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Corrosion Resistance of Thermally Aged at 500ºC AISI 348 Stainless Steel for Nuclear Fuel Cladding Applications

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1. Introduction

AISI 348 stainless steel has been considered a potential candidate for nuclear fuel cladding applications. Unlike conventional zirconium-based alloys, the predominant corrosion mechanisms in stainless steels are intergranular and pitting corrosion, both of which are strongly influenced by the alloy microstructure and service environment. Consequently, understanding the relationship between microstructural evolution and corrosion resistance is essential for assessing the feasibility of using AISI 348 in nuclear systems.

Stainless steels are widely employed in industrial and nuclear applications due to their combination of mechanical strength, corrosion resistance, and microstructural stability. Their corrosion resistance originates from the formation of a thin chromium-rich passive film on the surface, promoted by the presence of more than 10.5 wt.% chromium in the alloy composition. Among the austenitic stainless steels, AISI 348 is a stabilized grade derived from AISI 304 through the addition of niobium and tantalum, which reduce sensitization by promoting the preferential formation of Nb/Ta-rich carbides. In addition, the alloy exhibits good microstructural stability under irradiation, making it attractive for demanding nuclear environments.

Despite these advantages, prolonged exposure to elevated temperatures may promote microstructural changes, including carbide precipitation and the formation of secondary phases, which can affect passivity and increase susceptibility to localized and intergranular corrosion. Since nuclear fuel cladding materials are subjected to thermal exposure during service, evaluating the effects of thermal aging on the corrosion behavior of AISI 348 is of considerable technological interest.

Although extensive studies have been conducted on austenitic stainless steels such as AISI 304, AISI 321, and AISI 347, investigations focused specifically on AISI 348 remain relatively scarce. A bibliometric survey conducted using the Scopus database evidenced at Figure 1 revealed that AISI 348 represents only a small fraction of the publications related to stabilized austenitic stainless steels, highlighting the need for further research on its corrosion performance and long-term stability.

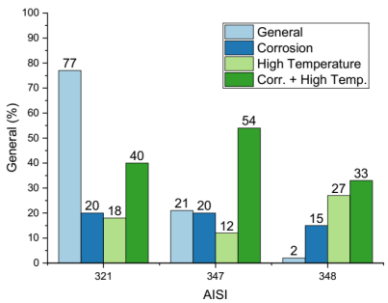


Figure 1 - Bibliometric survey

Therefore, this work investigates how microstructural evolution induced by thermal aging at 500 °C

affects the corrosion resistance and sensitization behavior of AISI 348 stainless steel. Potentiodynamic polarization and double-loop electrochemical potentiokinetic reactivation (DL-EPR) tests were employed to evaluate the influence of aging on the alloy corrosion performance and its suitability for nuclear fuel cladding applications.

2. Methodology

Commercial AISI 348 stainless steel plates were received and chemically characterized. The nominal chemical composition is presented in Table 1. According to the manufacturer's recommendations, the material was solution annealed at 1100 °C for 1 h followed by water quenching to suppress the precipitation of secondary phases during cooling. Subsequently, the plates were sectioned into coupons and thermally aged in a muffle furnace at 500 °C for 10, 50, 100, 250, 500, 750, and 1000 h. After each aging treatment, the specimens were water quenched and prepared for microstructural characterization and electrochemical testing.

Prior to all analyses, the specimens were prepared by grinding with SiC abrasive papers from 180 to 2500 grit using a rotating polishing machine. The initial 180-grit step was employed to remove the oxide scale formed during solution annealing and thermal aging. Mechanical polishing was subsequently performed using 4 μm, 3 μm, and 2 μm alumina suspensions. After polishing, the samples were cleaned in an ultrasonic bath containing a 50:50 water-acetone solution for 1–3 min and dried using a hot-air dryer before testing. Prior to electrochemical testing, all specimens were stored in a desiccator for approximately 24 h to allow stabilization of the naturally formed passive film while minimizing atmospheric contamination and moisture adsorption.

The corrosion behavior was evaluated by potentiodynamic polarization using a Gamry Reference 600 potentiostat. A miniature droplet electrochemical cell as shown on Figure 2. was employed to exclude crevice corrosion effects commonly associated with conventional O-ring sealed cells when testing passive stainless steels. The exposed working area corresponded to a circular region with a diameter of 3 mm, resulting in an area of approximately 0.071 cm^2. The electrolyte consisted of an aqueous 3.5 wt.% NaCl solution. All tests were performed at 25 ± 2 °C using an Ag/AgCl (3 M KCl) reference electrode and a platinum counter electrode with an exposed area at least twice that of the working electrode. Before each measurement, the open-circuit potential (OCP) was monitored for 500 s. The polarization scans were initiated at a potential 25 mV below the corrosion potential (Ecorr) and conducted at a scan rate of 2.5 mV s^{-1}. This scan rate was selected to prevent evaporation of the electrolyte droplet during the measurement. Polarization was interrupted when the anodic current reached 400 μA. For each aging condition, twelve measurements were performed, corresponding to four distinct regions evaluated on three independent specimens. All current values were normalized by the exposed area.

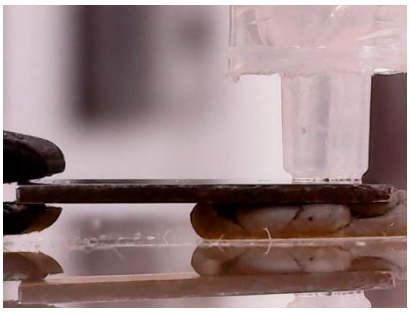


Figure 2: demonstration of droplet cell

The degree of sensitization (DOS) was determined by Double-Loop Electrochemical Potentiokinetic

Reactivation (DL-EPR) testing in accordance with ASTM G108 [2]. The experiments were conducted using a conventional flat electrochemical cell sealed with an O-ring. The exposed area corresponded to a circular region with a diameter of 5 mm, resulting in an area of approximately 0.196 cm^2. The electrolyte consisted of 0.5 M H_2SO_4, 0.01 M $KSCN$, and 0.5 M $NaCl$. All tests were performed at 25 $\pm$ 2 °C using an Ag/AgCl (3 M KCl) reference electrode and a platinum counter electrode with an exposed area at least twice that of the working electrode. Prior to testing, the specimens were maintained under open-circuit conditions for 500 s. The degree of sensitization was determined from the ratio between the reactivation current (Ir) and activation current (Ia), according to ASTM G108, with all current values normalized by the exposed area prior to analysis.

Microstructural characterization was performed by optical microscopy after chemical etching using a modified S-Risgbee Vander Arend reagent described by Nathanael et al. [1]. Metallographic specimens were mounted in bakelite and immersed in the etchant for 24 h. The etching procedure was employed to reveal microstructural features associated with thermal aging, including chromium-depleted regions and secondary phase precipitation. Micrographs were acquired using a Leica LM optical microscope. No image processing procedures were applied other than grayscale conversion when necessary to improve contrast.

3. Results and Discussion

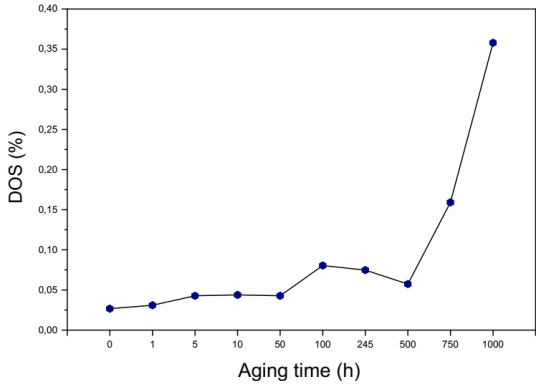


Figure 3 – Degrees Of Sensitization (DOS $\left[\frac{i_r}{i_a}\right]$) of AISI 348 based on DL-EPR method.

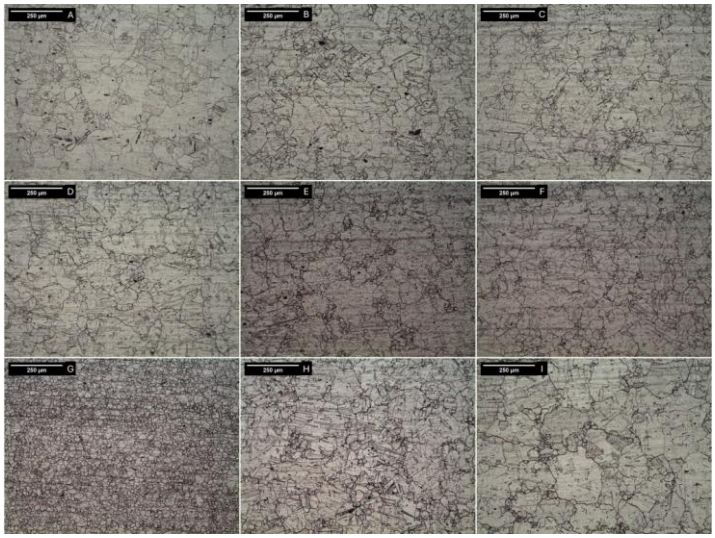


Figure 4 – AISI 348 Microstructure obtained by modified Arend etching, A: Solubilized (0h); B: 5h aging; C: 10h aging; D: 50h aging; E: 100h aging; F: 245h aging; G: 500h aging; H: 750h aging and I:

1000h aging.

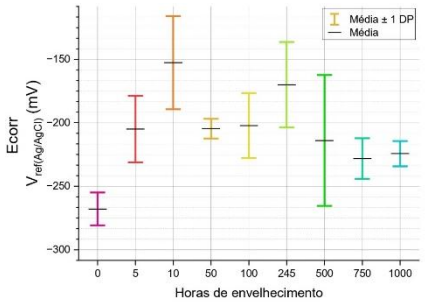


Figure 5 – Summary of corrosion potential per aging time, obtained by potentiodynamic polarisation.

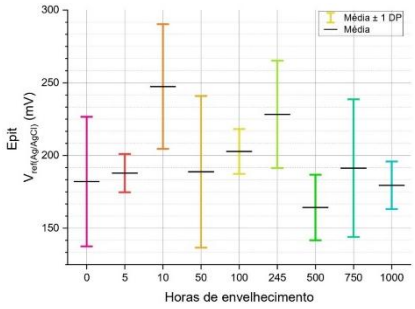


Figure 6 – Summary of pitting potential per aging time, obtained by potentiodynamic polarisation.

4. Conclusions

1 – After the aging treatment, evidence of secondary phase precipitation was observed through microstructural changes detected in the aged condition.

2 – Thermal aging at 500 °C did not promote significant changes in corrosion potential (Ecorr) or pitting potential (Epit) of AISI 348 stainless steel, suggesting that pitting corrosion resistance was not substantially affected under the investigated conditions.

3 – The Degree of Sensitization (DOS) increased after 500 h of aging, indicating enhanced susceptibility to intergranular corrosion and suggesting that this became the predominant corrosion mechanism in the material.

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References

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