidation treatment on the corrosion resistance of metal materials and create effective methods to improve the corrosion resistance of chemical oxidation film layers.

2. Basic principles of chemical oxidation treatment

Chemical oxidation treatment, as an efficient and multifunctional chemical process, is based on the basic principle of using strong oxidants to react with target substances, promoting their oxidation and changing their chemical structure and properties. This process involves the transfer of electrons, where the oxidant acquires electrons from the target substance and reduces itself, while the target substance is oxidized to a higher valence state. Common oxidants such as potassium permanganate, hydrogen peroxide, ozone, etc. all have strong oxidation capabilities and can effectively oxidize substances of different properties. During the reaction process, factors such as temperature, pressure, reaction time, and catalyst can all affect the oxidation efficiency and rate. Chemical oxidation treatment technology is widely used in fields such as environmental remediation, material modification, and organic synthesis. In the environmental field, it is used to treat harmful substances in wastewater and exhaust gas, converting them into harmless or low toxicity substances; In materials science, oxidation treatment can improve the surface properties of materials, such as enhancing wear resistance, corrosion resistance, etc. In short, chemical oxidation treatment plays an irreplaceable role in the development of modern technology due to its unique chemical principles and wide application prospects.

3. Corrosion resistance changes of different metal materials after chemical oxidation treatment

3.1. Aluminum alloy

Aluminum alloy has the characteristics of low density and high strength, and its processing performance is good. It is widely used in aerospace, automotive and other fields. However, the natural oxide layer of aluminum alloy has limited protective ability and is susceptible to environmental corrosion. Chemical oxidation treatment, such as Alodin 1200S oxidation, can form an amorphous oxide and chromate protective layer on the surface of aluminum alloy, which can significantly improve its corrosion resistance. Research has shown that by optimizing process parameters such as pretreatment, chemical oxidation time, and bath temperature, the corrosion resistance of the oxide film layer on Aluoding 1200S can be further improved.

3.2. Titanium alloy

Titanium alloys are widely used in aerospace, chemical, and biomedical fields due to their excellent specific strength, corrosion resistance, and high-temperature performance. However, a dense natural oxide film is easily formed on the surface of titanium alloys, which affects subsequent surface treatments such as chemical plating and electroplating. Micro arc oxidation treatment is an effective way to improve the corrosion resistance and wear resistance of titanium alloy surfaces. This technology forms a thick and dense oxide ceramic film on the surface of titanium alloy through high-voltage discharge, which can significantly enhance its corrosion resistance, wear resistance and other properties.

3.3. Magnesium alloy

Although magnesium alloys have advantages such as light weight, high strength, and good electromagnetic shielding performance, their poor corrosion resistance limits their widespread application. Chemical oxidation treatment is one of the effective methods to improve the corrosion resistance of magnesium alloys. However, the chemical conversion coating of magnesium alloys is usually thin and brittle, prone to pore formation, which affects their corrosion resistance. Anodizing treatment can generate a thick and stable oxide film on the surface of magnesium alloy, significantly improving its wear resistance and corrosion resistance.

4. Key factors affecting the corrosion resistance of chemical oxide coatings

4.1. Types and concentrations of oxidants

The selection and concentration of oxidants are the primary factors affecting the corrosion resistance of chemical oxide coatings. Different types of oxidants have different oxidation abilities and reaction mechanisms, and can form oxide films with different compositions, structures, and properties on metal surfaces. For example, chromate oxidation treatment can form a dense chromium oxide film on the surface of aluminum alloys, while potassium permanganate oxidation is more suitable for copper and its alloys. In addition, the concentration of the oxidant directly determines the rate of oxidation reaction and the thickness of the oxide film. When the concentration is too low, the oxide film may not be fully formed or the thickness may be insufficient, making it difficult to provide effective corrosion protection; If the concentration is too high, it may cause the oxide film to become rough, porous, or crack, which in turn reduces the corrosion resistance.

4.2. Processing conditions

The processing conditions, including processing temperature, time, pH value, and stirring intensity, have a significant impact on the corrosion resistance of the chemical oxide film layer. The processing temperature is a key factor affecting the oxidation reaction rate and film quality. Appropriately increasing the processing temperature can accelerate the oxidation reaction, promote the uniform formation and densification of the oxide film, but excessively high temperatures may lead to embrittlement of the film layer or damage to the substrate material. The processing time determines the thickness and integrity of the oxide film. A too short time may not form a complete oxide film, while a too long time may cause excessive oxidation or film detachment. The pH value indirectly affects the composition and structure of the oxide film by affecting the stability and reaction rate of the oxidant. The stirring intensity helps to ensure the uniform distribution of the oxidizing solution and sufficient contact between the reactants, promoting the uniform growth of the oxide film[1].

4.3. Metal matrix material and surface condition

The material and surface state of the metal substrate are also key factors affecting the corrosion resistance of chemical oxide coatings. Metals of different materials have different chemical activities and crystal structures, and their sensitivity and reaction mechanisms to oxidants vary. Therefore, when choosing chemical oxidation treatment methods, customized design should be carried out based on the specific material of the metal substrate. In addition, the roughness, cleanliness, and microstructure of the metal surface can also affect the adhesion and density of the oxide film. A rough surface may increase the adhesion area and mechanical biting force of the oxide film, but it may also become a channel for the penetration of corrosive media; A surface with high cleanliness is conducive to the formation of a uniform and dense oxide film.

4.4. Subsequent processing and sealing of holes

The metal surface after chemical oxidation treatment often requires subsequent treatment to enhance the corrosion resistance of the oxide film. Common follow-up methods include sealing treatment, painting, electroplating, etc. Sealing treatment can improve the density and corrosion resistance of the film layer by filling the micropores and cracks in the oxide film; Painting and electroplating can form an additional protective layer on the surface of the oxide film, further isolating corrosive media. In addition, for certain special chemical oxide film layers, such as anodic oxide films, they can also be beautified and functionally enhanced through processes such as heat treatment and electrolytic coloring[2].

5. Effective methods to improve the corrosion resistance of chemical oxide coatings

5.1. Optimizing chemical oxidation treatment process

Optimizing the chemical oxidation treatment process, this strategy aims to ensure that the generated oxide film layer has superior corrosion resistance by finely controlling various key links in the treatment process. The primary task of the staff is to precisely control the type and concentration of oxidants. Different types of oxidants have different mechanisms of action on metal surfaces, and selecting the appropriate oxidant can enhance the specific properties of the film layer in a targeted manner. Meanwhile, precise control of concentration is directly related to the rate of oxidation reaction and the thickness and density of the film layer. Excessive or insufficient concentration may lead to a decrease in the quality of the film layer. Additionally, optimize the processing temperature and time. Appropriate processing temperature can promote the uniform progress of oxidation reaction and avoid film defects caused by local overheating; A reasonable processing time can ensure that the film layer reaches the required thickness and maturity, neither too thin causing insufficient protection nor too thick causing stress concentration. In addition, adjust the pH value of the solution and enhance stirring and ventilation. The stability of pH value helps to maintain the activity and stability of oxidants, thereby ensuring the continuity and controllability of the reaction process; Adequate stirring and ventilation can ensure uniform contact and effective mass transfer between reactants, reducing the problems caused by uneven local reactions. Finally, regularly monitor and evaluate the effectiveness of the treatment. By regularly testing key indicators such as film thickness, density, and adhesion, problems in the process can be identified in a timely manner and corresponding adjustment measures can be taken. Meanwhile, conducting corrosion resistance tests on the processed metal materials can intuitively evaluate the effectiveness of process optimization and provide data support for subsequent improvements.

5.2. Introduction of composite oxidation technology

As an effective means of protecting metal surfaces, the corrosion resistance of chemical oxide coatings is directly related to the service life and safety of metal components. However, in the face of increasingly harsh operating environments and complex corrosion challenges, traditional single oxidation techniques are no longer able to meet the growing performance demands. In this context, composite oxidation technology has emerged as an important means to enhance the corrosion resistance of film layers with its unique advantages. Composite oxidation technology refers to the combination of multiple oxidation processes or material characteristics to form a denser, more stable, and multi protective oxide film layer. This technology achieves deep optimization of the microstructure and chemical composition of the oxide film layer by precisely controlling the electrochemical parameters, electrolyte composition, and types of additives during the oxidation process. When implementing composite oxidation technology, it is necessary to ensure that there is no interference from oil stains, oxides, and other impurities during the surface pretreatment of the substrate; In the core process of composite oxidation treatment, carefully designed process parameters are used to promote uniform oxidation reaction and dense growth of the film layer; In the subsequent sealing process, further reinforce the membrane structure, reduce micro pore defects, and improve the overall protective effect.

5.3. Strengthen subsequent processing and sealing of holes

In metal protection work, the chemical oxide film layer serves as an important barrier, and its corrosion resistance directly affects the service life and overall performance of the metal material. In order to further enhance the corrosion resistance of the chemical oxide film layer, strengthening the subsequent treatment and sealing technology has become an indispensable key step. As a necessary step after the chemical oxidation process, the subsequent processing aims to further strengthen and optimize the newly formed oxide film layer through a series of fine operations. This step not only involves cleaning and leveling the surface of the film layer, but also involves regulating the microstructure of the film layer and improving its performance. The staff should choose appropriate processing liquids and process parameters to promote denser crystallization inside the membrane layer, reduce porosity, and improve its corrosion resistance[3].

In addition, the purpose of sealing is to seal the small pores and defects that may exist in the oxide film layer, prevent corrosive media from entering the substrate through these channels, and ensure the integrity and durability of the film layer. Traditional sealing methods include hot water sealing, dichromate sealing, etc. Each of these methods has its own advantages and disadvantages, and should be selected according to specific situations. In recent years, with the continuous progress of materials science, new sealing materials and technologies have emerged, such as silicate sealing, organic polymer sealing, etc., providing more possibilities for improving the corrosion resistance of chemical oxide film layers. When implementing the strategy of strengthening subsequent processing and sealing, the following points should be noted: ensuring that the subsequent processing and sealing process are matched with the chemical oxidation process, avoiding adverse reactions or affecting the performance of the film layer; Strictly control process parameters and operating conditions to ensure the stability of treatment effectiveness and sealing quality; Conduct comprehensive testing and evaluation of the processed film layer to ensure that its corrosion resistance meets the expected target.

5.4. Improving the material and surface condition of metal matrix

In the process of metal anti-corrosion protection, chemical oxide film layer is an economical and efficient protective measure, and its corrosion resistance is directly related to the application scope and service life of metal materials. In order to further enhance the protective effectiveness of the chemical oxide film layer, workers should start with the fundamental strategy of improving the material and surface state of the metal substrate. The selection and optimization of metal matrix materials are the basis for improving the corrosion resistance of chemical oxide coatings. Different metal materials have different chemical properties and crystal structures, which will directly affect the quality and corrosion resistance of oxide coatings. Therefore, in the research and selection process of metal materials, factors such as corrosion resistance, oxidizability, and compatibility with oxide film layers should be fully considered. By utilizing advanced material preparation techniques such as alloying and heat treatment, the microstructure and chemical composition of the metal matrix are optimized, laying a solid foundation for the formation of its surface chemical oxide film layer[4].

In addition, the improvement of the surface state of the metal substrate is also crucial for enhancing the corrosion resistance of the chemical oxide film layer. Factors such as surface roughness, cleanliness, and the presence of micro defects will directly affect the adhesion and density of the oxide film layer. Therefore, before chemical oxidation treatment, strict pretreatment must be carried out on the surface of the metal substrate, including removing impurities such as oil stains, oxides, and rust, reducing surface roughness, improving surface flatness, and eliminating micro defects as much as possible. By using various surface treatment methods such as mechanical grinding, polishing, acid washing, and alkali washing, the surface state of the metal substrate can be significantly improved, creating favorable conditions for subsequent chemical oxidation treatment.

5.5. Adopting multi-layer film and composite coating technology

In the implementation of metal protection technology, the chemical oxide film layer serves as a key line of defense, and its corrosion resistance directly affects the effectiveness of metal materials in practical applications. In order to cope with more complex and diverse corrosion environments, the use of multi-layer film and composite coating technology has become an innovative way to improve the corrosion resistance of chemical oxide film layers. Multilayer film technology is the construction of multi-layered oxide film layers on a metal substrate. This design not only enhances the physical barrier effect of the film layer, but also improves the overall corrosion resistance through the interaction between each layer[5]. For example, one or more layers of organic coatings, inorganic ceramic films, or nanomaterial coatings can be coated on top of the chemical oxide film layer to form a composite film layer with a gradient structure and multiple protective mechanisms.This multi-layer structure can effectively block the penetration of corrosive media, while slowing down the speed of corrosion reactions, thereby significantly improving the corrosion resistance of the material. Composite coating technology combines multiple materials in a specific way to form coatings with excellent performance. On the basis of the chemical oxide film layer, materials such as metal ceramics, organic polymers, inorganic nanoparticles, etc. can be introduced to uniformly disperse and firmly adhere to the surface of the film layer through physical or chemical methods. Composite coatings not only enhance the hardness, wear resistance, and corrosion resistance of the film layer, but also endow it with new functional characteristics such as self-healing, conductivity, and thermal conductivity. When implementing multi-layer film and composite coating technology, it is necessary to comprehensively consider multiple aspects such as material selection, coating design, optimization of preparation process, and performance evaluation. By precisely controlling the thickness, composition, and structure of each layer of film, optimizing the interfacial bonding strength between the coating and the substrate, the multi-layer film and composite coating technology can ensure the best protective effect in practical applications.

6. Conclusions

In summary, effective methods to improve the corrosion resistance of chemical oxide film layers include optimizing the chemical oxidation treatment process, introducing composite oxidation technology, strengthening subsequent treatment and sealing, improving the material and surface state of the metal substrate, and adopting multi-layer film and composite coating technology. These methods can be used individually or in combination, and appropriate strategies and measures can be selected based on specific usage environments and performance requirements. With the continuous development of materials science and the deepening of technological innovation, it is believed that more effective methods will be developed in the future to further enhance the corrosion resistance of chemical oxide coatings.

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