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Environment-Induced Degradation and Crack-Growth Studies of Candidate Target Materials

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Task 4

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BACKGROUND

The primary objective of this task is to evaluate the effect of environmental and mechanical parameters on environment-induced degradations of candidate target structural materials for applications in spallation-neutron-target systems, such as accelerator-driven systems for the transmutation of waste. The materials selected for evaluation and characterization are martensitic stainless steels including Alloys HT-9, EP-823 and Type 422 stainless steel (SS).

More recently, this experimental program has been expanded to evaluate the effect of molten lead-bismuth eutectic (LBE) on the corrosion behavior of target structural materials in the presence of oxygen. Since the Materials Performance Laboratory (MPL) at UNLV currently cannot accommodate this type of testing, the Delta loop, a molten LBE loop at the Los Alamos National Laboratory (LANL), is used to expose the stressed test specimens to evaluate the stress corrosion cracking (SCC), and localized corrosion behavior in the molten LBE environment. Since the magnitude of the applied load during these tests cannot be monitored or controlled (as in conventional SCC experiments) in the LBE environment, the test specimens will be self-loaded. Two types of specimen configurations, namely C-ring and U-bend, are used to perform these experiments. SCC tests using these types of self-loaded specimens are also being performed at the MPL in aqueous environments having neutral and acidic pH values at ambient and elevated temperatures.

Constant load test setup.

Since electrochemistry can influence the localized corrosion (pitting and crevice) behavior, the susceptibility to localized attack was determined by cyclic potentiodynamic polarization (CPP) technique in similar environments. The SCC tests have been performed under controlled cathodic potential to study the effect of hydrogen on the cracking susceptibility. The magnitude of controlled potential was based on the measured corrosion potential obtained in specific test environments.

RESEARCH OBJECTIVES AND METHODS

The susceptibility to SCC has been evaluated by using both smooth and notched uniaxial tensile specimens, which were pulled in two aqueous environments of different pH values at ambient and elevated temperatures using either a constant load or a slow-strain-rate (SSR) technique. The SSR testing was performed at a strain rate of $3.3*10^{-6}$ sec^{-1} to optimize the effects of mechanical constraints and environmental parameters.

The notched specimens were used to increase the severity of cracking. The cracking susceptibility under a constant loading condition can be characterized either by the time-to-failure (TTF) or a threshold stress for SCC, below which no cracking occurs. For SSR testing, the cracking behavior was evaluated in terms of the ductility parameters such as percent elongation, percent reduction in area, and the true fracture stress obtained from the stress-strain diagram.

RESEARCH ACCOMPLISHMENTS

Smooth and notched tensile specimens of all three alloys were tested to evaluate their susceptibility to SCC in both neutral and acidic aqueous environments at ambient and elevated temperatures by using both constant-load and SSR testing techniques.

Cracking was observed in the constant load testing (see picture above) in the 90°C acidic solution at applied stress corresponding to 95, 90 and 85 percent of materials' YS values. A σ_{th} value for all three alloys was determined. However, the presence of a notch in the specimen reduced the σ_{th} value to much lower level (reduced yield load).

The results of SSR testing involving smooth specimens revealed reduced TTF, σ_f, and the ductility values in the acidic solution at the elevated temperature, showing a synergistic effect of pH and temperature on the cracking susceptibility.

The results of SSR testing involving notched specimen indicated that the presence of a notch further reduced the TTF and the ductility parameters. However, the σ_f value was increased due to the reduced cross-sectional area at the root of the notch.

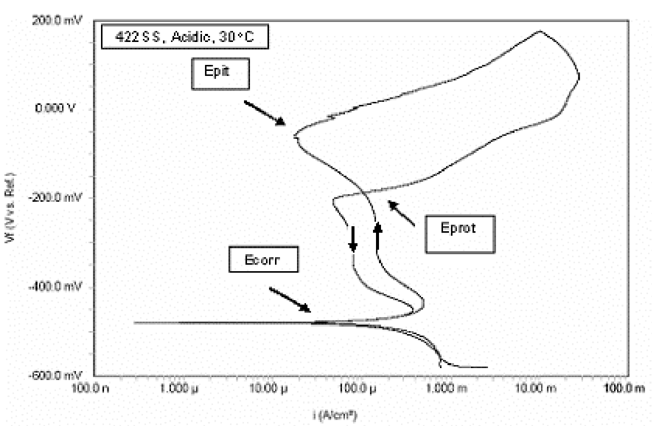
No failures were observed in U-bend specimens. However, C-ring specimens of alloy HT-9 exhibited cracking in the acidic solution at 50 and 100°C.

CPP testing was performed to evaluate the localized corrosion behavior of the test material. The E_{pit} values became more active with increasing temperature for both tempering times, showing more pronounced effect in the acidic solution.

The morphology of primary failure in all broken specimens was analyzed by SEM. The failure mode at the primary fracture face was ductile in the neutral solution. However, intergranular and/ or transgranular brittle failures were observed in the acidic solution.

The secondary cracks were studied by optical microscopy. Secondary cracks with branching were observed along the gage section of specimens failed in susceptible environments.

The nature of localized attack in polarized specimens was visually examined. Examination of the polarized specimens revealed multiple pits and crevices.



Cyclic Potentiodynamic Polarization Data

HIGHLIGHTS

- "Environment-Induced Degradation of Spallation Target Materials," ANS AccApp'03, June 1-5, 2003, San Diego, CA.
- "Cracking of Martensitic Stainless Steels Under Applied Electrochemical Potential," 204th Meeting of the Electrochemical Society, October 12-17, 2003, Orlando, FL.
- "Environmental Effects on Materials For Nuclear Applications," Materials Science & Technology (MS&T) 2003, November 9-12, 2003, Chicago, IL.
- "Effect of Environmental Variables on Cracking of Martensitic Stainless Steels Under Different Loading Conditions," ANS Global 2003, November 16-20, 2003, New Orleans, LA.
- "Characterization of Environment-Induced Degradation in Type 422 Stainless Steel," The Minerals, Metals and Materials Society (TMS) 2004, March 14-18, 2004, Charlotte, NC.
- "Stress Corrosion Cracking of Target Materials for Transmutation Applications," National Association of Corrosion Engineers, NACE, Corrosion 2004, March 28 - April 1, 2004, New Orleans, LA.
- "Environmental Effects on a Candidate Structural Material for Transmutation Application," ANS Student Conference 2004, April 1-3, 2004, Madison, WI.
- "Cracking of Target Structural Material in Different Environments," ANS Student Conference 2004, April 1-3, 2004, Madison, WI.
- "Stress Corrosion Cracking of Structural Target Material Alloy EP-823," ANS Student Conference 2004, April 1-3, 2004, Madison, WI.
- "Stress Corrosion Cracking and Localized Corrosion in Alloy HT-9", ANS Student Conference 2004, April 1-3, 2004, Madison, WI.
- "The Effect of Environmental and Mechanical Variables on Stress Corrosion Cracking of a Martensitic Stainless Steel for Transmutation Applications," ASME 12th International Conference on Nuclear Engineering, ICONE 12, April 25-29, 2004, Arlington, VA.
- "Stress Corrosion Cracking of Type 422 Stainless Steel for Transmutation Applications" poster presented at the International Youth Nuclear Congress 2004, May 9-13, 2004, Toronto, Canada.

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