SAND2011-6668P

Hydrogen Embrittlement of Aluminum Alloys

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Outline

- Objective and Motivation
- Background of Hydrogen Pre-charging
  - -in water
  - -in high pressure gas
- Materials and Procedure
- Experimental Data and Results of Hydrogen Pre-charging by Ultrasonic Agitation of DI-water
- Summary
- Future Work

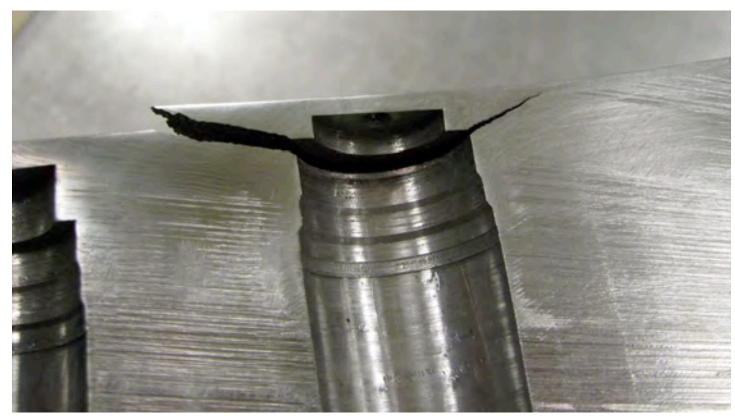
Motivation and Objective

Motivation:

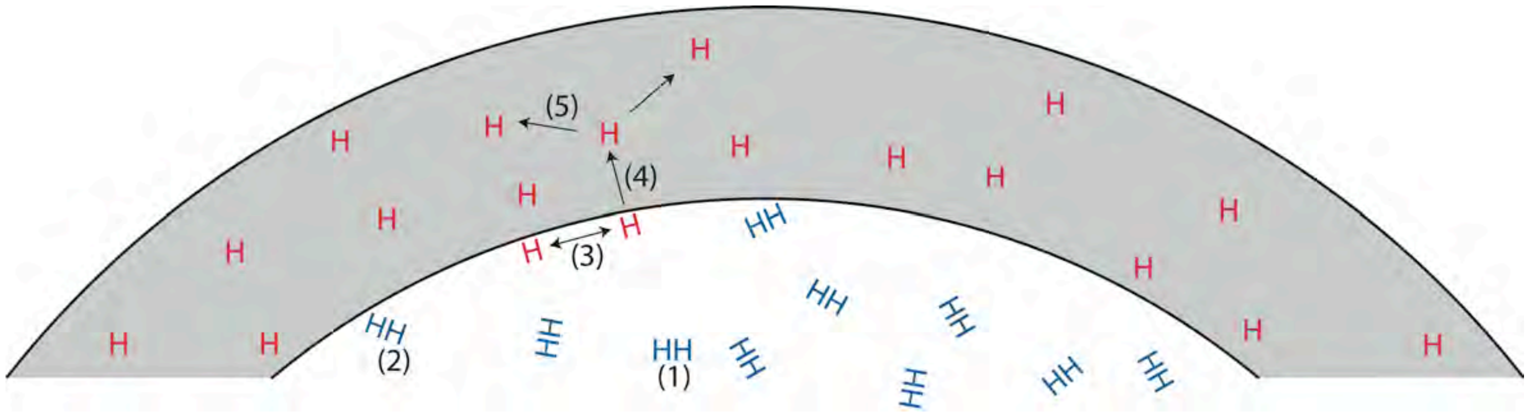
To determine the effect of hydrogen concentration on the embrittlement and mechanical properties of aluminum alloys

Objective:

Pre-charge aluminum with hydrogen by exposing the aluminum to an ultrasonic field to investigate intermediate hydrogen concentrations and their affects.



Diffusion, dissolution and permeation of hydrogen



Chemical Equilibrium: $\frac{1}{2}H_2 \leftrightarrow \underline{H}$

(1) Hydrogen gas
(2) Physisorption
(3) Dissociation
(4) Dissolution
(5) Diffusion

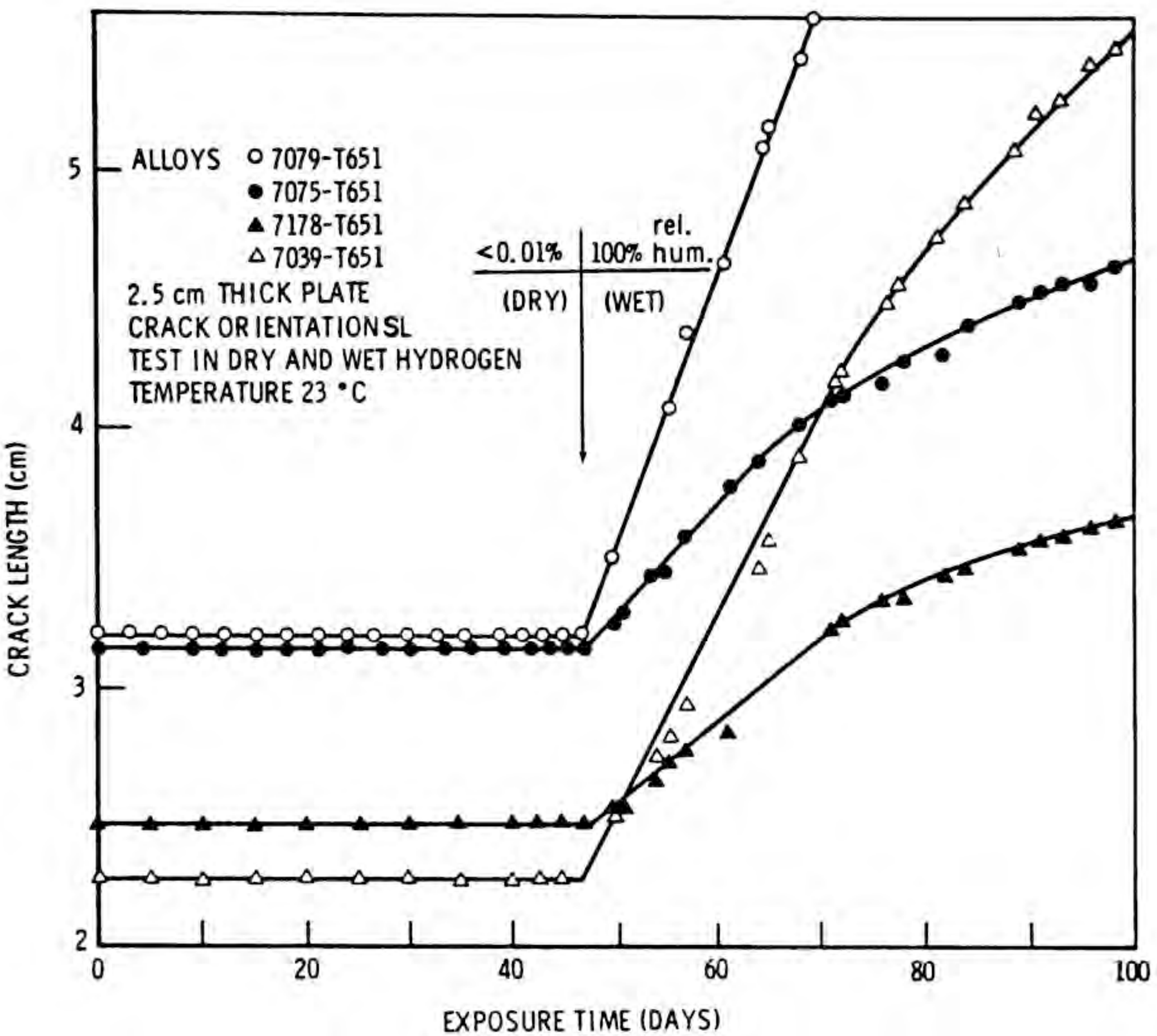
Solubility $K = \frac{c_L}{\sqrt{f}}$

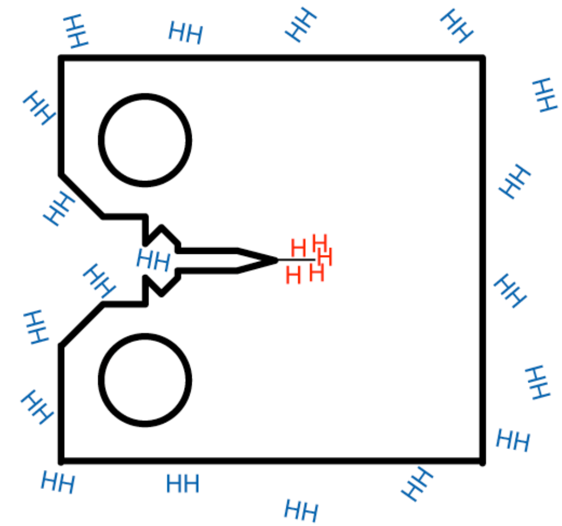
Diffusivity $J_\infty = D\frac{c_L}{t} = \frac{DK}{t}\sqrt{f}$

Permeability $\phi \equiv DK$

Ref: San Marchi and Somerday, ASME PVP-2011 conference.

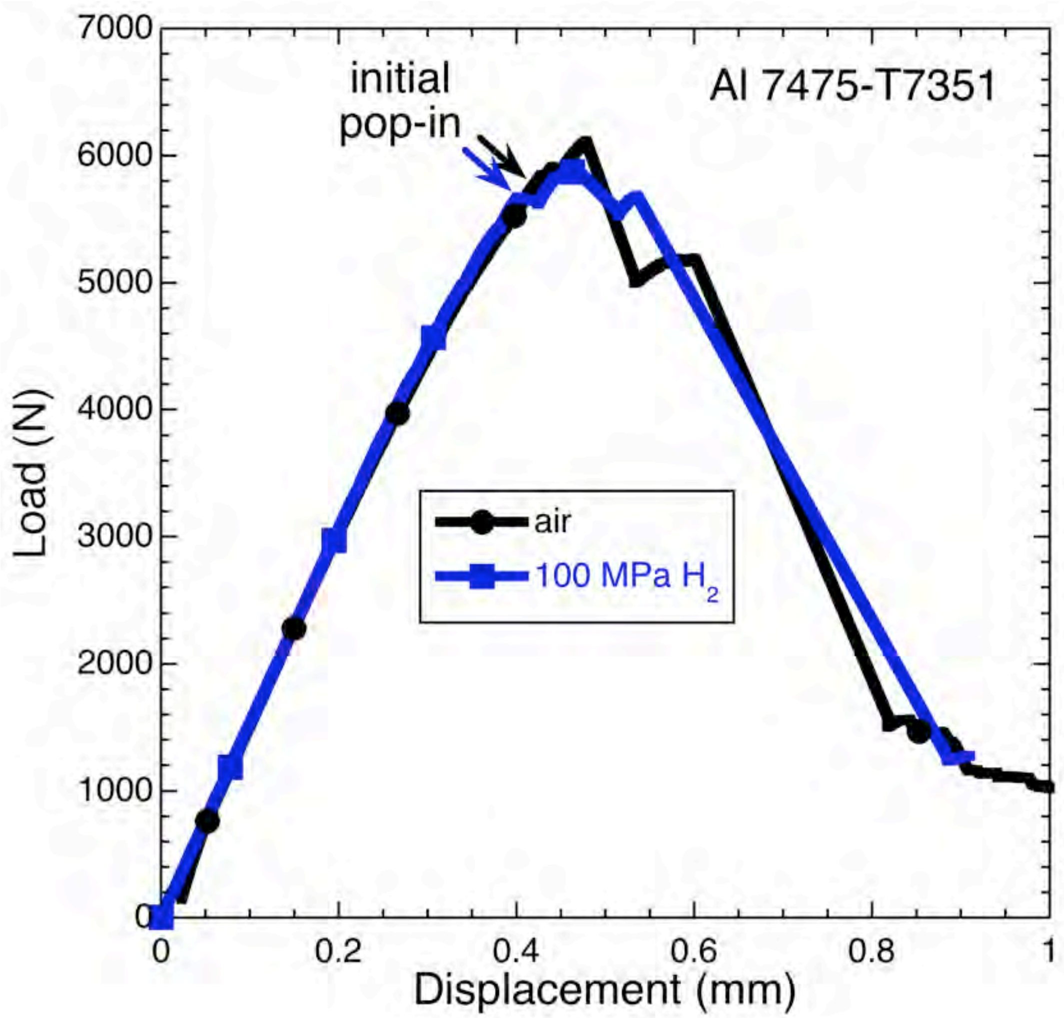
Aluminum alloys become susceptible to hydrogen-assisted fracture in the presence of water





Ref: M.O. Speidel, Hydrogen Embrittlement and Stress Corrosion Cracking, 1984

Fracture resistance of high-strength aluminum is not affected by hydrogen

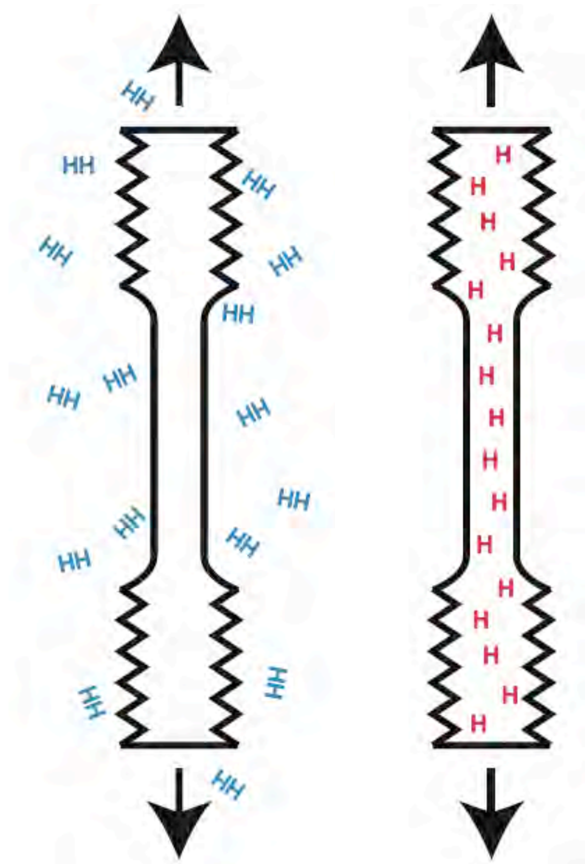


- SL/ST orientation
- Manufacturer reported toughness: 40 MPa $m^{1/2}$ (SL)
- Measured in laboratory <u>air</u>:
  44 MPa $m^{1/2}$
- Measured in gaseous <u>hydrogen</u> at pressure of 103 MPa:
  45 MPa $m^{1/2}$
  (average of 4 replicates)

Ref: San Marchi and Somerday, ASME PVP-2011 conference.

Techniques for pre-charging aluminum with hydrogen

- Ultrasonic Bath: exposure to an ultrasonic field produced by an ultrasonic bath containing H_2O or D_2O
- Gas plasma: immersion in H_2 gas plasma at different voltages
- Cathodic charging: immersion in H_2SO_4 or HCl with a $NaAsO_2$, a hydrogen recombination poison
- Chemical charging: etching NaOH, containing $NaAsO_2$, the hydrogen recombination poison

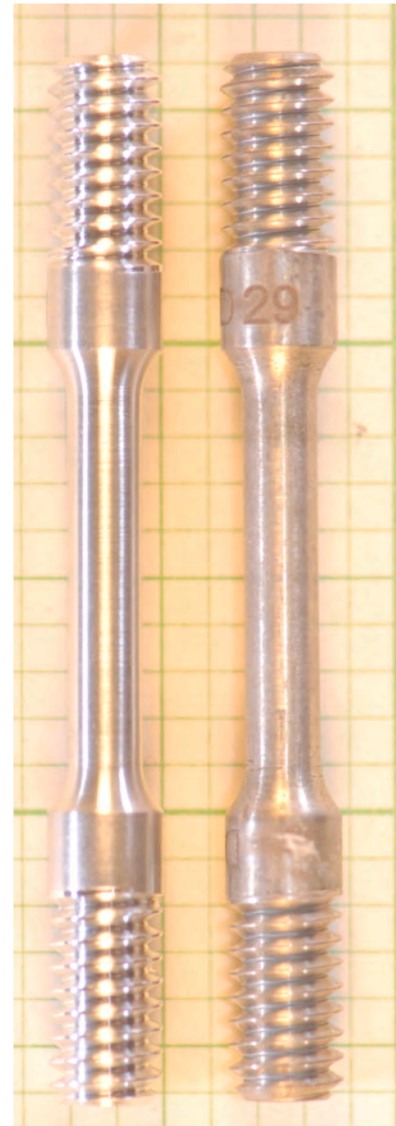


Materials and Experimental Procedure

- 2618-T61 aluminum tensile specimens with typical composition of 1.1% nickel, 1.2% iron, 1.5% magnesium, ~3% copper , and 93.5% aluminum

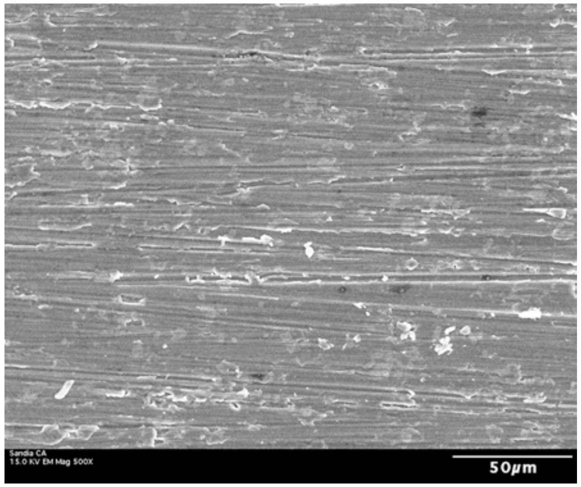
- Three 2618 aluminum tensile specimens, B213, B214, and B218, were exposed to an ultrasonic field in an ultrasonic bath

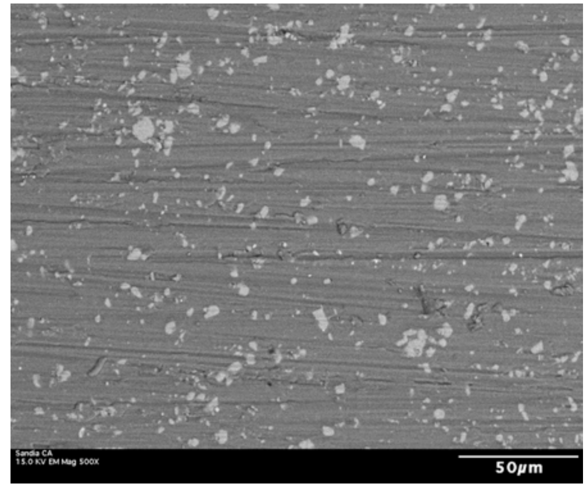
- Samples precharged for 26 hours, 100 hours, and 200 hours in DI water at a temperature of ~328 K



Ultrasonic field creates insignificant surface damage

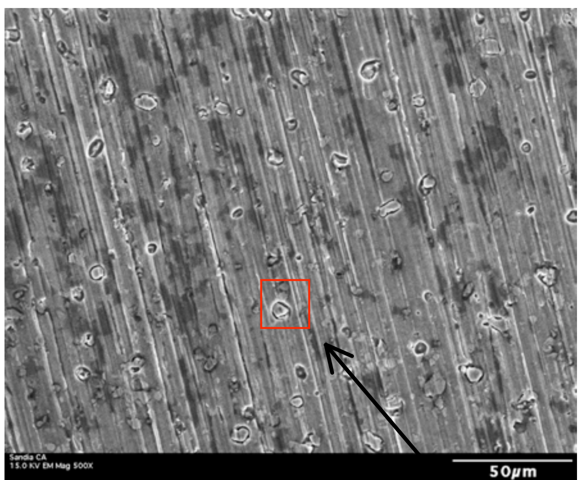
SEI of surface B215

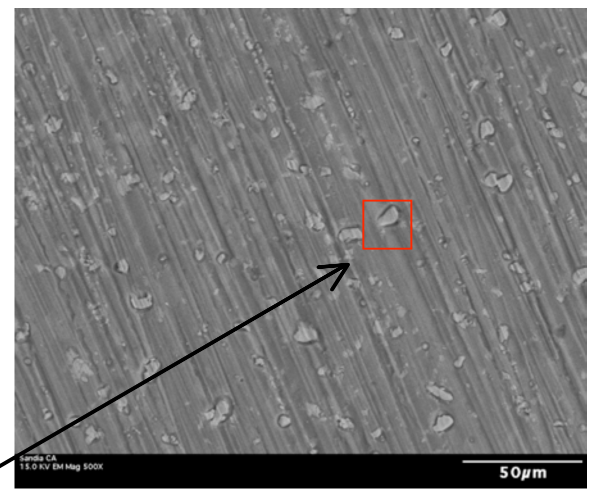




BEI of surface B215

SEI of surface B217 after 15 hours exposure to ultrasonic field

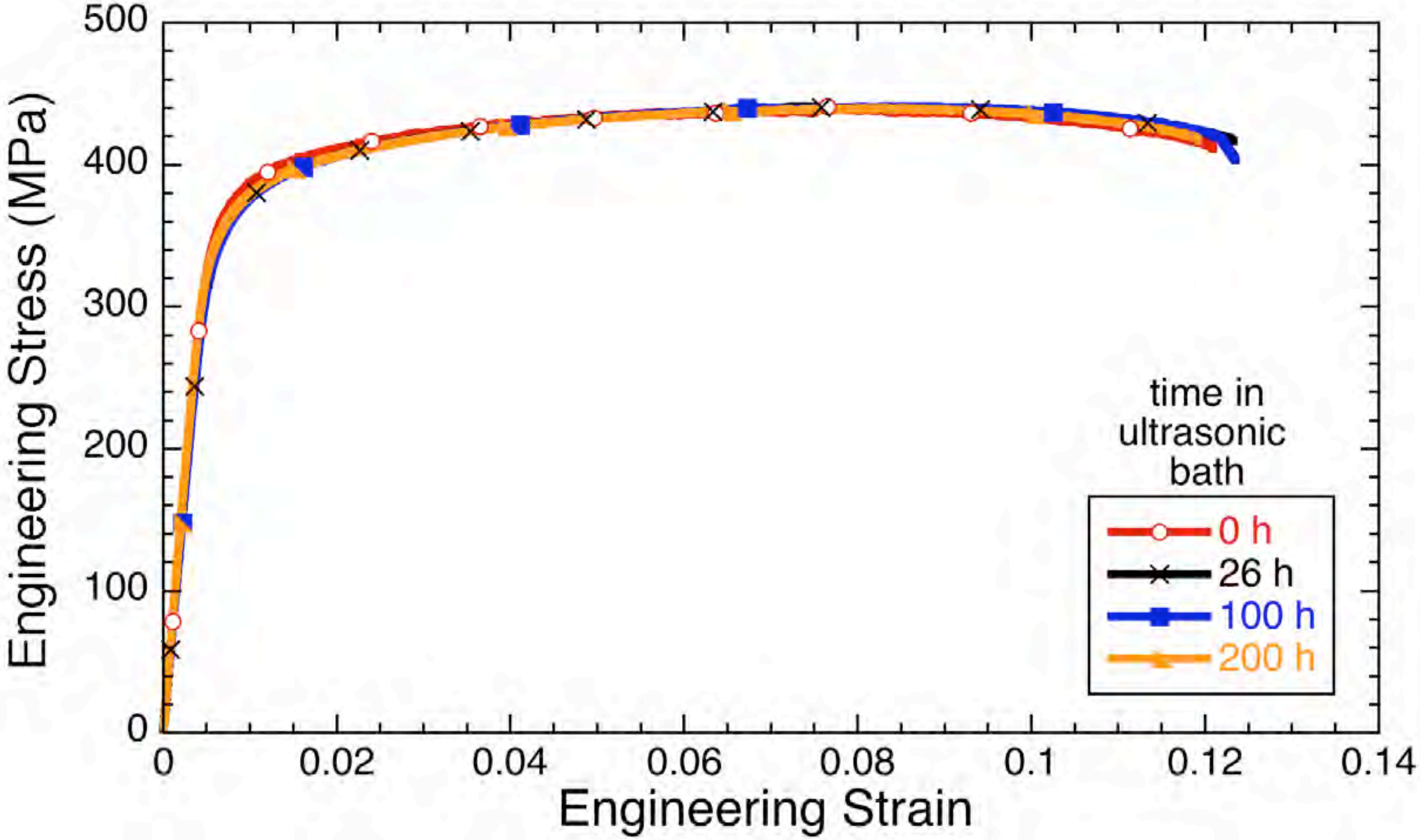




BEI of surface B217 after 15 hours exposure to ultrasonic field

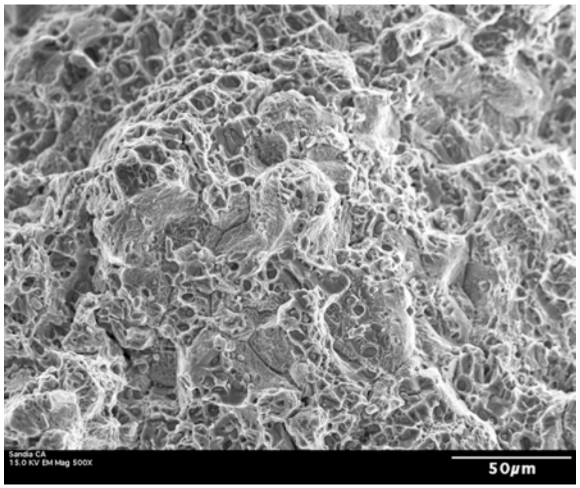
De-bonding particles

Tensile properties of aluminum unchanged by pre-charging

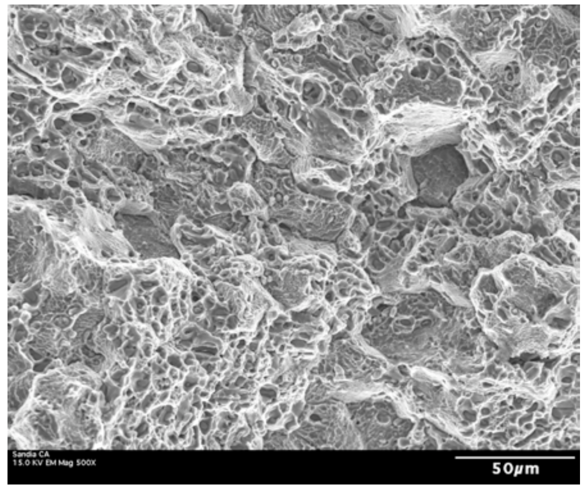


0 hr sample B201 contained 4 wt ppm
26 hr sample B218 contained 8 wt ppm
100 hr sample B213 contained 22 wt ppm
200 hr sample B214 contained 31 wt ppm

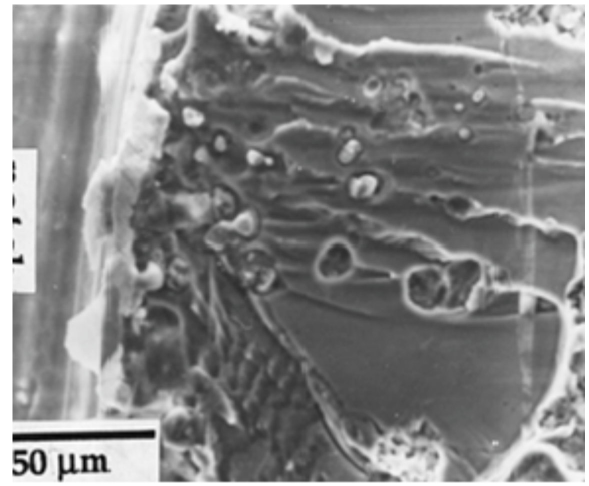
Fracture surfaces exposed to hydrogen similar to fracture surface in air



Air induced fracture of sample B201, 2618 Al, at 500x



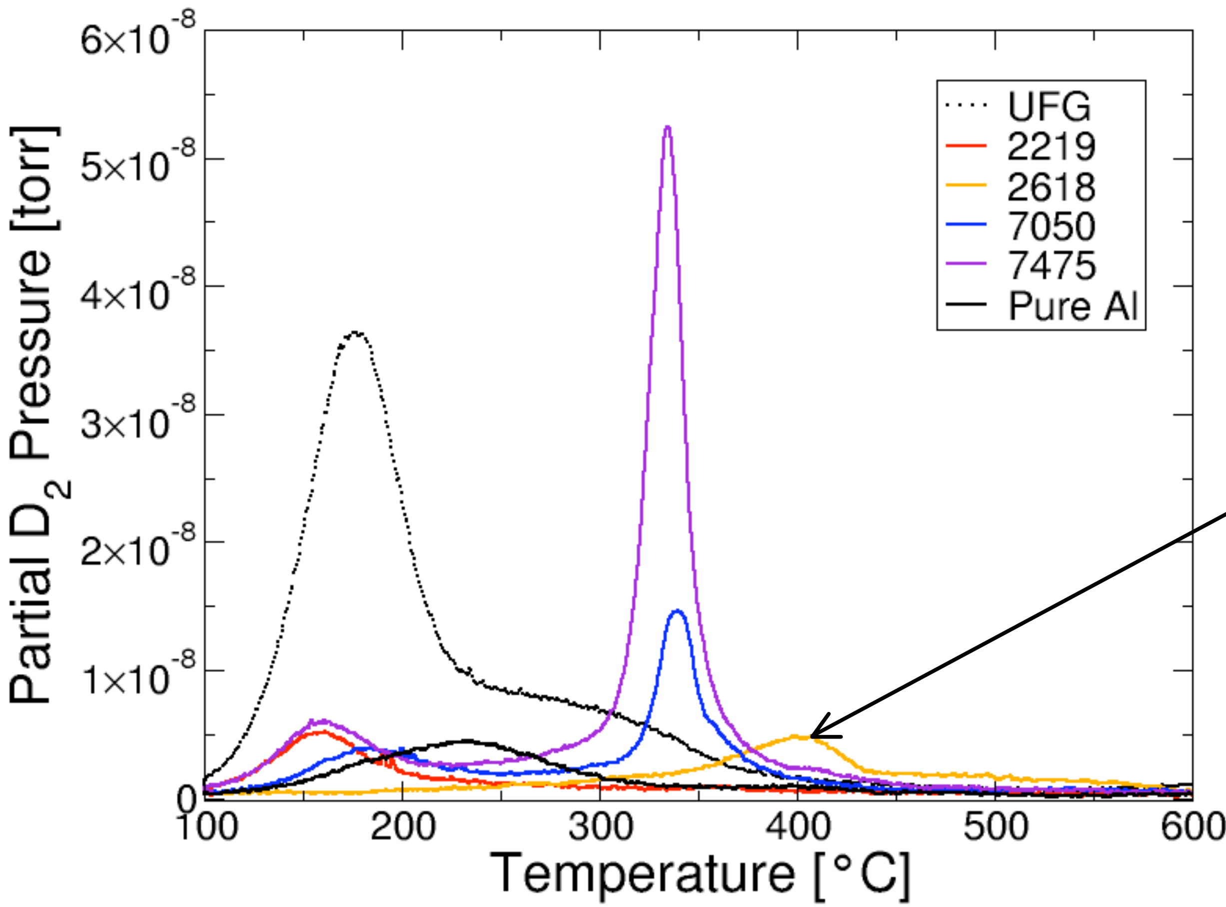
Hydrogen induced fracture of sample B213, 2618 Al, using ultrasonic bath pre-charging, at 500x



Ref.: Najjar et al Mater Sci Eng A238 p293

Fracture induced by hydrogen embrittlement of 7050-T74 Al, using cathodic charging, at 500x

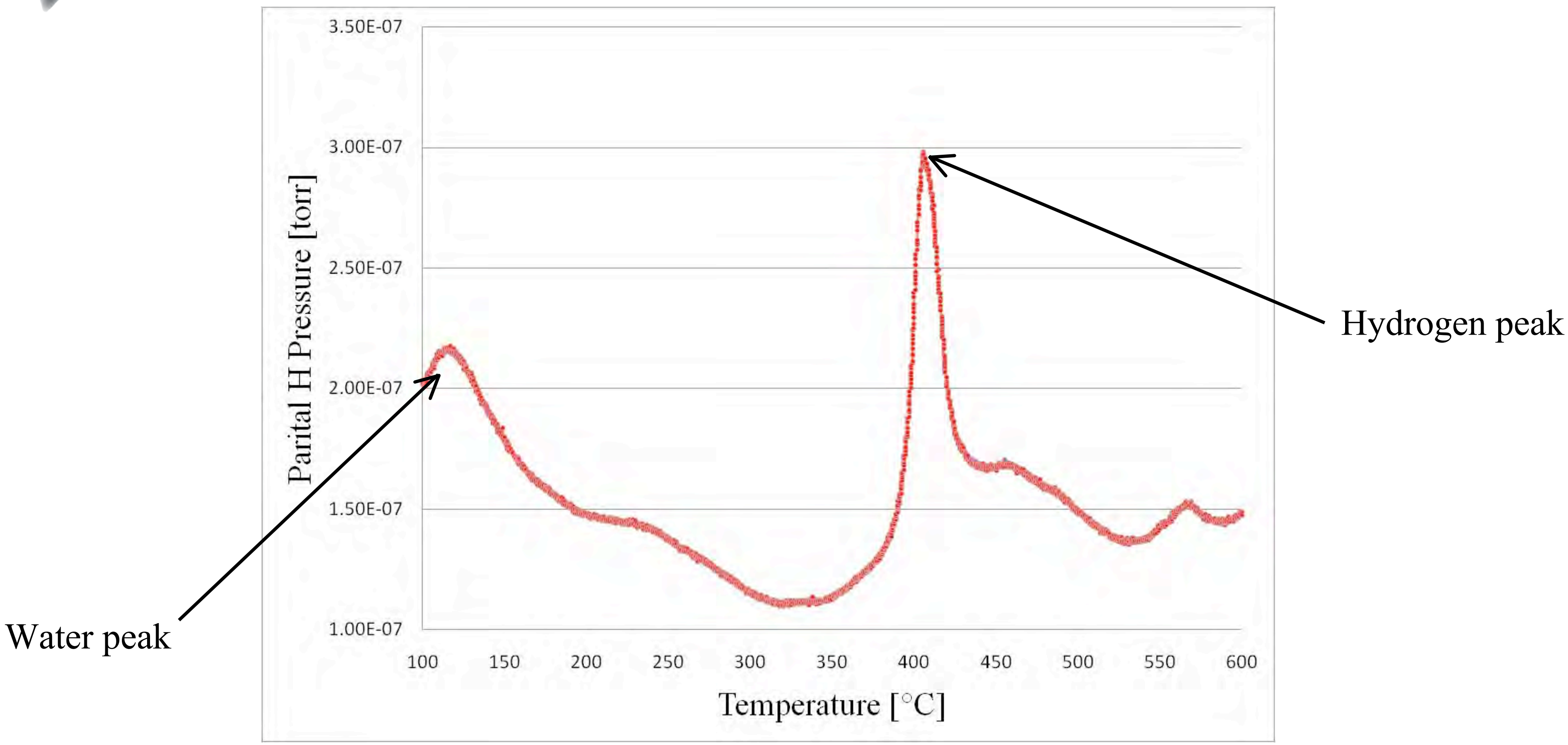
Thermal desorption of aluminum 2618 thermally pre-charged in high-pressure D_2



Ref: Karnesky.

- 2618 aluminum peak approximately the same as the pure aluminum peak
- the concentration of D_2 is much lower in the 2618 alloy than other aluminum alloys

Thermal desorption of ultrasonically pre-charged 2618 Al indicating the presence of hydrogen

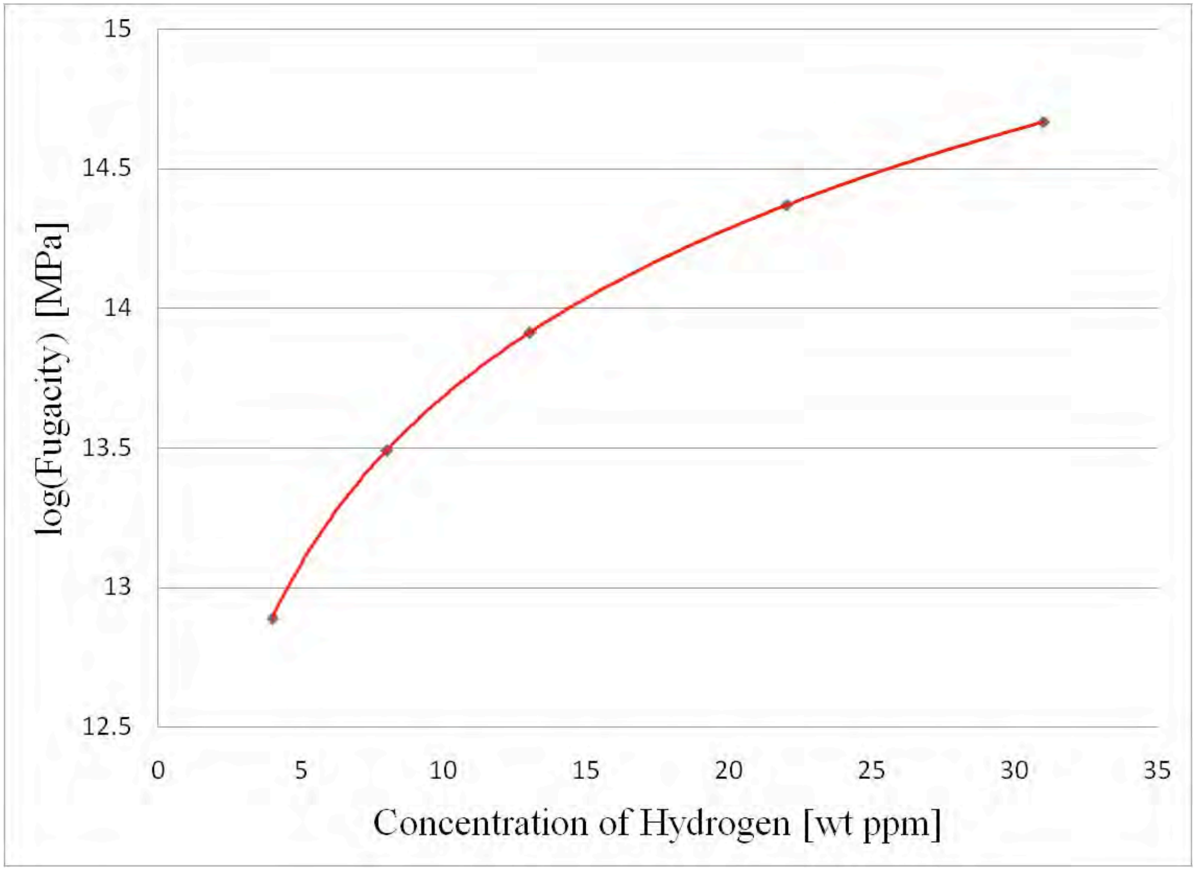


After 100 hours, hydrogen concentration is 22 wt ppm and the fugacity, the effective pressure of hydrogen at the surface of the sample, $f = \left[\frac{c_L}{K}\right]^2$, is ~$10^{14}$ MPa

Removing aluminum oxide layer decreases hydrogen concentration

- Used 220, 280, and 1200 grit sandpaper to remove the aluminum oxide layer formed by ultrasonically charging the sample B214 for 200 hours.
- Sample B214 with the oxide layer had a hydrogen concentration of 31 wt ppm
- Sample B214 with the oxide layer removed by sanding had a hydrogen concentration of 13 wt ppm

Fugacity increases with hydrogen concentration



Despite varying concentrations of hydrogen, the fugacity is >10^{12} MPa when the hydrogen concentration > 5 ppm

Summary

•Hydrogen is being dissolved into the aluminum during pre-charging through the ultrasonic agitation of DI water

•Pre-charging aluminum in an ultrasonic field significantly increases hydrogen content, which scales with the pre-charging time, in comparison to exposing aluminum to gaseous hydrogen

- Additional work is necessary to characterize hydrogen content of the oxide

•Tensile properties and the fracture surface of pre-charged aluminum remains unchanged by high hydrogen concentrations

Future Work

•Expose aluminum alloys, 7050 and 7475, to an ultrasonic field and measure the hydrogen concentration as well as the tensile properties to determine how different alloys are affected by the ultrasonic bath technique

•Pre-charge aluminum alloys in an ultrasonic field and remove varying surface layer depths to determine the affect aluminum oxide has on the measured concentration of hydrogen and the penetration depth of the hydrogen in the bulk samples