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

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Task 4
Environment-Induced Degradation and Crack-Growth Studies of Candidate Target Materials

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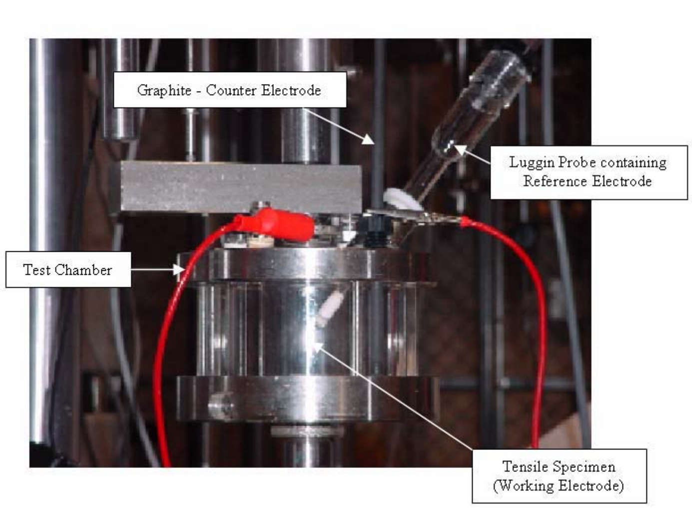
BACKGROUND

The primary objective of this task was to evaluate the effects of environmental and mechanical parameters on environment-induced degradations of candidate target structural materials for applications in spallation-neutron-target systems. The materials selected for evaluation and characterization were martensitic stainless steels including Alloys HT-9, EP-823, and 422.

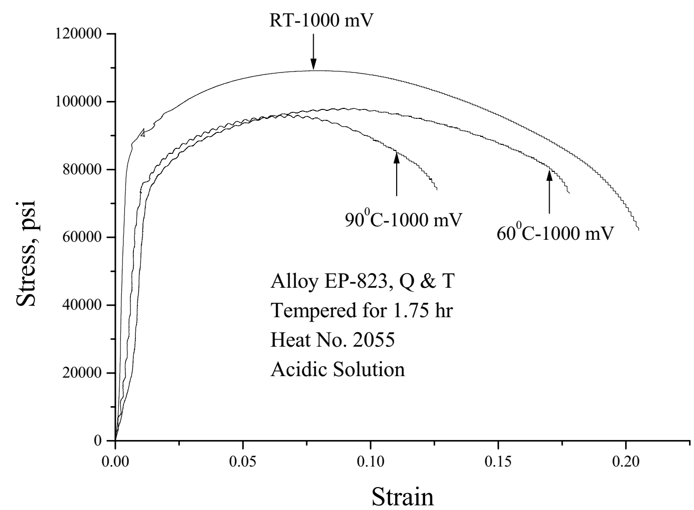
Accelerator-driven transmutation systems involve bombarding a target material such as molten lead-bismuth-eutectic (LBE) by a proton beam, thereby producing neutrons. The molten LBE target will be contained in a subsystem structural container made of a suitable material such as Alloys HT-9, EP-823, and 422. During the transmutation process, the target structural material may become susceptible to different types of environment-induced degradations such as stress corrosion cracking (SCC), hydrogen embrittlement (HE), and localized (pitting and crevice) corrosion. While the performance of these candidate materials in the presence of a molten LBE is yet to be evaluated, substantial work has been performed in this task to evaluate the corrosion behavior of these alloys in aqueous environments of interest. These baseline data can eventually be utilized to compare them to those yet to be generated in the molten LBE environment.

RESEARCH OBJECTIVES AND METHODS

This investigation was focused on the evaluation of the susceptibility of all three martensitic alloys to SCC, HE, and localized corrosion in neutral and acidic aqueous environments at ambient and elevated temperatures. State-of-the-art experimental techniques including constant-load (CL), slow-strain-rate (SSR), and cyclic potentiodynamic polarization (CPP) were employed to evaluate these corrosion phenomena.



Controlled Potential Test Setup



Stress vs Strain under Controlled Potential.

The susceptibility of these alloys to HE was evaluated by applying cathodic potential while the test specimens were loaded in tension by the SSR method. Optical microscopy and scanning electron microscopy (SEM) were used to analyze the metallurgical microstructures and fractography, respectively of the tested specimens.

RESEARCH ACCOMPLISHMENTS

The significant results derived from this task are summarized as follows:

- No failures were observed in smooth specimens of Alloys EP-823 and 422 in the neutral solution when tested at CL. However, Alloy HT-9 showed failure in the 90°C neutral solution at an applied stress (σ_a) of 112 ksi.
- All three alloys exhibited failure in the 90°C acidic solution at 95% of their YS values. Alloys HT-9 and 422 also showed failures at σ_a of 90 and 85% of their YS values, but no failure was observed with Alloy EP-823 at stresses below 0.95 YS.
- The magnitudes of the threshold stress (σ_{th}) for cracking for Alloys EP-823, HT-9 and 422 were 100, 95, and 98 ksi (689, 655, and 676 MPa), respectively based on CL testing in the 90° C acidic solution. The presence of a notch in the test specimen reduced the σ_{th} values in all three alloys.
- The results of SSR testing in the acidic solution involving smooth specimens showed gradual reduction in ductility parameters (percent elongation - %El and percent reduction in area-%RA), time-to-failure (TTF), and true failure stress (σ_f) with increasing temperature, indicating a synergistic effect of pH and temperature in enhancing the cracking susceptibility. The presence of a notch in the specimen produced enhanced SCC susceptibility due to the stress concentration. However, the σ_f value was increased due to plastic constraint resulting

from triaxial stress field at the notch.

- The magnitude of %El, %RA, TTF, and σ_f was reduced under an applied potential of -1,000 mV (Ag/AgCl) compared to those obtained without an applied potential.
- The failure mode at the primary fracture face of the specimen tested in the neutral solution, determined by SEM, was characterized by dimpled microstructure, indicating ductile failures. However, intergranular and/or transgranular brittle failures were observed in the acidic environment.
- Secondary cracks with branching were observed by optical microscopy on all three tested materials along the gage section of the specimens tested in the acidic solution.

TASK 4 PROFILE

Start Date: June 2001
Completion Date: December 2004

Theses Generated:

Ramprashad Prabhakaran, M.S., "Environment-Induced Degradations in a Target Structural Material for Transmutation Applications," August 2004.

Sudheer Sama, M.S., "Embrittlement and Localized Corrosion in Alloy HT-9," August 2004.

Phani P. Gudipati, M.S., "Stress Corrosion Cracking Resistance of Martensitic Stainless Steels for Transmutation Applications," December 2004.

Mohammad K. Hossain, Ph.D., "Stress Corrosion Cracking and Hydrogen Embrittlement of Martensitic Alloy EP-823," December 2004.

Venkataramakrishnan Selvaraj, M.S., "Environment Assisted Cracking of Target Structural Materials under Different Loading Conditions," December 2004.

Journal Articles:

A.K. Roy and M. K. Hossain, "Cracking of Martensitic Alloy EP-823 under Controlled Potential," *Journal of Materials Engineering and Performance,* ASM International, (In Review).

A.K. Roy, M. K. Hossain, R. Prabhakaran and S. Sama, "Environment-Assisted Cracking of Structural Materials under Different Loading Conditions," *Corrosion*, NACE International, April 2005, Vol. 61, No. 4, pp. 364-370.

A.K. Roy, R. Prabhakaran, M. K. Hossain and S. Sama, "Stress Corrosion Cracking of Nuclear Transmutation Structural Materials," *Materials Performance*, NACE International, September 2004, Vol. 43, No. 9, pp. 52-56.

Conference Proceedings:

A.K. Roy, and M. K. Hossain, "Environment Induced Embrittlement of Martensitic Stainless Steel for Transmutation Applications," Corrosion 2005, NACE International, Houston, TX, April 2005.

A.K. Roy, *Phani P. Gudipati*, Venkataramakrishnan Selvaraj, "Environment Degradation of Martensitic Stainless Steels for Transmutation Applications," MS&T 2004, New Orleans, LA, September 26-29, 2004.

A.K. Roy, R. Prabhakaran, "Stress Corrosion Cracking of Type 422 Stainless Steel for Transmutation Applications," International Youth Nuclear Congress (IYNC) 2004, Toronto, Canada, May 9-13, 2004.

R. Prabhakaran and A.K. Roy, "The Effect of Environmental and Mechanical Variables on Stress Corrosion Cracking of Martensitic Stainless Steels for Transmutation Applications," ICONE-12, Student Paper Competition, Arlington, VA, April 25-29, 2004.

A.K. Roy, M. K. Hossain, R. Prabhakaran, S. Sama, V. Selvaraj, P.P. Gudipati, "Stress Corrosion Cracking of Target Materials for Transmutation Applications," Corrosion 2004, NACE International, New Orleans, LA, March 28-April 1, 2004.

A.K. Roy, R. Prabhakaran, "Characterization of Environment-Induced Degradation in Type 422 Stainless Steel," TMS 2004, Charlotte, NC, March 14-18, 2004.

A.K. Roy, R. Prabhakaran, M. K. Hossain, S. Sama, V. Selvaraj, P.P. Gudipati, "Effect of Environmental Variables on Cracking of Martensitic Stainless Steels under Different Loading Conditions," ANS Meeting–Global 2003, New Orleans, LA, November 16-20, 2003.

A.K. Roy, R. Prabhakaran, M. K. Hossain, S. Sama, V. Selvaraj, P.P. Gudipati, "Environmental Effects on Materials For Nuclear Applications," MS&T 2003, Chicago, IL, November 9-12, 2003.

A.K. Roy, S. Sama, R. Prabhakaran, M. K. Hossain, "Cracking of Martensitic Stainless Steels under Applied Electrochemical Potential," 204th Meeting of the Electrochemical Society (ECS), Abstract No. 1255, Orlando, FL, October 12-17, 2003.

A.K. Roy, R. Prabhakaran, M. K. Hossain, S. Sama, B. J. O'Toole, "Environment-Induced Degradation of Spallation Target Materials," ANS Meeting, AccApp'03, San Diego, CA, June 1-5, 2003.

A.K. Roy, M. K. Hossain, B. J. O'Toole, "Stress Corrosion Cracking of Martensitic Stainless Steel For Transmutation Applications," The 10th International High-Level Radioactive Waste Management Conference, Las Vegas, NV, March 30-April 3, 2003.

R. Prabhakaran, "Stress Corrosion Cracking of Type 422 Stainless Steel For Applications in Spallation-Neutron-Target Systems," Spallation Neutron Source (SNS)-JINS-NICEST 2003, Oak Ridge, TN, March 12, 2003.

A.K. Roy, M.K. Hossain, and B.J. O'Toole, "Stress Corrosion Cracking of Martensitic Stainless Steel for Transmutation Applications," International High-Level Radioactive Waste Management Conference, Las Vegas, NV, Sept. 2002.

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