

Corrosion Resistance of SS316 Alloy and its Welds in a Cl-based Molten Salt Environment

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1. Introduction

Molten Salt Reactors (MSRs) offer a promising solution for small modular reactors in the near future, with safe operation and enhanced cost efficiency. Their design relies on low pressure, contributing to heightened safety and simplicity. However, corrosion-related challenges remain a significant research topic in developing next-generation MSRs, compounded by the limited available corrosion data.

Pipes or tanks, as parts of storage systems in MSRs, are connected through welding. Hence, comprehending the corrosion performance of structural materials and their welded joints holds technological significance in the design of energy-storage systems [1]. The current study focuses on investigating the corrosion behavior of SS316 and its weld joint within a NaCl-KCl eutectic salt environment. The SS316 alloy stands as a promising candidate material for high-temperature MSRs structural applications [2]. By immersing both the SS316 welded material and its SS316 parent counterpart in NaCl-KCl eutectic salt at 750 °C for 500 hours, a direct comparison of their corrosion performance was facilitated. This assessment provides insight into how the SS316 weld material, and its parent metal withstand corrosion within NaCl-KCl eutectic salt, thereby offering valuable perspectives on the applicability of welding techniques in the design of molten chloride salt-based storage systems.

2. Method and Results

2.1 Materials and Molten Salt Corrosion Testing

A single-V butt weld is present at the center of an SS316 alloy measuring 30 (x) × 10 (y) × 5 (z) mm³, which was supplied by Korea Institute of Machinery & Materials. Small holes (φ3 mm) were drilled into each alloy to allow for suspension by a wire during the immersion corrosion test (Fig. 1. (a)). Prior to the corrosion test, each sample underwent polishing, progressing from SiC paper with a grit of 2000 to a 1 μm diamond suspension.

NaCl and KCl salts, with purity in excess of 99.0%, were provided by Sigma-Aldrich. Within a glove box, under an argon atmosphere with oxygen and water concentrations below 0.1 ppm, these salts were blended to create the NaCl-KCl eutectic salt composition, NaCl (50.6 mol%)-KCl (49.4 mol%). Subsequently, they were heated at 700 °C for 24 hours to stabilize and purify the NaCl-KCl eutectic salt.

Three parent-metal samples and three weld-metal samples (Fig. 1. (a)) were suspended from an alumina crucible using SS316 wire, and then the crucible was filled with the prepared NaCl-KCl eutectic salt, completely submerging the samples (Fig. 1. (b)). The set of crucibles was completed by covering the crucible lid to prevent the salt from evaporating during the corrosion test (Fig. 1. (c)).

After 500 hours, the samples were taken out of the furnace, and the molten salt was promptly poured into a bowl with a significant surface area, rapidly cooling it down. In order to remove the remaining solidified salt from the sample's surfaces, the samples were washed with distilled water and ethanol.

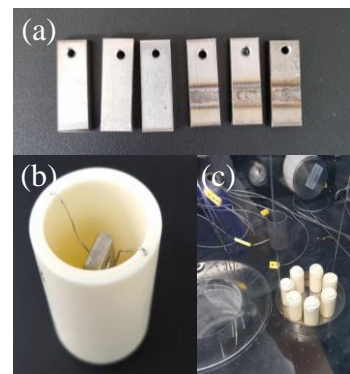


Fig. 1. (a) Three parent metal samples and three weld metal samples were used in the experiment. (b) The SS316 samples were suspended from an alumina crucible using SS316 wire. (c) A set of six crucible samples and a molten salt crucible for a thermocouple were loaded into the furnace.

2.2 Characterisation of corrosion samples and salts

Before and after the corrosion test, using a precision scale with an accuracy of 0.1 mg, the mass of the

samples was then measured to calculate the material's mass loss due to exposure to the molten salt at 750 °C for 500 hours.

The surface and cross-sectional images of the samples were examined using scanning electron microscopy (SEM) to analyze the alterations in corroded samples.

The comprehensive microstructure of both the parent-metal and weld-metal SS316 will be investigated through the utilization of electron backscatter diffraction (EBSD) and energy dispersive X-ray spectroscopy (EDS) detectors. These methods were employed to characterize the microstructural attributes of the extracted specimens and assess the impacts of exposure to molten salt.

Furthermore, in order to measure corrosion product concentration as a complement to microstructural and compositional evaluations, the salts underwent inductively coupled plasma atomic emission spectroscopy analysis. Through this analysis, the concentration of corrosion products was measured by comparing the salt's ingredients before and after the corrosion experiment.

2.3 Mass Loss and Microstructural Analysis of Parent and Welded SS316

The Figure 2 illustrates the mass loss measurements (per unit surface area, mg/cm²) for both SS316 parent-metal and weld-metal samples. These measurements are a result of their exposure to NaCl-KCl eutectic salt at 750 °C for 500 hours. The mass loss values for each individual material are provided for all six test samples (three from each region, represented by solid symbols). The figure also includes the average value (represented by a diamond symbol) along with the standard deviation indicated by error bars for each group.

The findings of material mass loss presented in Fig. 2 reveal that the parent metal exhibits a higher mass loss compared to the weld metal. This observation implies a more pronounced corrosion attack on the parent metal samples. The welding process cannot be attributed to differences in composition, thus both the parent and weld metal possess identical chemical composition. The noticeable difference in corrosion behavior between the original SS316 metal and the welded portion cannot be explained by the corrosion driven by thermodynamic interactions between alloying elements and the molten salt. It is believed that this results from microstructural changes, specifically in the length of high-angle grain boundaries (HAGBs), which are related to the grain size, as well as the distribution of secondary-phase particles (M₆C carbides) during the welding process [1].

Figure 3 presented post-corrosion surface morphologies of parent and welded SS316 when exposed to purified NaCl-KCl eutectic salt under an Ar atmosphere at 750 °C for 500 hours. The samples' surfaces and cross-sections prior to the corrosion test

were comparatively smooth. Significant grain boundary corrosion was evident, accompanied by the formation of numerous small, discontinuous corrosion pits along the grain boundaries [3]. EBSD and EDS maps of the parent metal and weld metal regions depict the microstructure and chemical composition, respectively. The current EDS maps clearly indicate a distribution of the same alloying elements within the corrosion-affected layer of both the parent and weld metal samples. The EBSD maps present the influence of alloy microstructure in terms of grain size, grain boundary length, and precipitates [4].

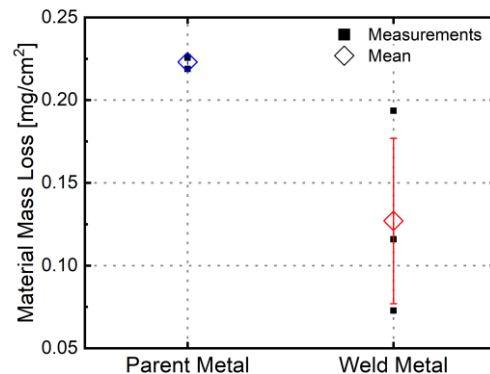


Fig. 2. Mass loss [mg/cm²], per unit area of the sample surface, for SS316 weld metal and base metal after being exposed to a NaCl-KCl eutectic salt environment at 750 °C for 500 hours. Each individual measurement is represented by a square, the average mass loss is indicated by a diamond, and the deviation from the average is shown by the error bars indicating standard deviation (SD).

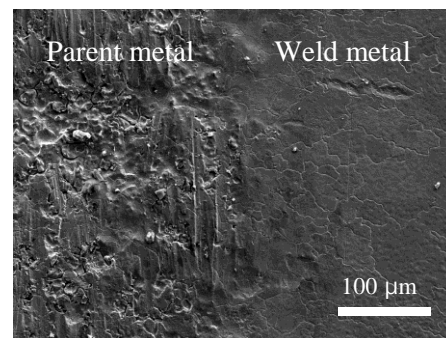


Fig. 3. Surface SEM images of parent and welded SS316 immersed in NaCl-KCl eutectic salt at 750 °C under Ar for 500.0 h after corrosion test. SEM images were captured at the interface between the weld and the parent material of SS316.

3. Conclusion

In the present study, SS316 parent and weld metal corrosion behavior was assessed after exposure to NaCl-KCl eutectic salt at 750 °C for 500 hours. Despite the weld metal and parent metal regions having equivalent chemical compositions, the weld metal was 50% less affected by the exposure to molten chloride salt. The

results draw attention to the significance of microstructural characteristics, namely the length of high-angle grain boundaries, which is linked to grain size, and the distribution of secondary-phase particles. The improved corrosion resistance of the weld metal primarily stems from its significantly larger grain size, resulting in fewer occurrences of HAGBs. Additionally, the smaller M_6C carbides present in the weld metal exhibit lesser promotion of galvanic corrosion compared to the larger M_6C carbides in the parent metal. This study underscores that SS316 alloy welds are well-suited for energy-storage systems utilizing molten chloride salts.

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