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Corrosion of Steel by Lead Bismuth Eutectic

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Task 3

Corrosion of Steel by Lead Bismuth Eutectic

J.W. Farley, A. Johnson, and D.L. Perry

BACKGROUND

There is an active international interest in lead-bismuth eutectic and similar liquid lead systems because of the relevance to the transmutation of nuclear waste, fast reactors, and spallation neutron sources. A successful program in nuclear waste processing that includes transmutation in accelerator-driven systems and fast reactors, would significantly decrease the space requirements for geological repositories.

Materials in these systems must be able to tolerate high neutron fluxes, high temperatures, and chemical corrosion. For lead bismuth eutectic (LBE) systems, there is an additional challenge because the corrosive behaviors of materials in LBE are not well understood. Most of the available information on LBE systems has come from the Russians, who have over 80 reactor-years experience with LBE coolant in their Alpha-class submarine reactors. The Russians found that the presence of small amounts of oxygen (on the order of parts per million) in the LBE significantly reduced corrosion. However, a fundamental understanding and verification of its role in the corrosion of steels is incomplete.

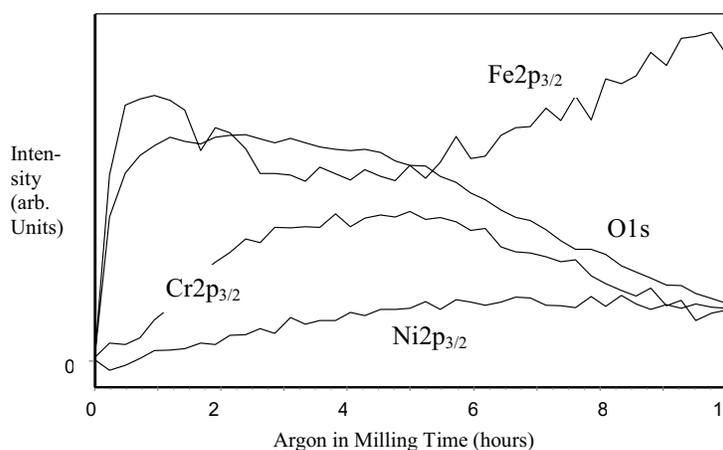
RESEARCH OBJECTIVES AND METHODS

This research program has analyzed various steel samples that have been exposed to lead bismuth eutectic as part of the national program to develop LBE and allied technologies. The

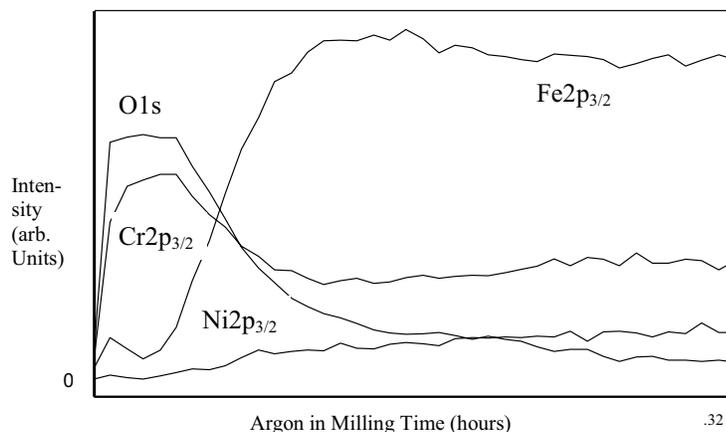
goal of this research is to understand the basic science of corrosion in the steel/LBE system. This information will be paramount in developing engineering efforts to control, avoid, and/or minimize the effect of corrosion of steels by LBE in transmuter and LBE systems. Additionally, this program provides UNLV researchers with hands-on experience that will be crucial in developing the UNLV molten metal program.

Investigators performed post-experiment testing and analysis on steel samples that have been exposed to lead bismuth eutectic. Surface analysis techniques were employed that included Scanning Electron Microscopy (SEM), Energy Dispersive X-ray (EDAX) spectroscopy, X-ray Photoelectron Spectrometry (XPS), and laser Raman spectrometry.

These techniques, applied to the steel surface, have probed the surface morphology, elemental composition, and oxidation states as a function of position. Chemical alterations and resulting chemical species were studied at the steel surface. Additionally, the experimental facilities at the Advanced Light Source (Lawrence Berkeley National Laboratory) and the Advanced Photon Source (Argonne National Laboratory) were used to characterize the systems. This allowed spectroscopic characterization of the stainless steel before and after interaction with LBE to determine its composition.



Sputter Depth Profile of annealed 316/316L stainless steel sample. Note iron oxide at the surface.



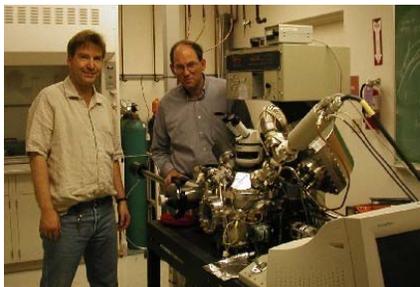
Sputter Depth Profile of cold-rolled 316/316L stainless steel sample. Note chromium oxide at the surface.

RESEARCH ACCOMPLISHMENTS

Several samples were compared having the same or similar compositions (standard nuclear grade 316/316L) but different surface preparation, including cold-rolled, annealed and a special low-corrosion treatment, "D-9." The cold-rolled sample had an order of magnitude less corrosion (i.e., both lower oxidation and less weight change) than the annealed sample.

Sputter depth profiling of the exposed annealed sample and cold-rolled sample showed a marked difference in oxide layer composition between the annealed and cold-rolled sample. The annealed sample showed a complex oxide structure (iron oxide over chromium/iron oxide mixtures) of tens of microns thickness, while the cold-rolled sample was covered with a simple, primarily chromium oxide layer approximately one micron thick. Interestingly, the D-9 material behaved more like the annealed than the more resistant cold-rolled material. In addition to these studies of 316/316L steel, other compositions of steel such as HT9 were also studied. These studies show the importance of surface preparation in resistance to corrosion by LBE.

The measurements are useful because they can be used to test theoretical models of corrosion, developed by DOE scientists at Los Alamos National Laboratory. Fruitful collaborations with DOE scientists at Los Alamos, at Pacific Northwest National Laboratory, and at Idaho National Energy Engineering Laboratory have been established.



Allen Johnson and John Farley next to an X-ray Photoelectron Spectrometer.

HIGHLIGHTS

- ◆ "Surface Studies of the Corrosion of Stainless Steel by Lead Bismuth Eutectic: Surface Preparation Effects on 316 Stainless Steels," presented at the American Nuclear Society Summer Meeting, San Diego, CA, June 1-5, 2003
- ◆ "The Corrosion of Stainless Steel by Lead Bismuth Eutectic: Surface Effects," presented at the AFCI Semi-Annual Review, Santa Fe, NM, August 27-28, 2003.
- ◆ "Chemical Species Involved in High Temperature Corrosion Resulting from the Interaction Between Stainless Steel and Lead-Bismuth Eutectic," presented at the 38th Western Regional Meeting of the American Chemical Society, Long Beach, CA, October 15-18, 2003.
- ◆ "Surface Studies of the High Temperature Corrosion of Stainless Steel by Oxygen Controlled Lead-Bismuth Eutectic," presented at the American Vacuum Society, Baltimore, MD, Nov. 2-7, 2003.
- ◆ "Corrosion of Steels by Lead Bismuth Eutectic: Observations, Models, and Implications," presented at the AFCI Semi-Annual Review, Livermore, CA, Feb. 24-26, 2004.
- ◆ "Mechanisms of Lead-Bismuth Eutectic Corrosion Chemistry involving Stainless Steels in Nuclear Reactor Cooling Systems," presented at the Annual Meeting of the American Chemical Society, Anaheim, CA, March 29-31, 2004.

FUTURE WORK

In the future, analytical work will continue and the analytical repertoire will be expanded. For example, laser Raman spectroscopic studies and x-ray diffraction studies have already been started.

A small lead facility will be constructed, which will allow the exposure of steel samples to oxygen-controlled lead bismuth eutectic at various temperatures and conditions.

Experiments will be conducted that employ ion implantation in steel samples. By implanting isotope-labeled alloy constituents (e.g., nickel), one can examine the migration of these constituents of steel under realistic conditions. Migration rates will be measured, which are crucial inputs to the theoretical models of the corrosion process currently being developed at Los Alamos National Laboratory.

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