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The Role of Hydrogen Isotopes in Deformation and Fracture of Aluminum Alloys

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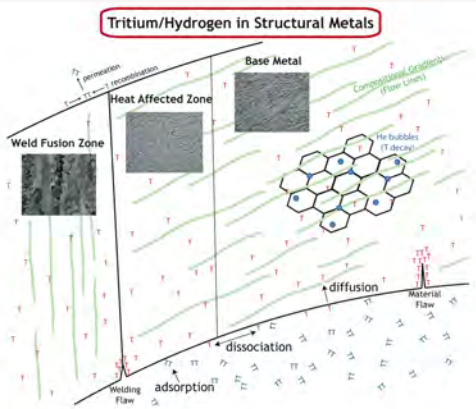
What is the challenge?

- Virtually all metals are embrittled by hydrogen.
  - Hydrogen embrittlement is a process by which hydrogen permeates a material and substantially reduces its resistance to fracture
  - Materials selection is greatly limited by compatibility with hydrogen
  - Environments of gaseous hydrogen isotopes are encountered in many applications:
    - Nuclear weapons
    - Fusion energy
    - Petrochemical processing
    - Fuel cell technologies
- Advantages of aluminum alloys in gaseous hydrogen service environments compared to steels, include
  - Low permeability to hydrogen
  - Low solubility for hydrogen
  - Hydrogen embrittlement has not been observed in gaseous environments.

This project investigates fundamental hydrogen-metal interactions with the aim of evaluating aluminum alloys for containment of hydrogen isotopes in nuclear weapons.



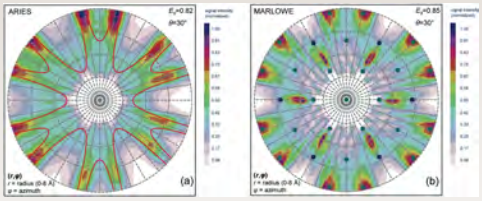
Hydrogen diffuses into metal and interacts with the metal's microstructure. Hydrogen is "trapped" at specific features in the microstructure and will segregate to stress concentrators. In the case, of tritium, radioactive decay also produces helium bubbles in the metal.

What have we learned so far?

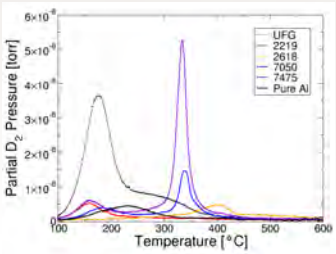
- Aluminum surfaces have been characterized using LEIS.
- Hydrogen transport properties are not sensitive to alloy content.
- Hydrogen trapping does depend on alloy content.
- Fracture resistance and fatigue crack growth of commercial aluminum alloys are not changed by exposure to high-pressure gaseous hydrogen.

Surface science

a) Experimental LEIS map shows atomic structure of the Al(111) surface in real space over a 1 nm radius. Method is being extended to hydrogen-covered surfaces.
b) The experimental results can be simulated with sophisticated simulation tool.



from: RD Kolasinski, JA Whaley, RA Karnesky, C San Marchi and R Bastasz. Nucl Instrum Meth B (online 2011) doi:10.1016/j.nimb.2010.11.038.

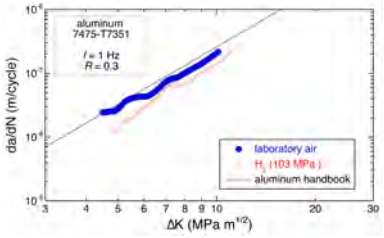


Hydrogen transport

Thermal desorption spectra for several aluminum alloys and pure aluminum that were previously exposed to high-pressure gaseous hydrogen, showing the strength of hydrogen trapping in these alloys.

Hydrogen-assisted fracture

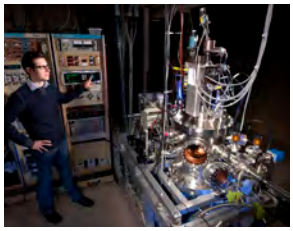
Fatigue crack growth curves for aluminum alloy 7475 in the T7351 temper, showing no effect of hydrogen at pressure of 103 MPa.



What is our innovation?

We are evaluating fundamental hydrogen-aluminum interactions using unique facilities at Sandia, Livermore CA:

- Low energy ion scattering (LEIS) to investigate thermodynamics and kinetics of hydrogen adsorption-desorption processes on aluminum surface
- Thermal desorption spectroscopy (TDS) to measure trapping of hydrogen in aluminum
- Mechanical testing *in situ* in high-pressure gaseous hydrogen (at pressure of 100 MPa) to probe fracture behavior



The Angle Resolved Ion Energy Spectrometer (ARIES) at Sandia/CA is one of the only instruments in the world that has been specifically optimized for investigating hydrogen on surfaces.

Mechanical testing in high-pressure gaseous hydrogen requires specialized hardware and custom transducers, which have been developed over many years at Sandia/CA.

What is in progress?

- Binding location and height of H on the Al(111) surface are being investigated.
- Trapping sites are being identified and characterized.
- Input from surface and transport studies will aid optimization of experimental procedures for mechanical testing.

Why is this important for our nation?

- Provides the scientific basis for comprehensive evaluation of aluminum alloys for tritium containment in nuclear weapons;
  - an important innovation to ensure the safety and security of the stockpile.
- Has broad applicability to materials selection for hydrogen fuel applications
  - will influence international codes and standards for hydrogen-powered vehicles and infrastructure

Acknowledgements:

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