



*...working with industry to develop and apply technology, measurements and standards*

## **Evaluation of the Susceptibility of Simulated Welds In HSLA-100 and HY-100 Steels to Hydrogen Induced Cracking**

**R. E. Ricker, M. R. Stoudt, and D. J. Pitchure**

**Materials Performance Group  
Metallurgy Division**

**Materials Science and Engineering Laboratory  
National Institute of Standards and Technology  
Gaithersburg, MD 20899-8553**

*For more information contact: [richard.ricker@nist.gov](mailto:richard.ricker@nist.gov)*

*Presented at the ACS/ASM Conference  
Materials Innovations in an Emerging Hydrogen Economy  
Feb 25-27, 2008, Cocoa Beach, FL*

# Objectives

More than one...

## Objective 1:

... to demonstrate that one need not have access to a high pressure hydrogen gas testing facility to investigate the effects of hydrogen on materials, test hypotheses, study relationships between microstructure and embrittlement, and work on innovations for hydrogen fuel systems.

## Objective 2:

... to compare the susceptibility of a low carbon HSLA steel of a composition similar to future pipeline steels to the susceptibility of a normal carbon strengthened steel of equivalent yield strengths.

## Objective 3:

... to compare the susceptibility of the same steels following a heat treatment that emulates the thermal history of a single pass weld and generates microstructures representative of weld heat affected zones (HAZ) in these two steels.

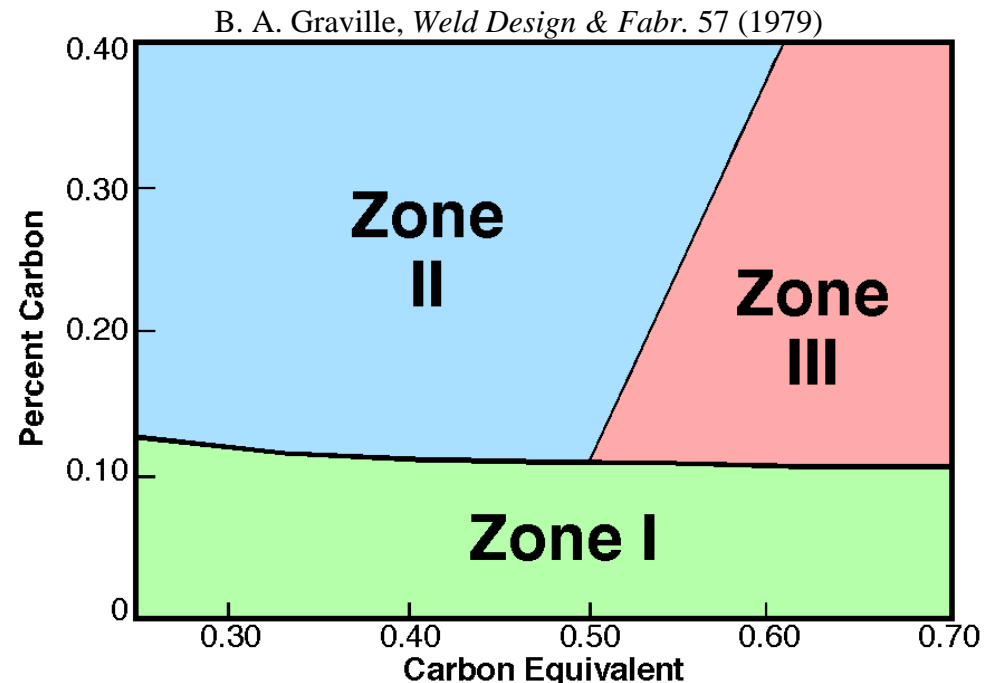
# Hypothesis

The microstructures of HSLA 100 will make it less susceptible than HY 100

Element	HY-100	HSLA-100
Carbon (% mass)	0.16	0.015
Manganese	0.25	0.95
Nickel	2.94	3.55
Molybdenum	0.43	0.61
Chromium	1.59	0.61
Vanadium	0.005	---
Aluminum	---	0.054
Copper	0.05	1.71
Niobium	---	0.044
Silicon	0.23	0.38
Phosphorus	0.009	0.008
Sulfur	0.013	0.0015

Parent Metal		HY-100	HSLA-100
YS	(MPa)	690	690
UTS	(MPa)	800	740
STF	(%)	10.0	12.3
RA	(%)	69.0	80.5

Simulated Weld HAZ		HY-100	HSLA-100
UTS	(MPa)	866	797
STF	(%)	7.4	6.7
RA	(%)	61.6	88.9



$$CE = C + \frac{Mn}{6} + \frac{Si}{7} + \frac{Ni}{55} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{5} + 1.3Nb$$

**HSLA-100 is a low carbon precipitation hardened Zone I steel**

**HY-100 is a carbon strengthened Zone III steel with Cr to increase hardenability**

# Experimental

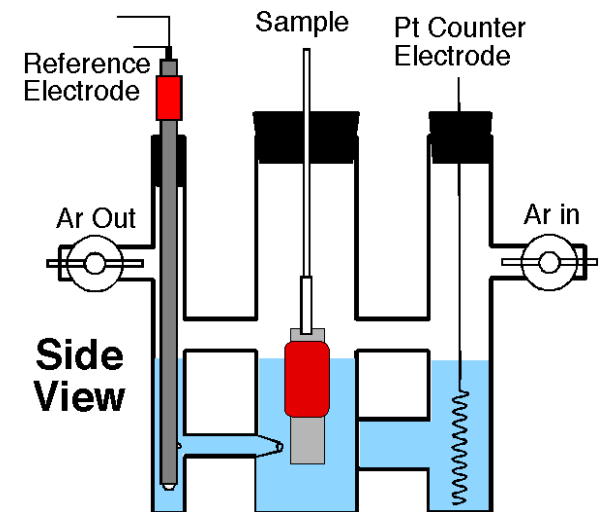
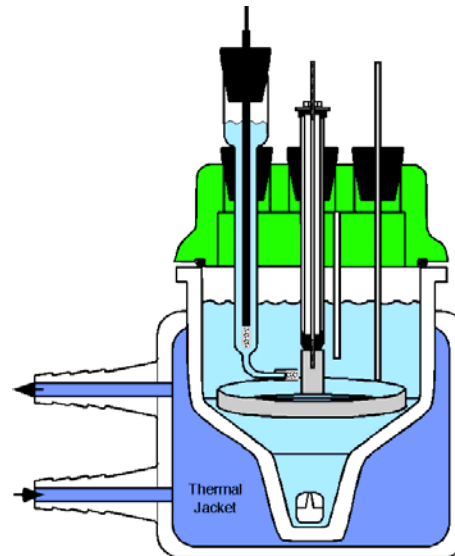
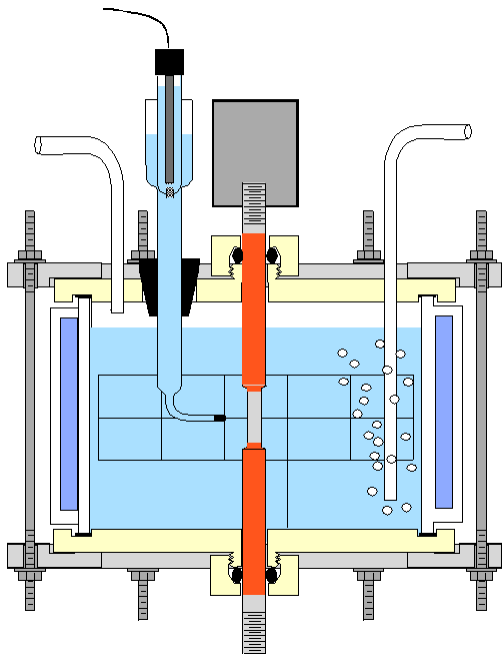
## Electrochemical Tests of HE Hypothesis

### Materials:

- Compositions (given)
- Rolled Plate  $\approx 25$  mm thick
- Cylindrical Tensile Samples
- Samples cut in rolling direction
- Weld Simulation (1 pass)

### Experiments:

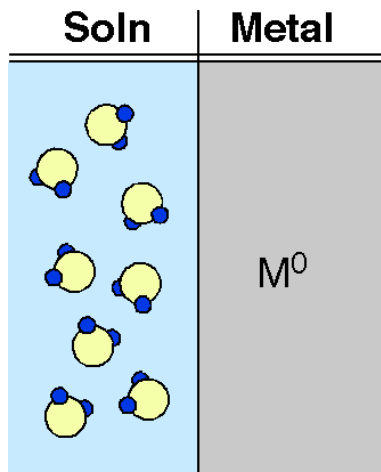
1. Quant. Metall.
2. SSR Tensile Tests
3. Electrochemical Polarization
4. Electrochemical Abs.-Des.
5. SEM Fractography



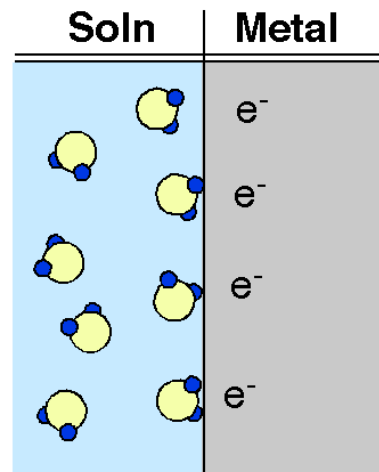
# Electrochemical Hydrogen Charging Note

Cathodic Currents Produce H(ads) - The H(ads) Produces H<sub>2</sub>(g)

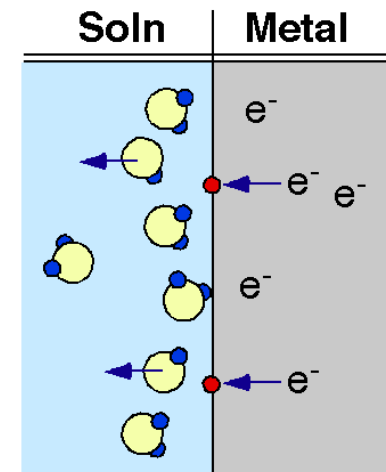
a)  $E \approx PZC$



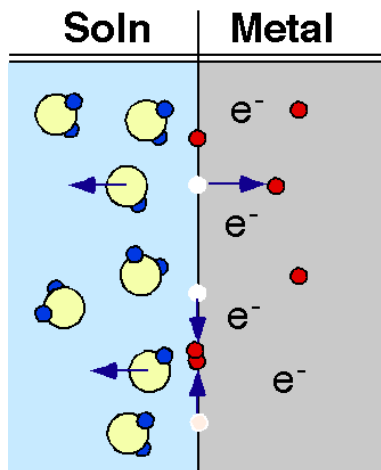
b)  $PZC > E$



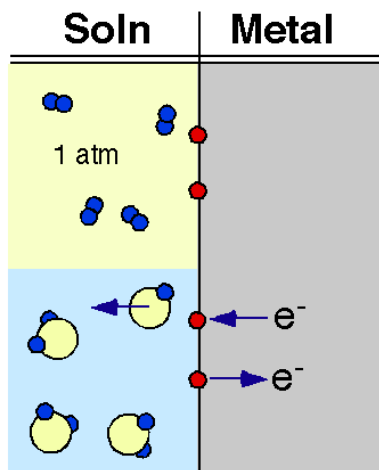
c)  $PZC \gg E - H(ads)$



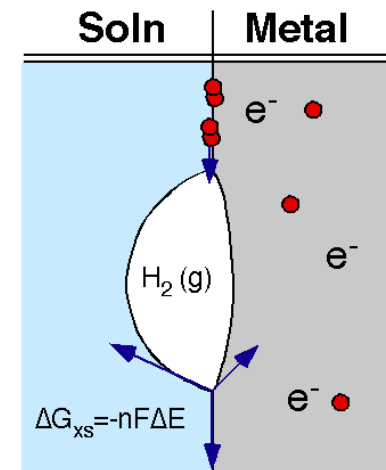
d) Recomb/Abs



e)  $E = E(H^+/H_2(1 atm))$



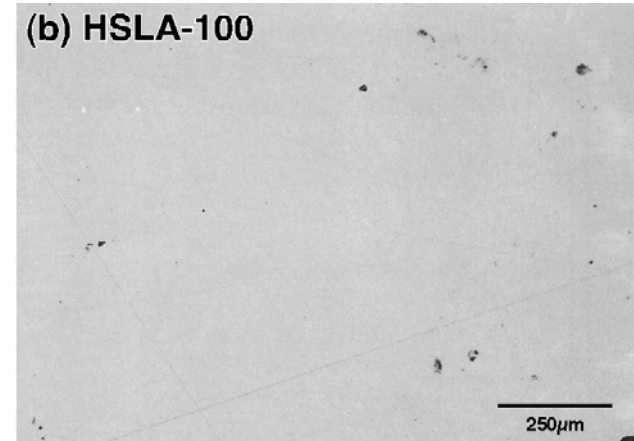
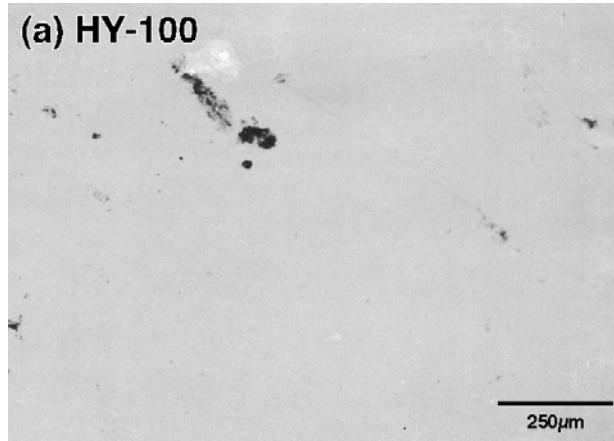
f) Bubble Nucleation



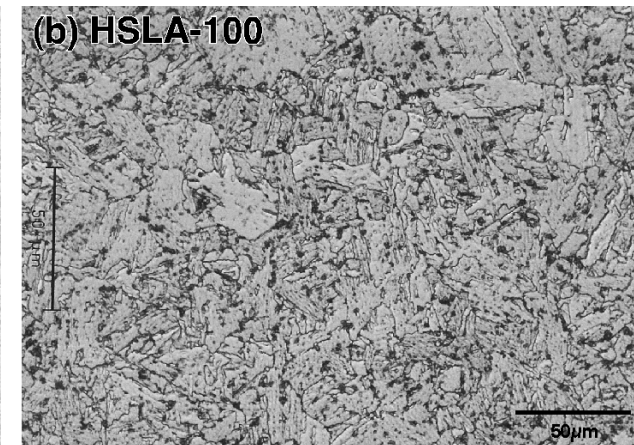
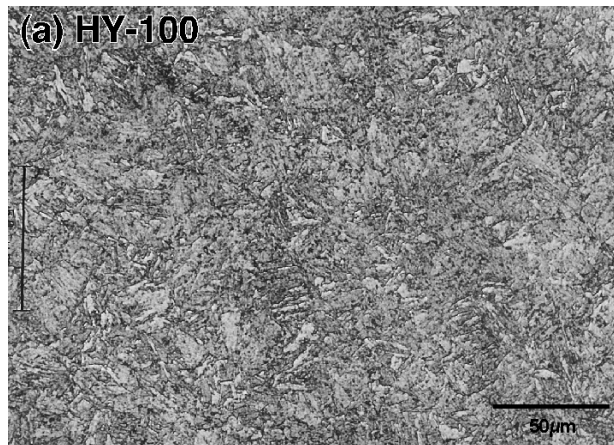
# Metallography

## Alloy Parent Metal

Unetched to reveal  
microconstituent  
particles



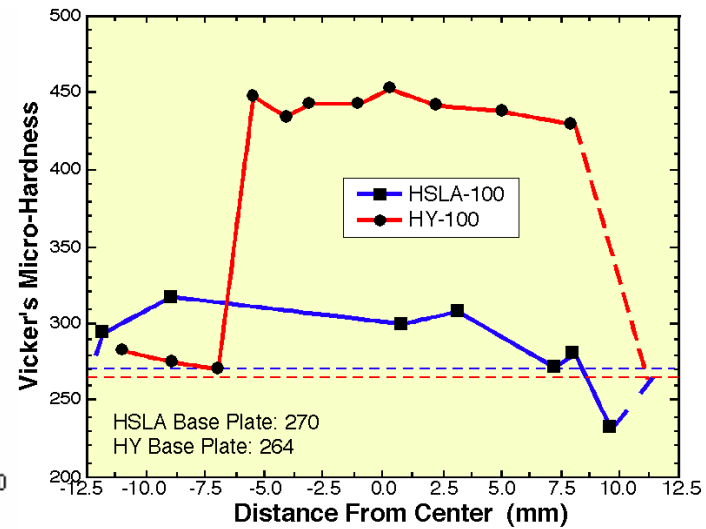
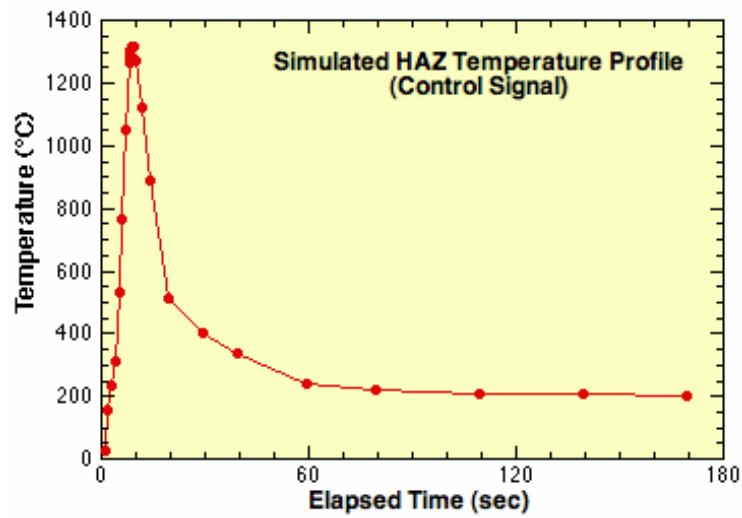
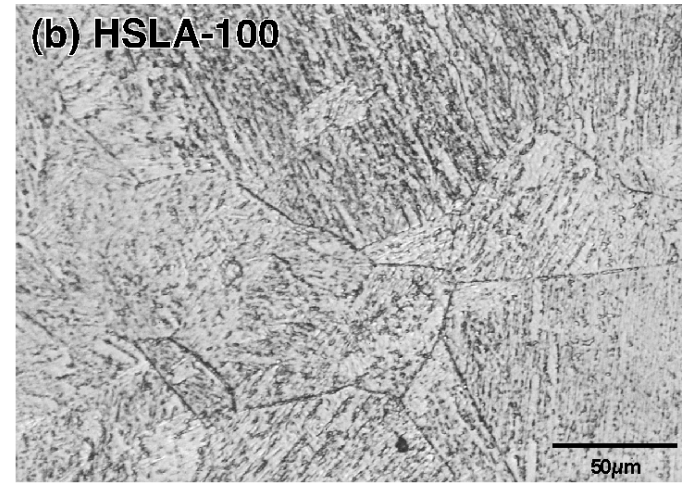
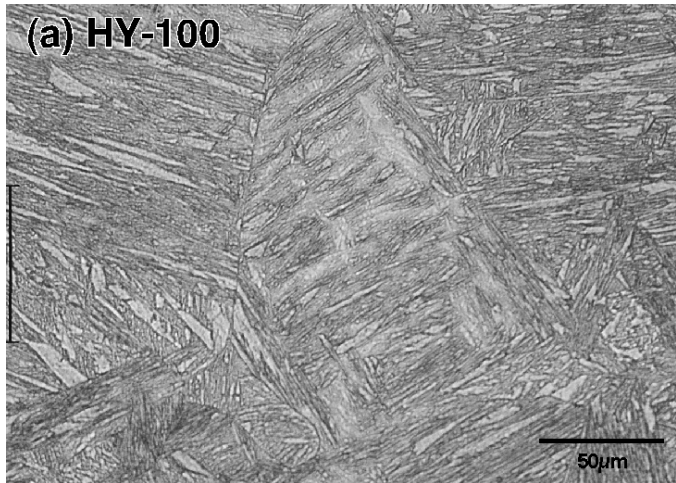
Etched to reveal  
microstructure



Prior Austenite Grain Size ( $\mu\text{m}$ )	$19.4 \pm 8.4$	$36.4 \pm 11.3$
Inclusions per unit area	$72.0 \pm 5.6$	$18.9 \pm 1.8$
Inclusion Size ( $\mu\text{m}$ )	$9.3 \pm 6.3$	$1.9 \pm 1.4$
Mean Inclusion Spacing ( $\mu\text{m}$ )	$65.2 \pm 37.6$	$175 \pm 105$
Inclusion Aspect Ratio	0.17	1.00

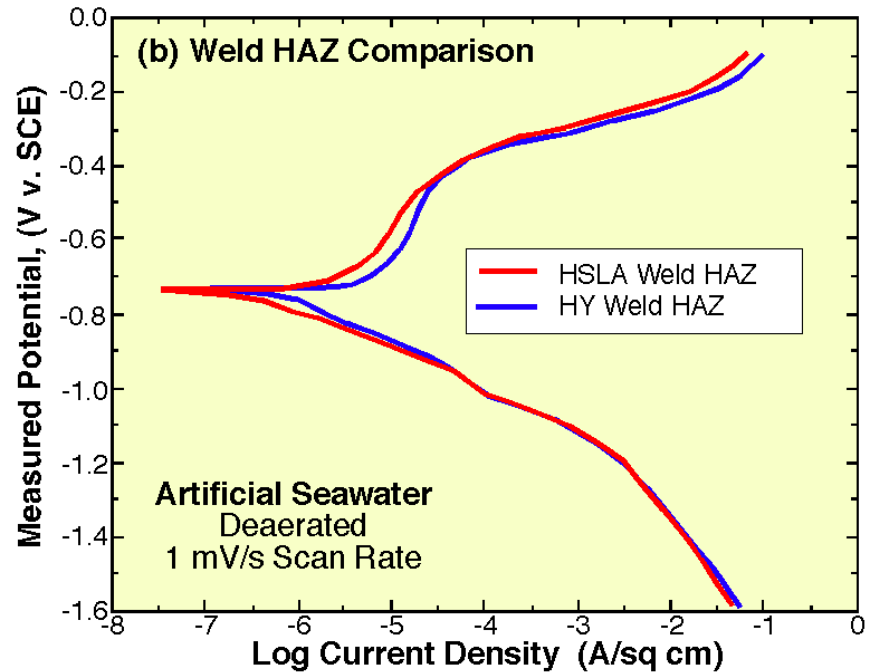
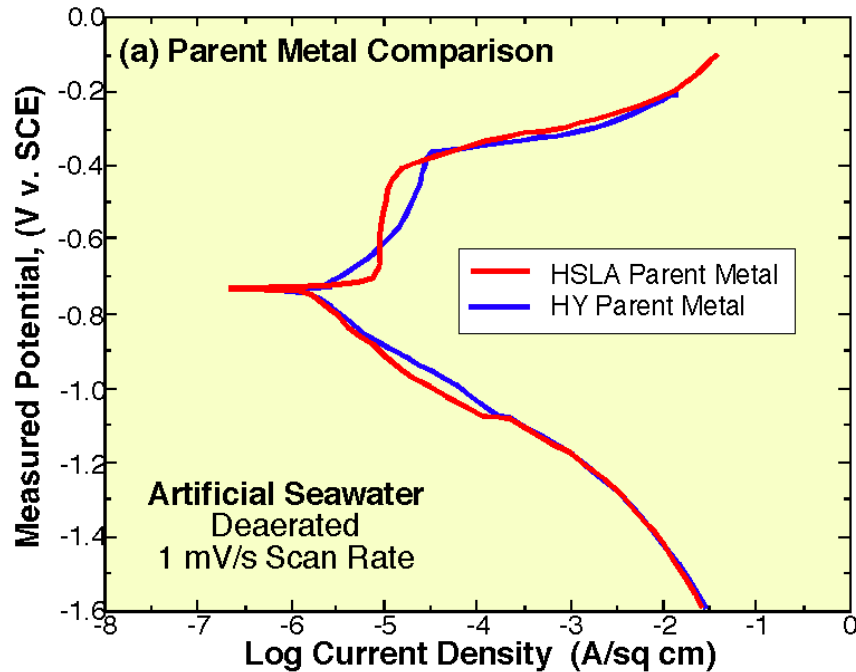
# Metallography

## Simulated Weld Heat Affected Zone Microstructures



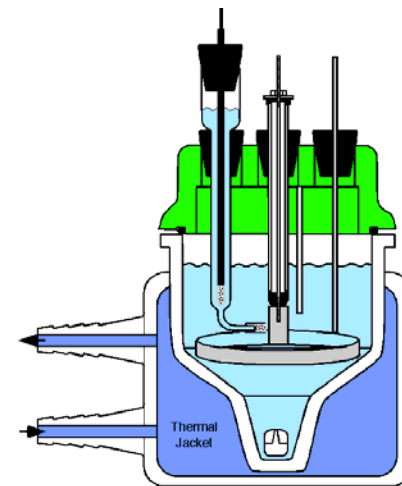
# Electrochemical Measurements

## Potentiodynamic Polarization Curves



Used to evaluate the current-potential relationships for the different alloys in the cathodic charging solution (artificial seawater)

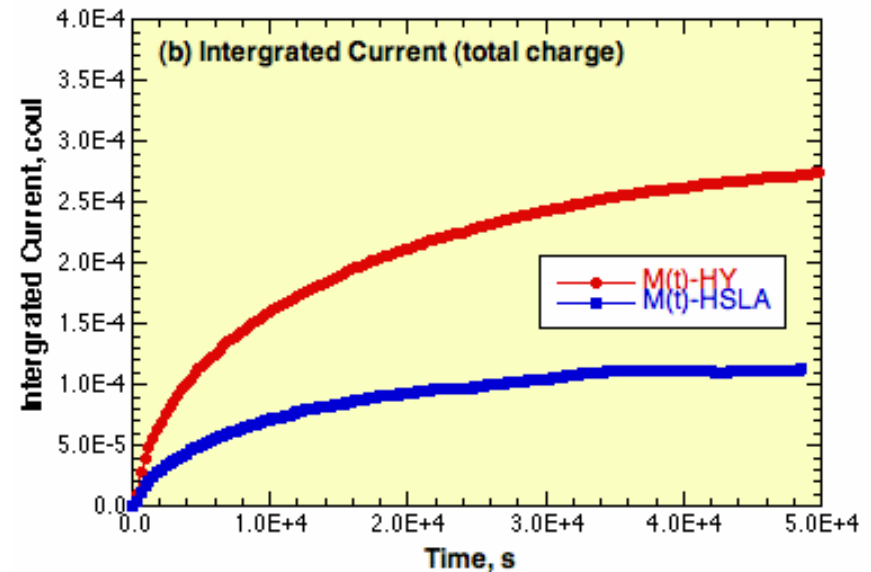
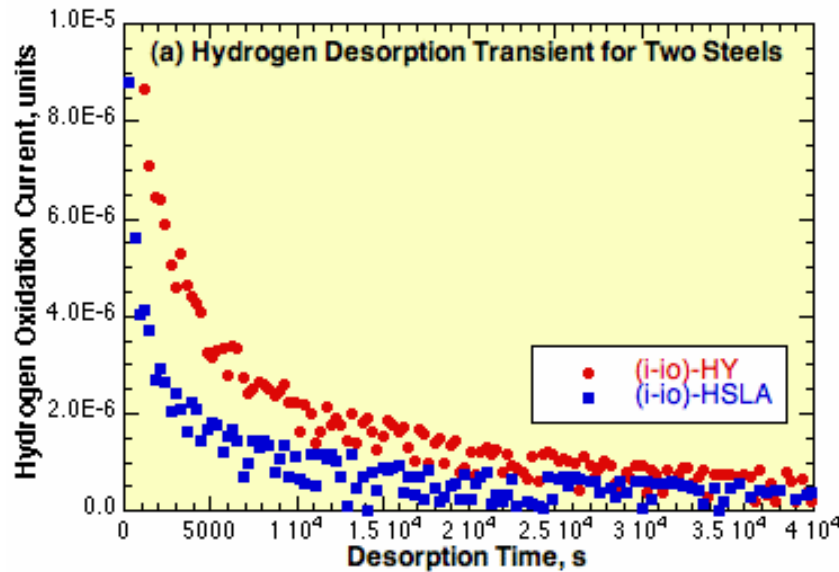
No differences that would influence H uptake were found.





# Electrochemical Absorption and Desorption

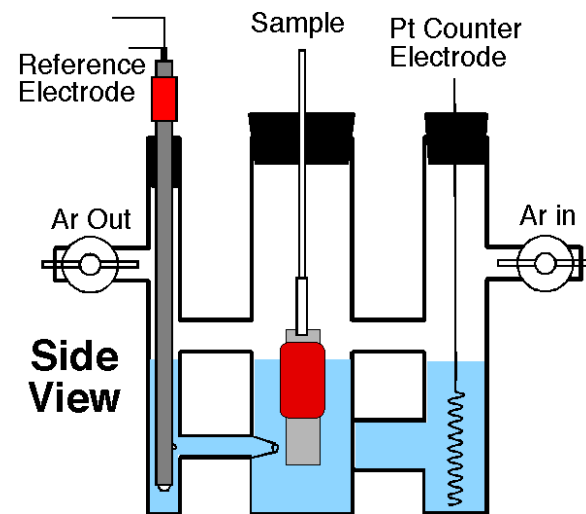
## To Compare Solubility and Diffusivity



Used to evaluate the H diffusivity and solubility in the parent metal of the alloys

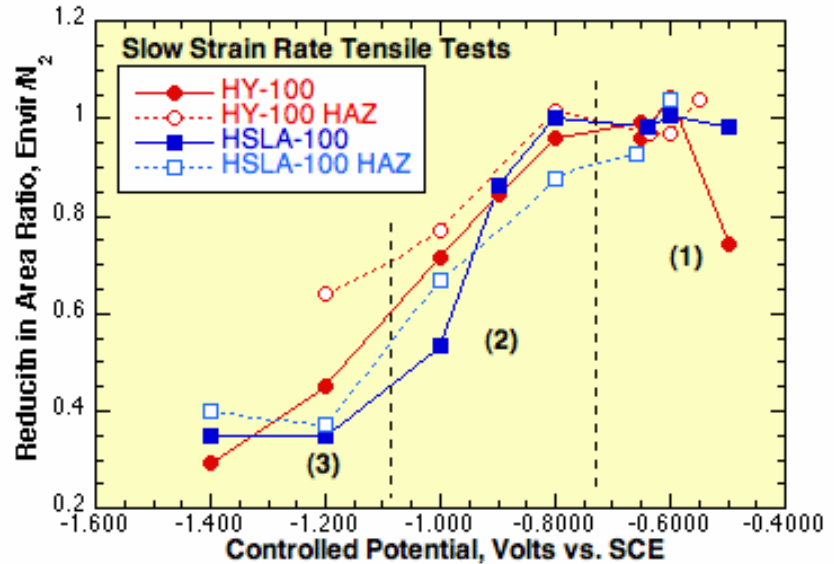
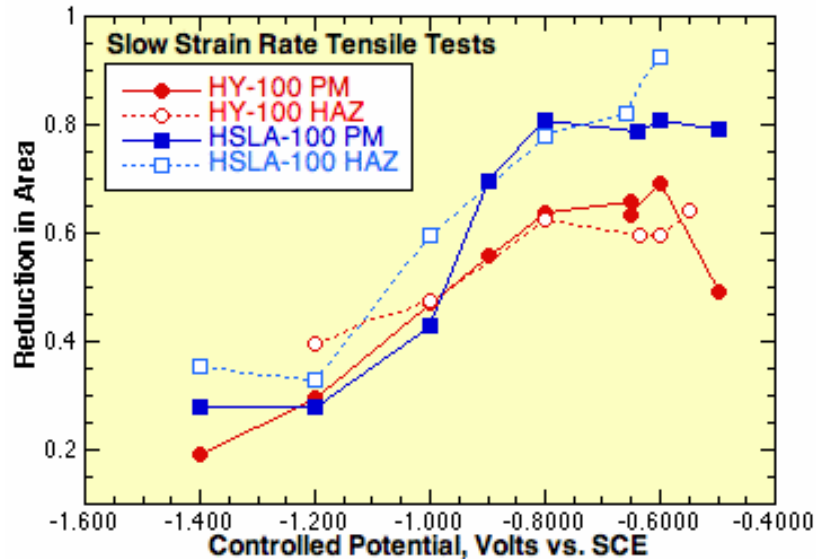
No significant difference was found in the diffusivities

More H was absorbed in the HY-100 steel at the same potential



# Susceptibility to Hydrogen Embrittlement

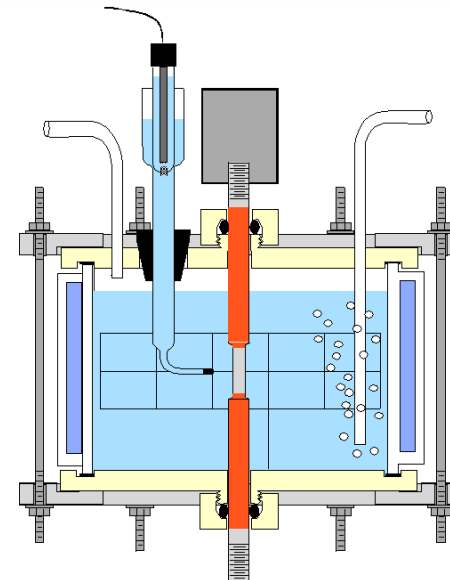
## Slow Strain Rate Tensile Tests at Cathodic Potentials



Used to evaluate changes in ductility as the H partial pressure increases

Both alloy exhibited reduced ductility in both the parent metal and the simulated weld HAZ

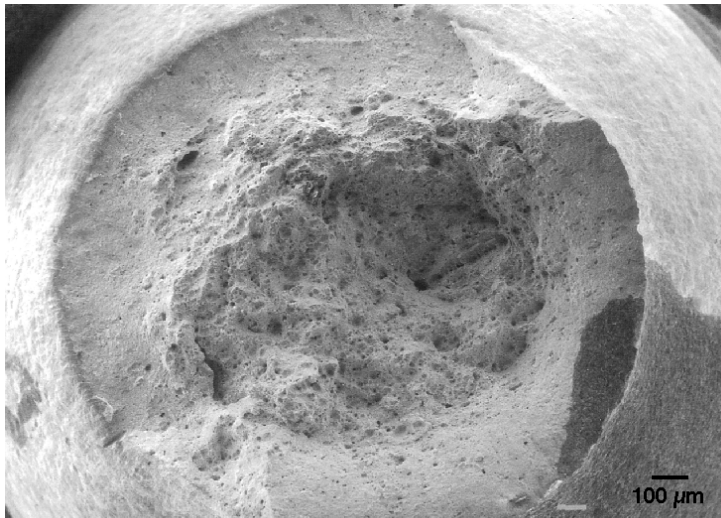
The changes were of similar magnitude



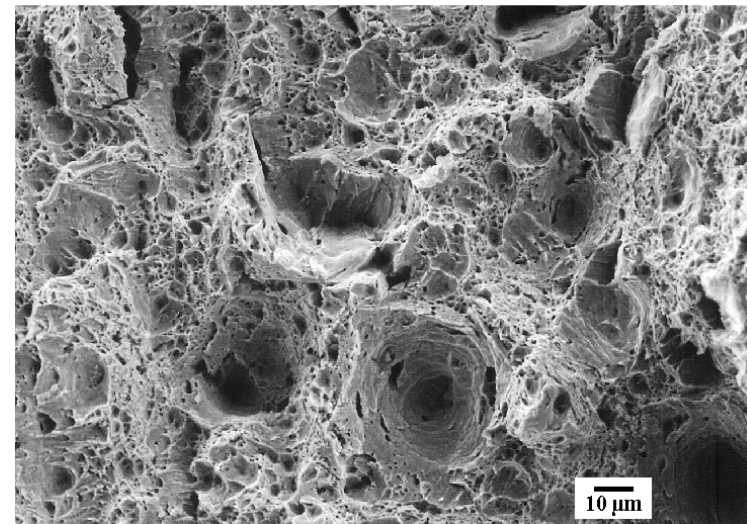
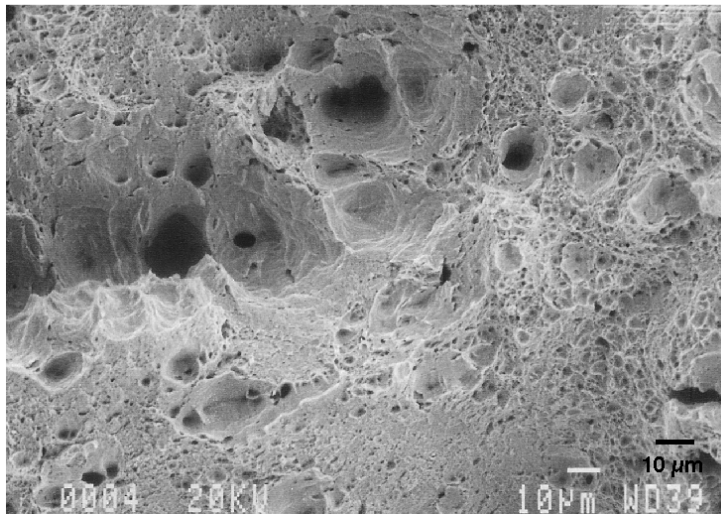
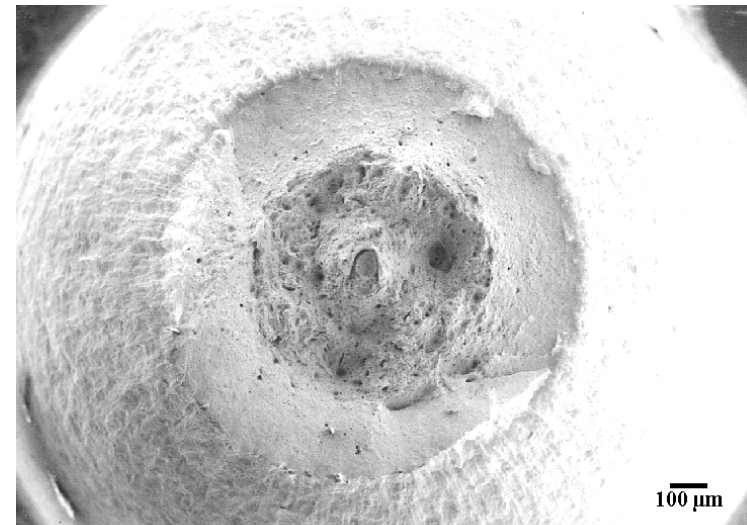
# SEM-1

## Fractography for Low P(H<sub>2</sub>)

**HY-100**



**HSLA-100**

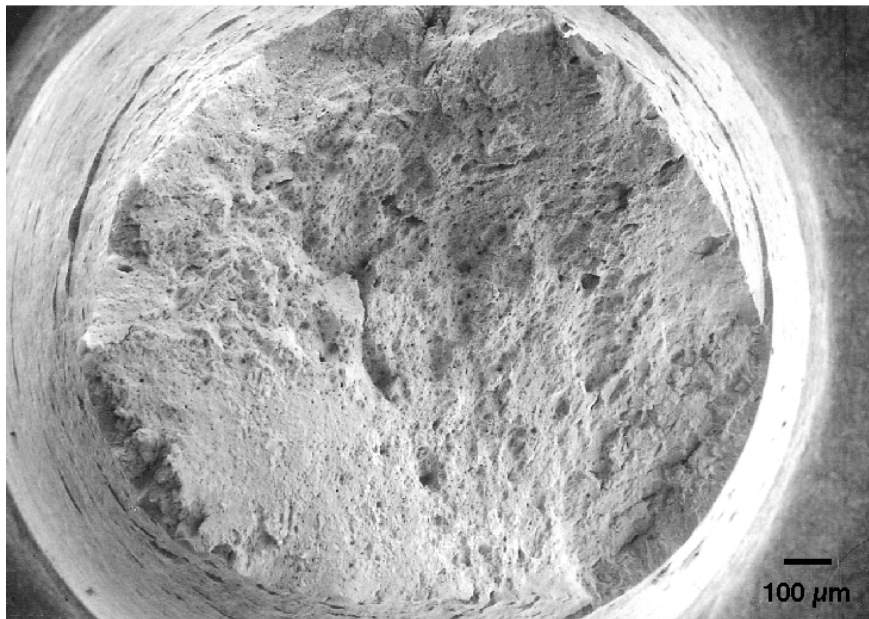


## SEM-2

### Fractography for Medium P(H<sub>2</sub>)

MSEL

**HY-100**



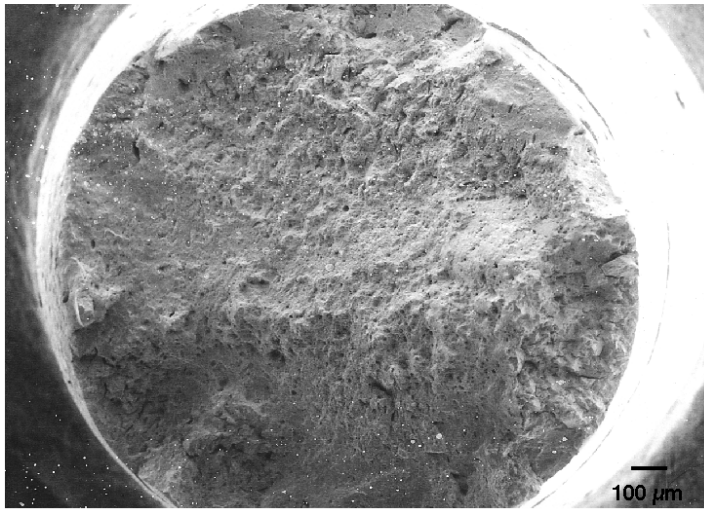
**HSLA-100**



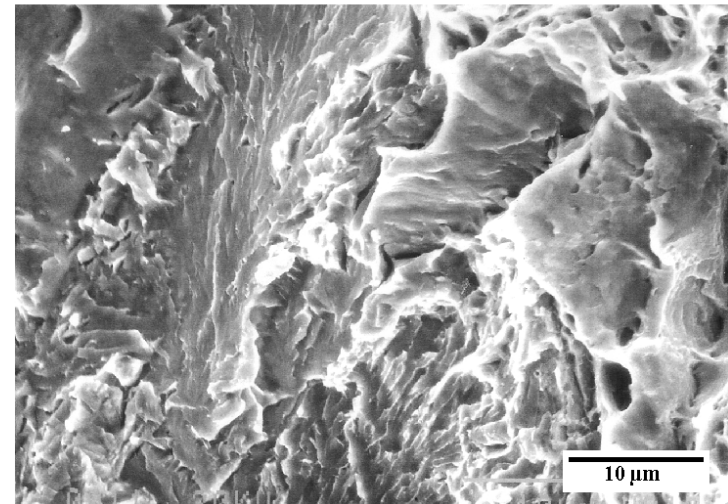
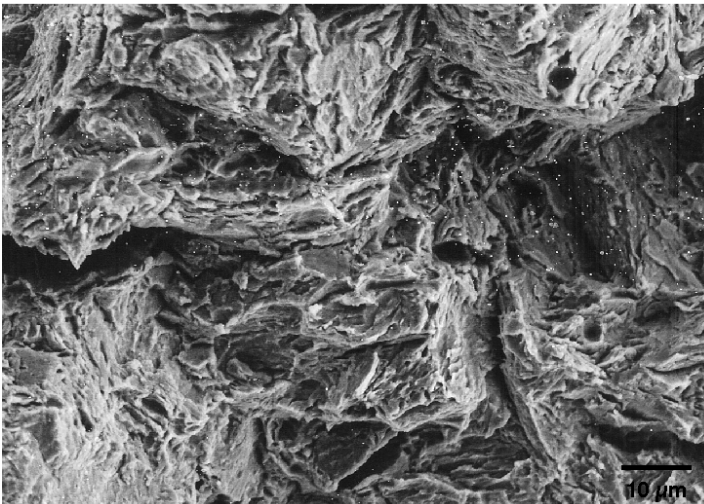
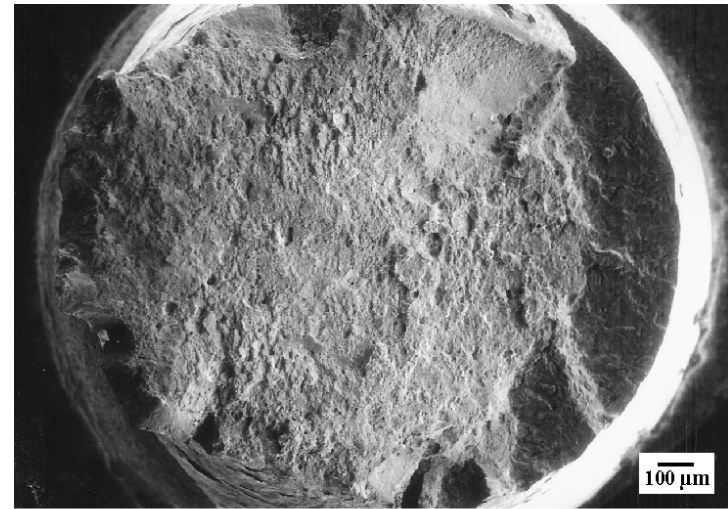
# SEM-3

## Fractography for High P(H<sub>2</sub>)

**HY-100**



**HSLA-100**



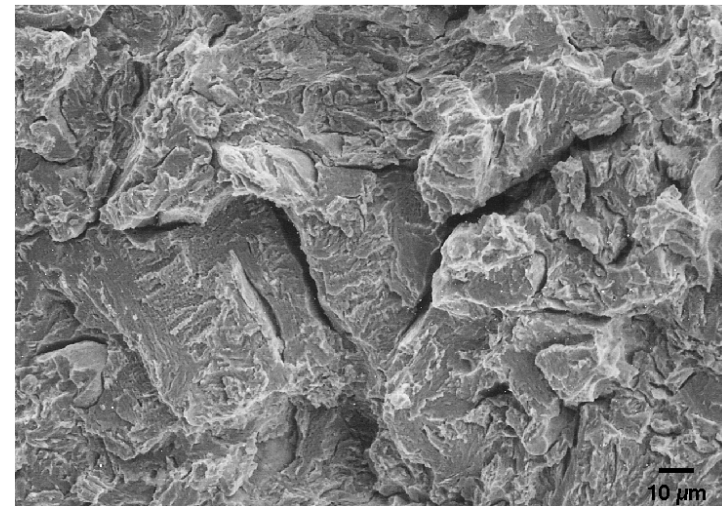
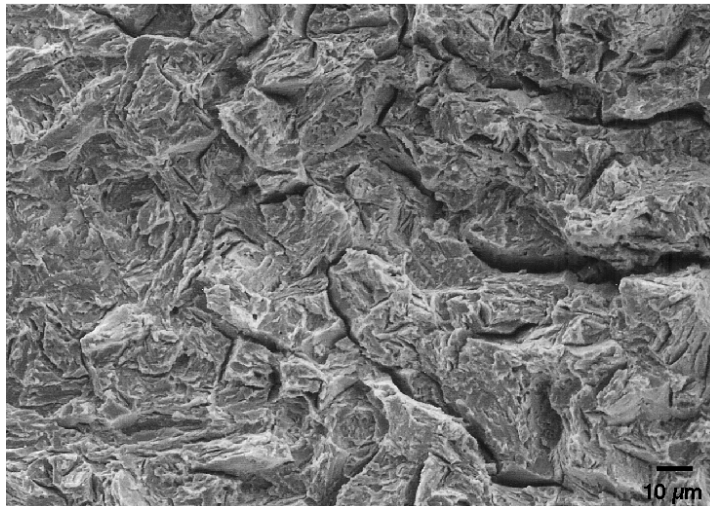
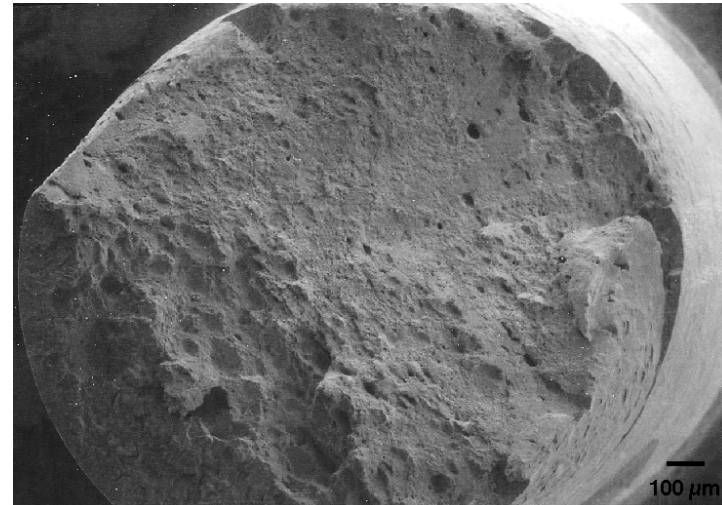
# SEM-4

## Fractography of Simulated Weld HAZs at High P(H<sub>2</sub>)

**HY-100**



**HSLA-100**

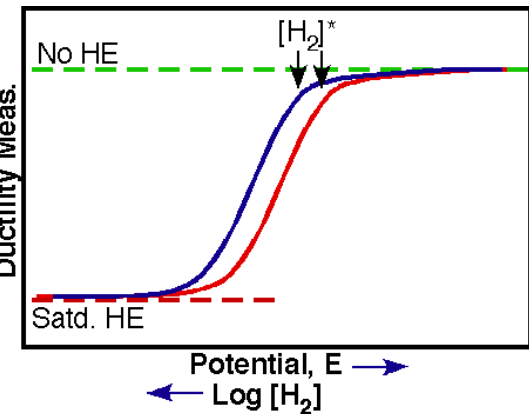
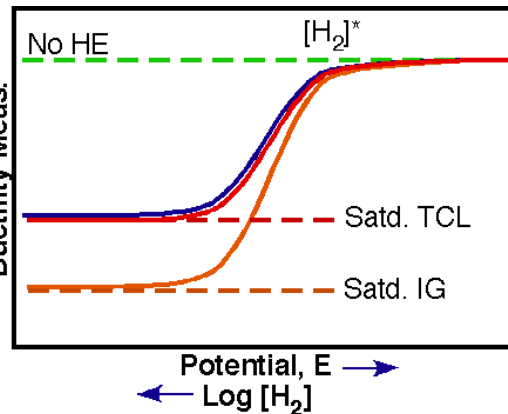
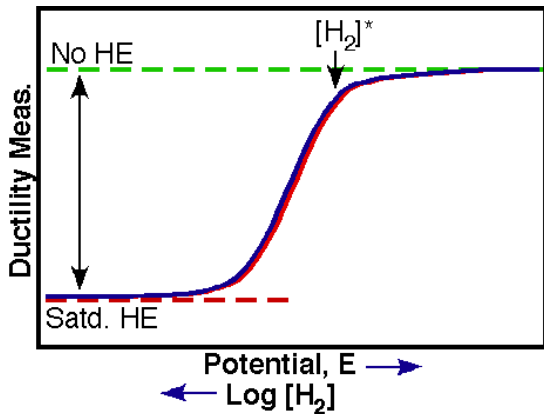
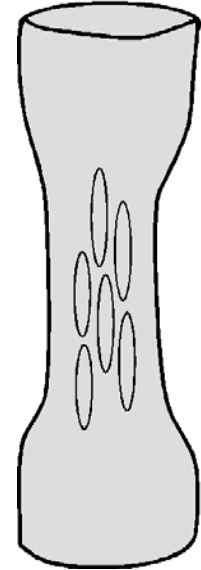


# Discussion

1. The HSLA-100 and HY-100 microstructures are very different.
2. After the simulated weld heat treatment, the microstructures are even more different.
3. Even with these differences, very similar trends were observed for all 4 conditions with increasing H activity.
4. Fractography was consistent with the view that increasing hydrogen partial pressure results in changing fracture modes:
  - a) Normal MVC
  - b) Assisted MVC
  - c) Transgranular “cleavage-like” (TCL)
  - d) Intergranular and Interfacial modes

# Discussion (cont)

5. Testing in the rolling direction reduces the availability of intergranular and interfacial fracture modes.
6. In this case, TCL fracture may be determining the lower bound of the embrittlement observed in the samples.
7. Uncertainty in the electrochemical testing conditions and reproducibility contribute to scatter and may inhibit resolving differences in critical hydrogen activities to initiate cracking.





# Conclusions

- 1. The parent metal samples exhibited similar trends with increasing hydrogen activity indicating similar resistance or susceptibility to embrittlement by hydrogen.**
- 2. The simulated weld heat affected zones samples exhibited similar trends with no significant differences.**
- 3. Testing in the rolling direction suppressed intergranular and interfacial fracture modes limiting hydrogen to inducing TCL fractures.**
- 4. Therefore, the TCL fracture modes of these alloys have similar sensitivities to hydrogen.**
- 5. The hydrogen induced cracking typically observed in welds of HY steels occurs at grain boundaries and other interfaces.**
- 6. Electrochemical measurements can be used to help study and understand HE and guide innovation or alloy development for the hydrogen economy.**