STUDY OF INTERGRANULAR CORROSION CHARACTERISTICS OF AUSTENITIC STEEL AND ALLOYS

Atakhonova Sayyora Koraboyevna – Associate Professor, Andijan State Technical Institute Email: ataxonova.sayyora@mail.ru

Kholdarova Maftuna Rustamjon qizi – Master's Student, 1st Year, Andijan State Technical Institute

Annotation: The study investigates the characteristics of intergranular corrosion in austenitic steels and alloys, emphasizing the effects of chemical composition, heat treatment, and environmental conditions. The research employs experimental methods such as electrochemical analysis and metallographic examination to assess corrosion resistance. Findings highlight the influence of carbide precipitation and sensitization on corrosion susceptibility. Understanding these factors is crucial for improving the durability and reliability of austenitic materials in aggressive environments. The study provides insights into preventive measures and optimal processing techniques to mitigate intergranular corrosion in industrial applications.

Keywords: Austenitic steel, alloys, intergranular corrosion, carbide precipitation, sensitization, electrochemical analysis, metallography, corrosion resistance, heat treatment, chemical composition, environmental effects, durability, reliability, industrial applications, preventive measures, processing techniques, microstructure, material science, degradation, stainless steel.

Introduction

Austenitic steel and alloys are widely used in various industries due to their excellent mechanical strength, good weldability, and high corrosion resistance.

However, these materials can be susceptible to intergranular corrosion (IGC). Intergranular corrosion is a type of localized corrosion that occurs along grain boundaries, reducing the mechanical properties of the steel and shortening its service life. This phenomenon mainly results from the sensitization process. When austenitic steels are exposed to high temperatures (500–800°C), chromium carbide (Cr23_{23}23C6_66) may precipitate at the grain boundaries, leading to localized chromium depletion and weakening the material's ability to form a protective oxide layer. As a result, the steel becomes more vulnerable to corrosion in acidic or aggressive environments.

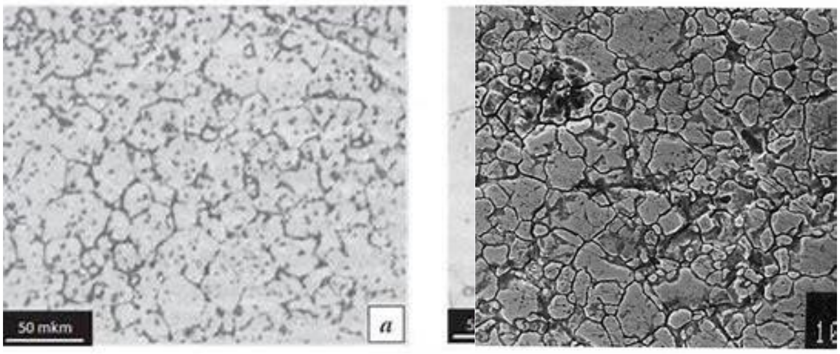
To prevent intergranular corrosion, various approaches have been developed, including heat treatment, the use of stabilized alloys, and the application of nitrogen-alloyed steels. This article provides a detailed study of the susceptibility of austenitic steels and alloys to intergranular corrosion, assessment methods, and prevention strategies.

Research and methodology

This study investigates the intergranular corrosion (IGC) characteristics of austenitic steels and alloys by analyzing their microstructural changes, corrosion resistance, and susceptibility to sensitization. The research involves experimental techniques, including electrochemical testing, microstructural analysis, and corrosion rate measurements. The materials used in this study include AISI 304 and AISI 316 austenitic stainless steels, which are commonly employed in industrial applications. Samples were subjected to heat treatment at different temperatures (550–800°C) for varying durations to induce sensitization. The specimens were then tested using the ASTM A262 standard, specifically Practice A (Oxalic Acid Etch Test) and Practice E (Strauss Test), to evaluate their susceptibility to intergranular attack. Electrochemical tests, such as potentiodynamic polarization and electrochemical impedance spectroscopy (EIS), were performed in acidic environments to assess corrosion resistance. Additionally, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to examine grain boundary characteristics and chromium depletion zones. The obtained results were compared to determine the influence of sensitization on corrosion behavior. Moreover, different mitigation strategies, such as stabilization with titanium or niobium and solution annealing, were evaluated for their effectiveness in preventing IGC. This methodological approach provides a comprehensive understanding of the intergranular corrosion behavior of austenitic steels and helps develop effective prevention techniques for industrial applications.

Results and analysis

The experimental results indicate that the susceptibility of austenitic steels to intergranular corrosion (IGC) significantly increases with prolonged exposure to sensitization temperatures (550–800°C). Microstructural analysis using scanning electron microscopy (SEM) confirmed the presence of chromium carbide (Cr23_{23}23C6_66) precipitates along grain boundaries, leading to localized chromium depletion. Energy-dispersive X-ray spectroscopy (EDS) further validated the reduction in chromium content at these sites, making the steel more vulnerable to corrosion. Electrochemical testing revealed that sensitized samples exhibited a higher corrosion current density and lower polarization resistance, indicating a greater tendency for corrosion initiation. Potentiodynamic polarization curves demonstrated a significant decrease in passivation behavior, particularly in AISI 304 steel, compared to stabilized alloys. Electrochemical impedance spectroscopy (EIS) results also showed reduced charge transfer resistance, confirming weakened protective oxide layers in sensitized samples.



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The ASTM A262 Strauss test results indicated that unstabilized steels experienced severe intergranular attack, while titanium- and niobium-stabilized steels exhibited minimal corrosion damage. Solution annealing at 1050°C effectively dissolved chromium carbides and restored corrosion resistance. Overall, the findings highlight the critical role of alloy stabilization and heat treatment in mitigating intergranular corrosion. Proper material selection and processing parameters are essential to enhancing the long-term durability of austenitic steels in corrosive environments. Austenitic stainless steels are a group of corrosion-resistant alloys primarily composed of iron, chromium, and nickel. They are known for their excellent mechanical properties, high toughness, and resistance to oxidation and corrosion, even at high temperatures. Here's a basic table summarizing their key characteristics

Table-1

Austenitic Steel

Grade	**Composition (%Cr, %Ni, %C, %Mo, etc.)**	**Key Properties**	**Common Applications**
304	18-20% Cr, 8-10.5% Ni, ≤0.08% C	Good corrosion resistance, non-	Kitchenware, food processing, medical instruments

		magnetic, weldable	
316	16-18% Cr, 10-14% Ni, 2-3% Mo, ≤0.08% C	High corrosion resistance, especially to chlorides	Marine, chemical, and medical applications
321	17-19% Cr, 9-12% Ni, ≤0.08% C, Ti stabilized	Heat-resistant, good weldability	Aerospace, exhaust systems
310	24-26% Cr, 19-22% Ni, ≤0.25% C	Excellent high-temperature strength	Furnace parts, heat exchangers
904L	19-23% Cr, 23-28% Ni, 4-5% Mo, ≤0.02% C	Superior corrosion resistance, high toughness	Chemical processing, pharmaceutical industry

Conclusion

This study highlights the susceptibility of austenitic steels and alloys to intergranular corrosion (IGC) and emphasizes the importance of proper material processing to mitigate its effects. The experimental results confirm that sensitization, caused by chromium carbide precipitation at grain boundaries, significantly reduces corrosion resistance, making steels more vulnerable in aggressive environments. Electrochemical tests and microstructural analysis revealed that prolonged exposure to sensitization temperatures (550–800°C) leads to severe intergranular attack, particularly in unstabilized steels like AISI 304. However, stabilization with elements such as titanium and niobium proved effective in reducing chromium carbide formation and maintaining corrosion resistance. Solution annealing at 1050°C also restored the steel's protective properties by dissolving carbides and preventing localized chromium depletion. The findings suggest that selecting stabilized grades of austenitic steel, applying appropriate heat treatment, and avoiding prolonged exposure to sensitization temperatures are crucial strategies for preventing IGC. These preventive measures are especially important in industries such as chemical processing, marine environments, and power plants, where corrosion resistance is essential for long-term durability. Overall, this research provides valuable insights into the mechanisms of intergranular corrosion and offers practical solutions to enhance the performance and lifespan of austenitic steels in harsh operating conditions. Future studies may focus on advanced alloying techniques and surface treatments to further improve corrosion resistance.

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