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CORROSION RESISTANCE OF STRUCTURAL AMORPHOUS METAL

T. Lian, S. D. Day, J. C. Farmer

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Lawrence Livermore National Laboratory

INTRODUCTION

Corrosion costs the Department of Defense billions of dollars every year, with an immense quantity of material in various structures undergoing corrosion. For example, in addition to fluid and seawater piping, ballast tanks, and propulsions systems, approximately 345 million square feet of structure aboard naval ships and crafts require costly corrosion control measures. The use of advanced corrosion-resistant materials to prevent the continuous degradation of this massive surface area would be extremely beneficial. The potential advantages of amorphous metals have been recognized for some time [Latanision 1985]. Iron-based corrosion-resistant, amorphous-metal coatings under development may prove important for maritime applications [Farmer et al. 2005].

Such materials could also be used to coat the entire outer surface of containers for the transportation and long-term storage of spent nuclear fuel, or to protect welds and heat affected zones, thereby preventing exposure to environments that might cause stress corrosion cracking [Farmer et al. 1991, 2000a, 2000b]. In the future, it may be possible to substitute such high-performance iron-based materials for more-expensive nickel-based alloys, thereby enabling cost savings in a wide variety of industrial applications. It should be noted that thermal-spray ceramic coatings have also been investigated for such applications [Haslam et al. 2005].

This report focuses on the corrosion resistance of a yttrium-containing amorphous metal, SAM1651. SAM1651 has a glass transition temperature of $\sim 584^{\circ}\text{C}$, a recrystallization temperature of $\sim 653^{\circ}\text{C}$, and a melting point of $\sim 1121^{\circ}\text{C}$. The measured critical cooling rate for SAM1651 is ≤ 80 K per second, respectively. The yttrium addition to SAM1651 enhances glass formation, as reported by Guo and Poon [2003]. The corrosion behavior of SAM1651 was compared with nickel-based Alloy 22 in electrochemical polarization measurements performed in several highly concentrated chloride solutions.

EXPERIMENTS

Corrosion tests were performed on as-received SAM1651 vacuum arc-melted drop cast ingots. The ingots were cast into cylindrical molds to form long rods with a nominal diameter of 4-5 millimeters and a length of ~ 75 millimeters. The nominal composition of SAM1651 material is listed in Table 1. Two SAM1651 ingots, identified as #0005 and #19643 were mounted in an epoxy rod that exposes the ingot in cross section (4-5 mm diameter) for electrochemical testing. The epoxy-mounted specimens were ground with abrasive papers and given a 600-grit silicon carbide finish.

A temperature-controlled, borosilicate glass (Pyrex) cell was used for the electrochemical tests. This five-port cell had a working electrode (the test specimen), a reference electrode, and a counter electrode. A standard silver silver-chloride electrode, filled with near-saturation potassium chloride solution, was used as the reference, and communicated with the test solution via a Luggin probe placed in close proximity to the working electrode to minimize Ohmic losses. Numerical corrections for the reference electrode junction potential have been estimated, and have been found to be insignificant (Farmer et al. 2000a). The Luggin probe is equipped with a water-cooled jacket to keep the reference electrode at ambient temperature, thereby maintaining an accurate potential measurement. A water-cooled condenser was inserted into the vessel to prevent the loss of volatile species from the electrolyte. The solution was deaerated using a bubbled nitrogen gas purge through a fifth port (see Figure 1).

Each electrochemical test includes a potentiodynamic polarization measurement after a 24-hour immersion in test solutions. A scan rate of 0.167 mV/s (or 600 mV/hr) was used in the potentiodynamic scans. The test solutions

included 3.5 m NaCl, 6 m NaCl, 5 M CaCl₂, and seawater from Half Moon Bay, California. All tests were conducted at 90°C.

The Alloy 22 test data was generated on 5/8 inch diameter disc specimens. The composition of Alloy 22 is also listed in Table 1.

RESULTS AND CONCLUSIONS

Figure 2 shows the polarization behavior of SAM 1651 ingot #19643 in seawater at 90°C, 3.5 molal NaCl at 90°C, and 5M CaCl₂ at 105°C. SAM1651 has demonstrated excellent corrosion resistance based on the results of these polarization measurements.

In Figure 3, the polarization behavior of SAM1651 is compared to Alloy 22 in 5M CaCl₂ at 105°C. SAM1651 shows higher breakdown potential than Alloy 22, an indication of better resistance to localized corrosion. Figure 4 also shows that SAM1651 has a comparable corrosion resistance to Alloy 22 in 6m NaCl solutions at temperatures near the electrolyte boiling point.

Based on preliminary test results, SAM1651 demonstrates a promising corrosion resistance that is comparable to that of Alloy 22, the preferred material for the outer barrier of nuclear waste storage containers. Additional tests have been planned to fully characterize the corrosion performance of SAM1651 in a range of environments. Future tests will assess the corrosion behavior of SAM1651 thermal spray coatings on various metal substrates.

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Samples of drop-cast ingots of SAM1651 were fabricated by Dr. Craig Blue and his colleagues at Oak Ridge National Laboratory. These materials were prepared under contract for Lawrence Livermore National Laboratory.

REFERENCE

J. C. Farmer et al., Nuclear Engineering Design, Vol. 129, pp. 57-88 (1991).

J. C. Farmer et al., Proc. 2000 ASME Pressure Vessel and Piping (PVP) Conference, Seattle, Washington, July 23-27, 2000, Transportation, Storage, and Disposal of Radioactive Materials, American Society of Mechanical Engineers, New York, NY, PVP Vol. 408, pp. 53-70 (2000a).

J. C. Farmer et al., Proc. 2000 ASME Pressure Vessel and Piping (PVP) Conference, Seattle, Washington, July 23-27, 2000, Transportation, Storage, and Disposal of Radioactive Materials, American Society of Mechanical Engineers, New York NY, PVP Vol. 408, pp. 71-81 (2000b).

J. C. Farmer et al., Proc. 2005 ASME Pressure Vessel and Piping (PVP) Conference, Denver, Colorado, July 17-21, 2005, American Society of Mechanical Engineers, PVP2005-71664, New York, NY, 7 p. (2005a).

J. C. Farmer et al., DARPA-DOE High-Performance Corrosion-Resistant Materials Principal Investigator's Meeting, UCRL-PRES-214672, Turtle Bay Resort, Oahu, Hawaii, January 10-13, 2005, Lawrence Livermore National Laboratory, Livermore, California, 407 pages (2005b).

J. J. Haslam, J. C. Farmer, R. W. Hopper, K. R. Wilfinger, Ceramic Coatings for Corrosion Resistant Nuclear Waste Container Evaluated in Simulated Ground Water at 90C, UCRL-JRNL-206107; Metallurgical and Materials Transactions A, Volume 36A, May 2005, p. 1085-1095 (2004).

F. Guo, S. J. Poon, Applied Physics Letters, 83 (13) 2575-2577 (2003).

R. M. Latanison, Workshop on Amorphous Metals and Semiconductors, EPRI, May 12-18 (1985).

Table 1. Composition of SAM1651 and Alloy 22

	Fe (%)	Cr (%)	Mo (%)	C (%)	Y (%)	B (%)	Ni (%)	Co (%)	W (%)
SAM1651	48.0	15.0	14.0	15.0	2.0	6.0			
Alloy 22	3.65	21.23	13.37	0.003			55.29	1.7	2.93

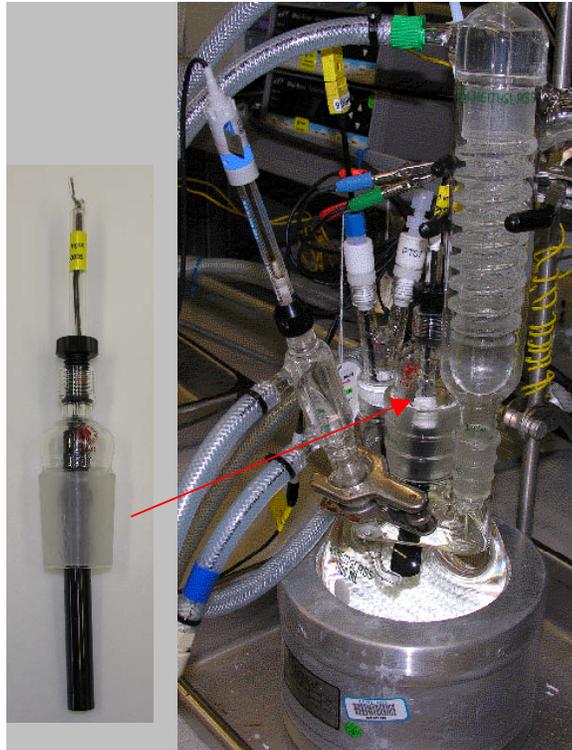


Figure 1. Electrochemical test apparatus.

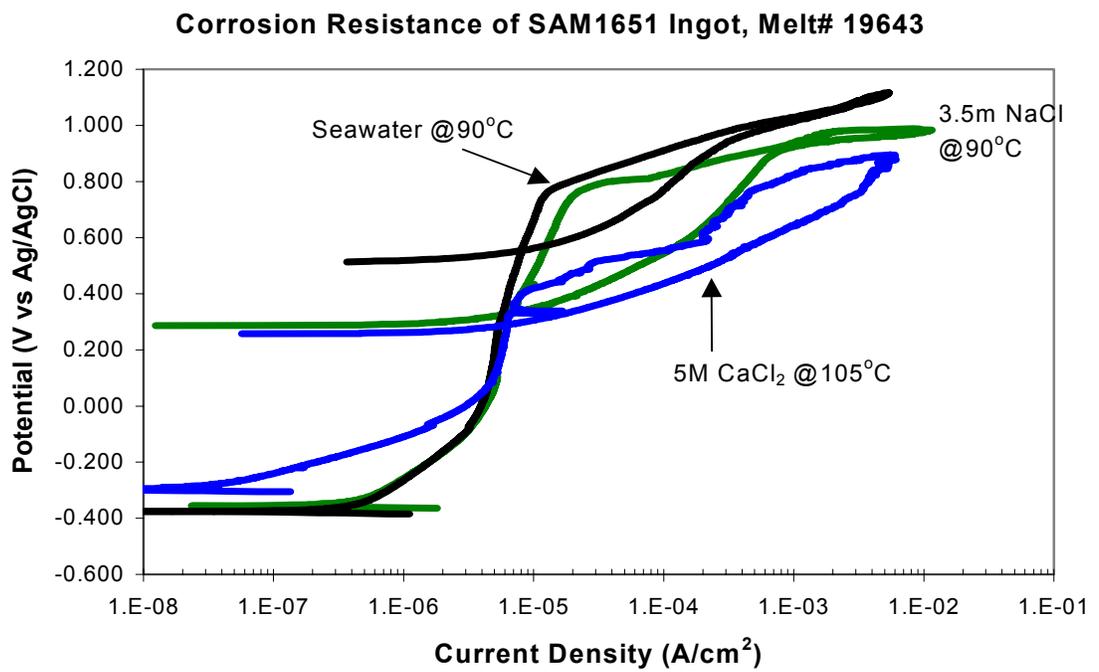


Figure 2. Electrochemical polarization behavior of SAM1651 material in various chloride solutions.

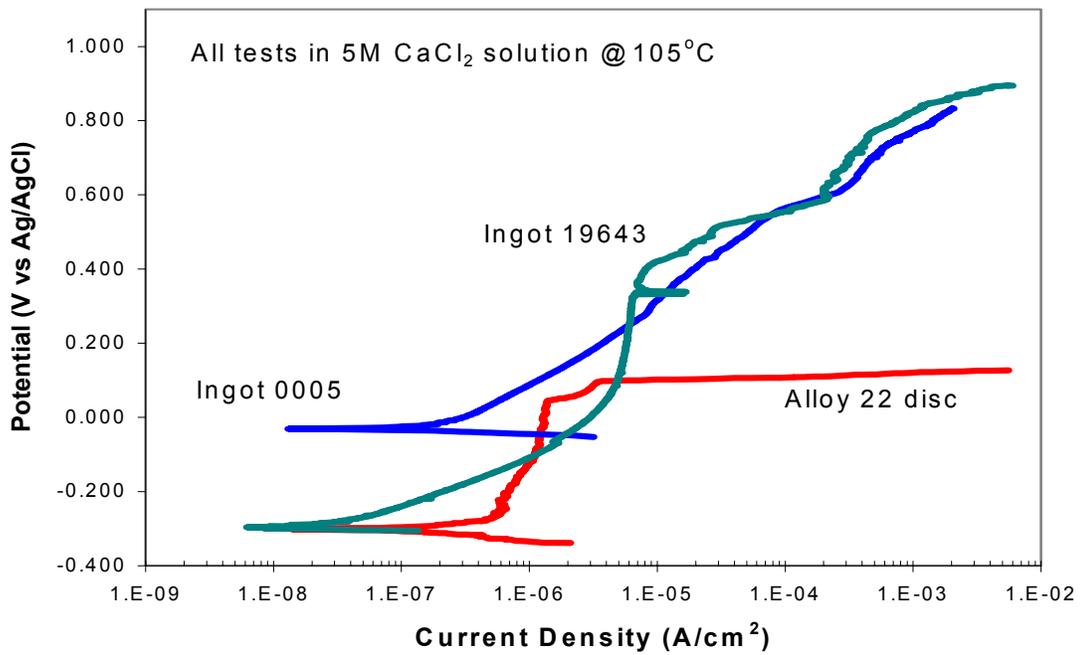


Figure 3. Comparison of Polarization Behavior Between SAM1651 Ingots and Alloy 22 Disc in 5M CaCl₂ Solution at 105°C

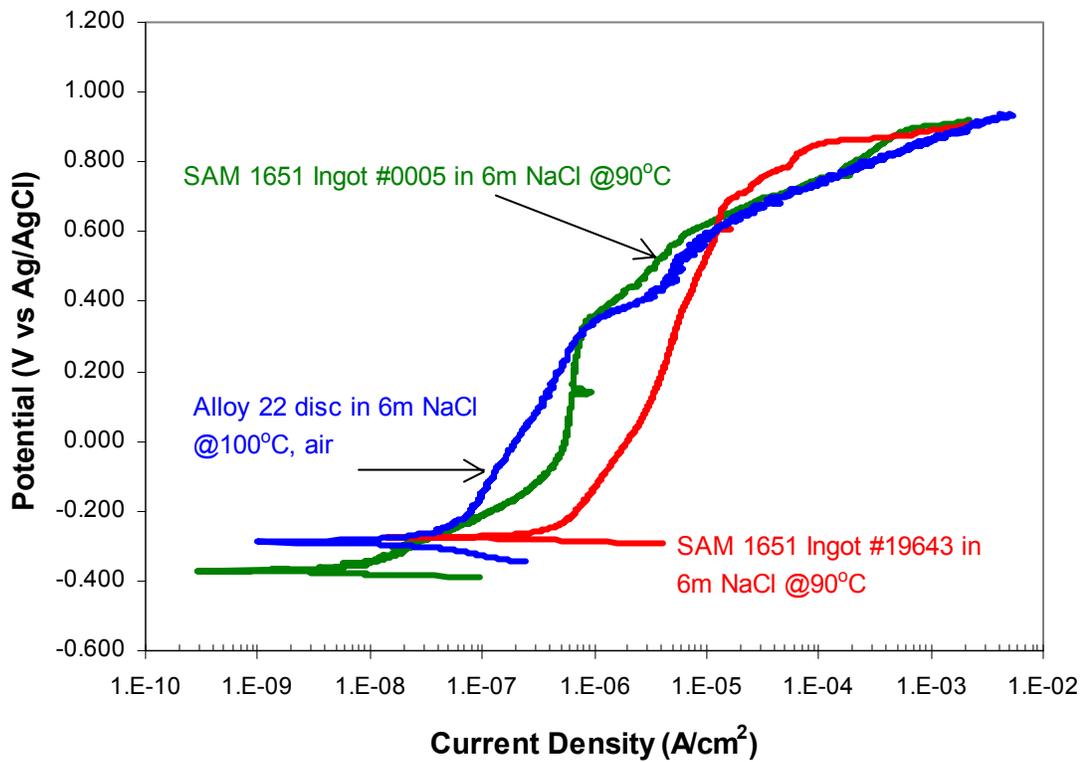


Figure 4. Comparison of polarization behavior between SAM1651 ingots and Alloy 22 disc, in 6m NaCl solutions