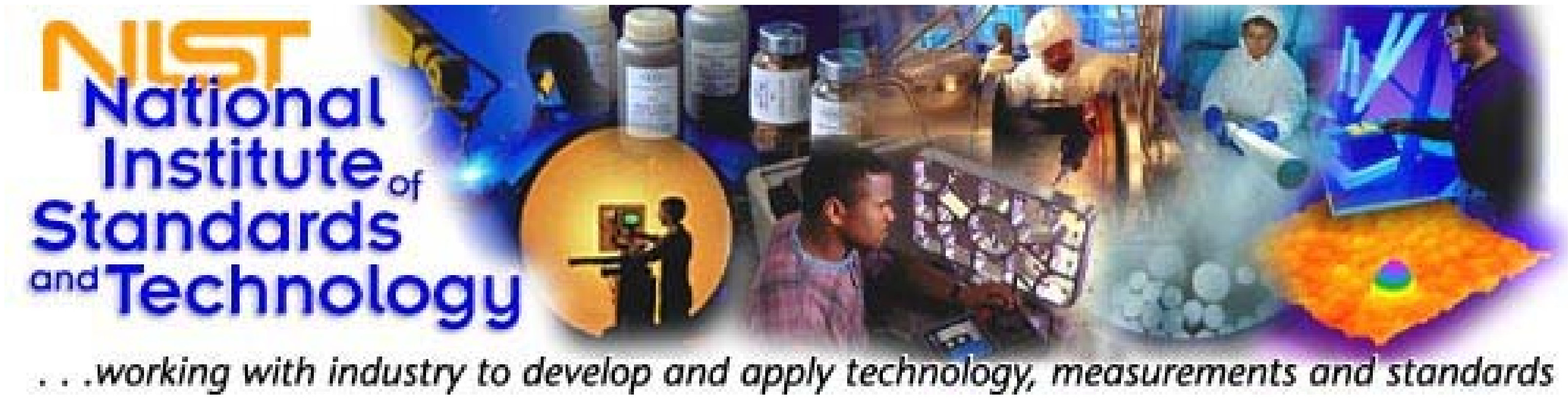

Evaluation of the Susceptibility of Simulated Welds In HSLA-100 and HY-100 Steels to Hydrogen Induced Cracking

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Objectives

More than one…

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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:

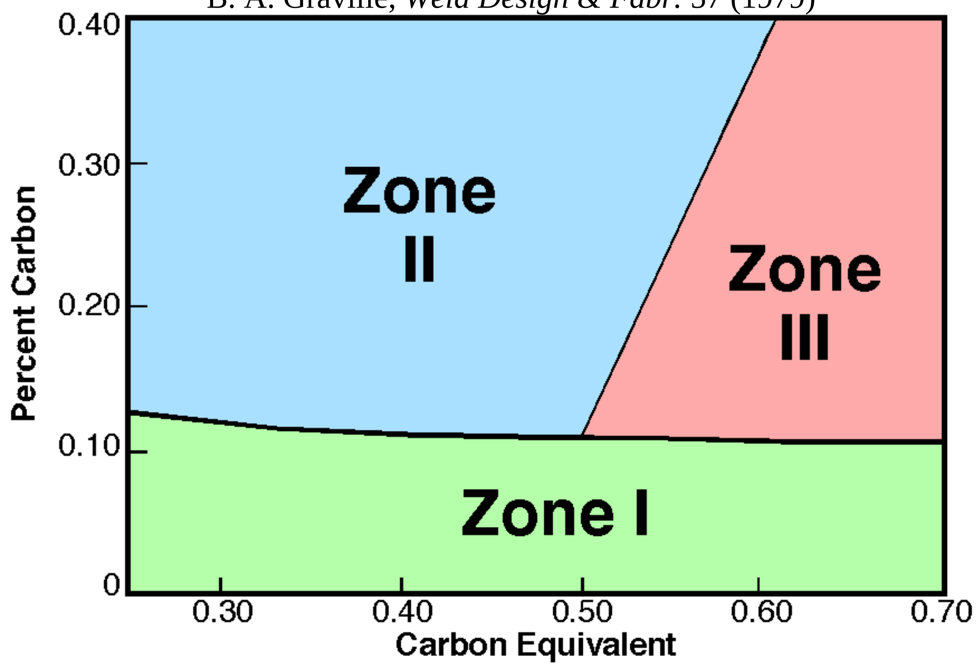
… to compare the susceptibility of the same steels following a heat treatment that emulates the thermal history of a single pass weld and generates microstructures representative of weld heat affected zones (HAZ) in these two steels.

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			
YS	(MPa)	690	690
UTS	(MPa)	800	740
STF	(%)	10.0	12.3
RA	(%)	69.0	80.5
Simulated Weld HAZ			
UTS	(MPa)	866	797
STF	(%)	7.4	6.7
RA	(%)	61.6	88.9

B. A. Graville, *Weld Design & Fabr*. 57 (1979)



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

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

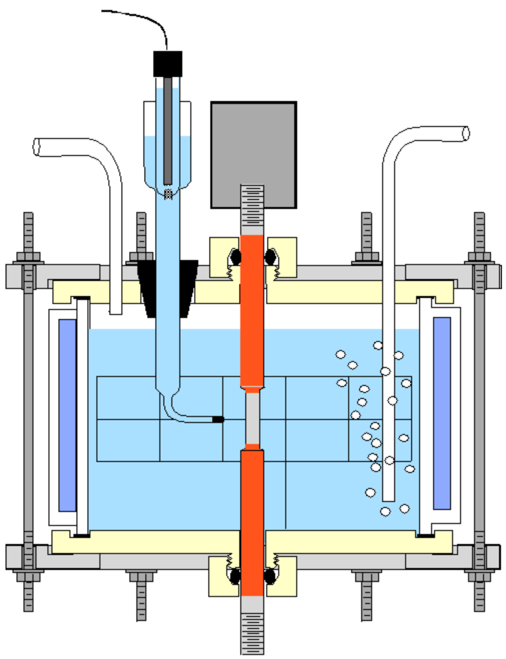
Electrochemical Tests of HE Hypothesis

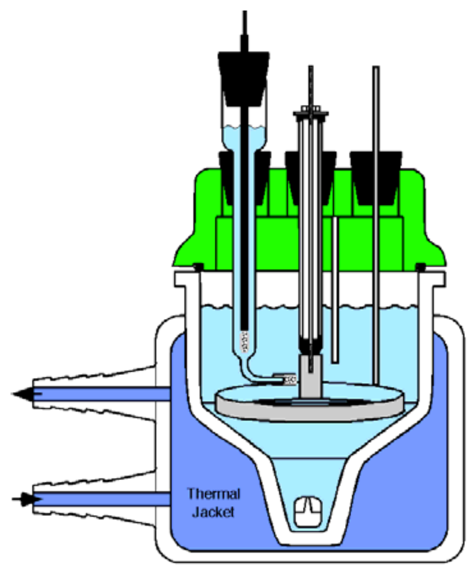
Materials:

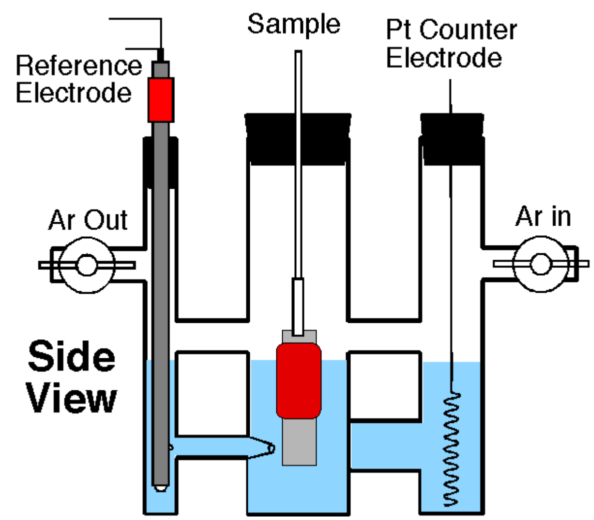
- Compositions (given)
- Rolled Plate ≈25 mm thick
- Cylindrical Tensile Samples
- Samples cut in rolling direction
- Weld Simulation (1 pass)

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_2(g)

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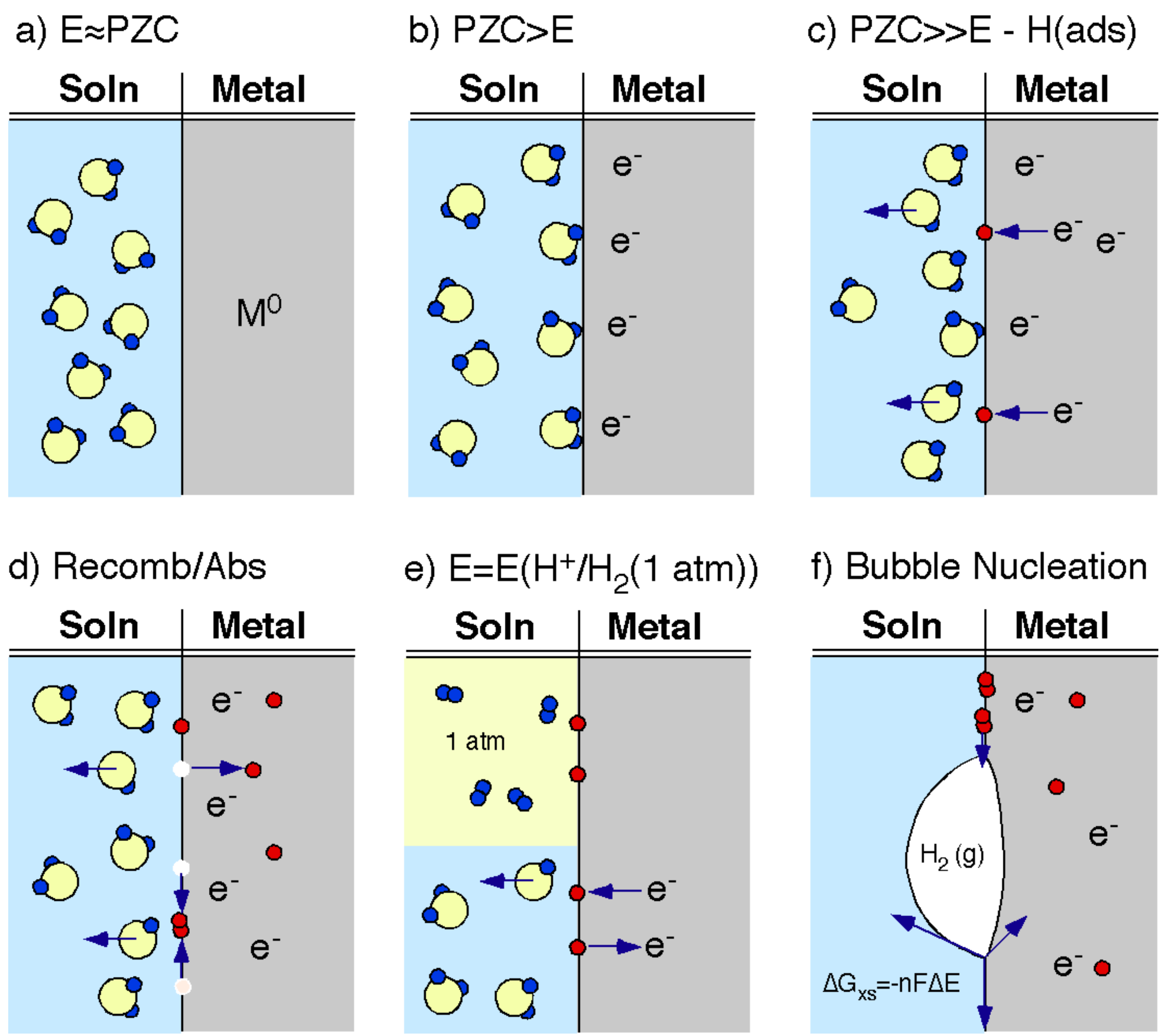

Metallography

Alloy Parent Metal

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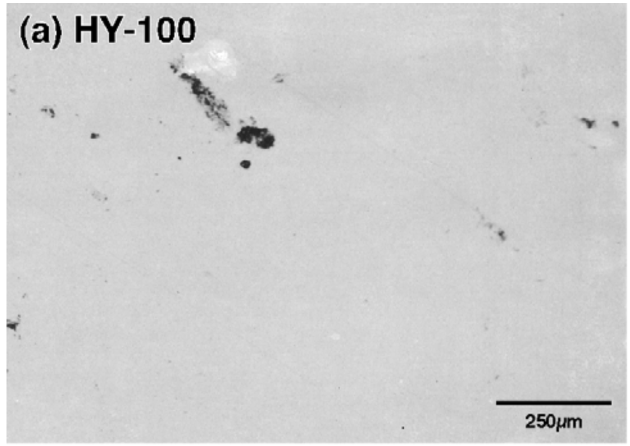
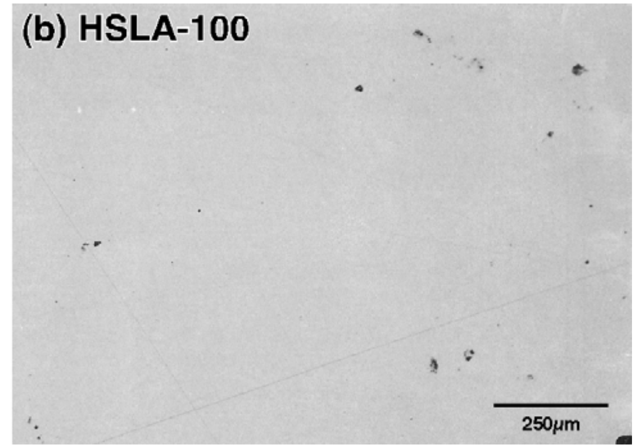
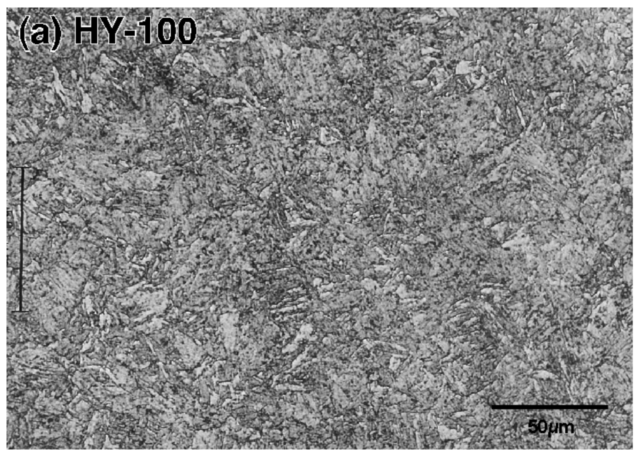
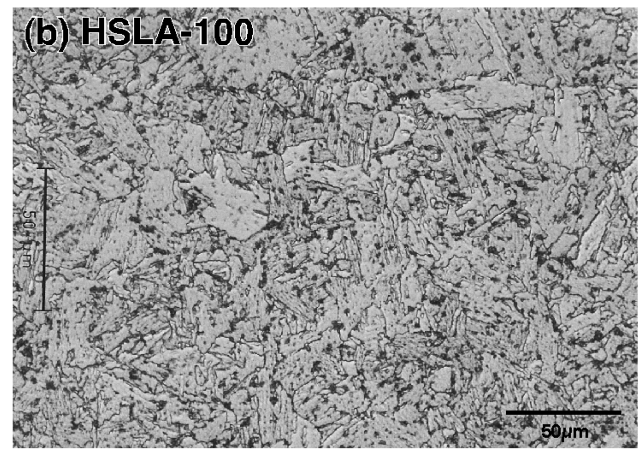
Unetched to reveal microconstituent particles





Etched to reveal microstructure

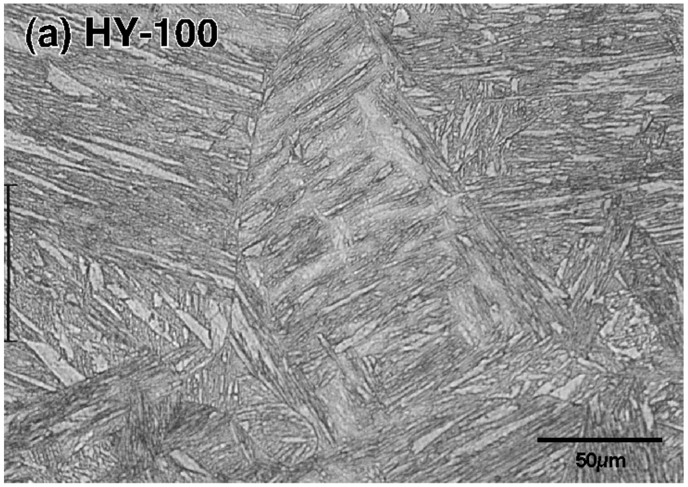


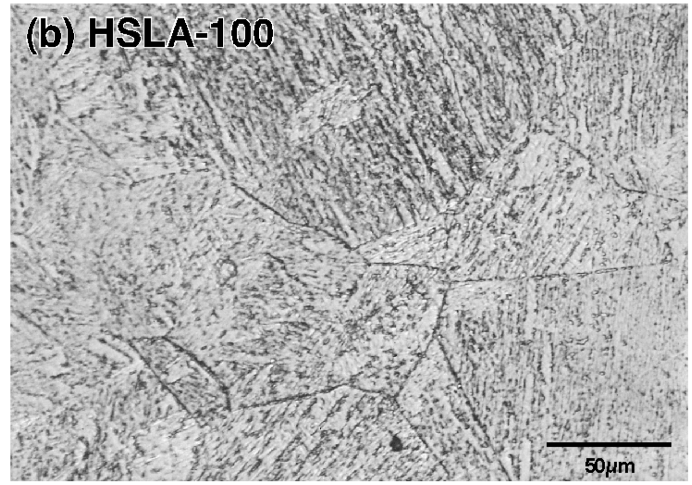


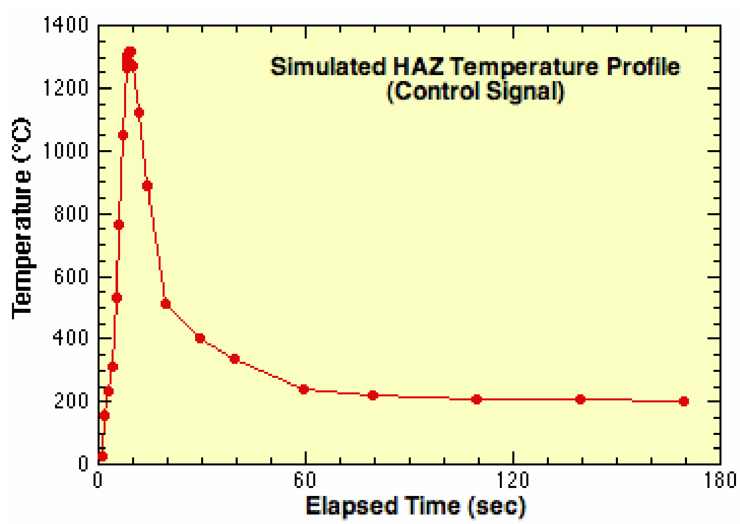
Prior Austenite Grain Size (μm)	19.4 ±8.4	36.4 ±11.3
Inclusions per unit area	72.0 ±5.6	18.9 ±1.8
Inclusion Size (μm)	9.3 ±6.3	1.9 ±1.4
Mean Inclusion Spacing (μm)	65.2 ±37.6	175 ±105
Inclusion Aspect Ratio	0.17	1.00

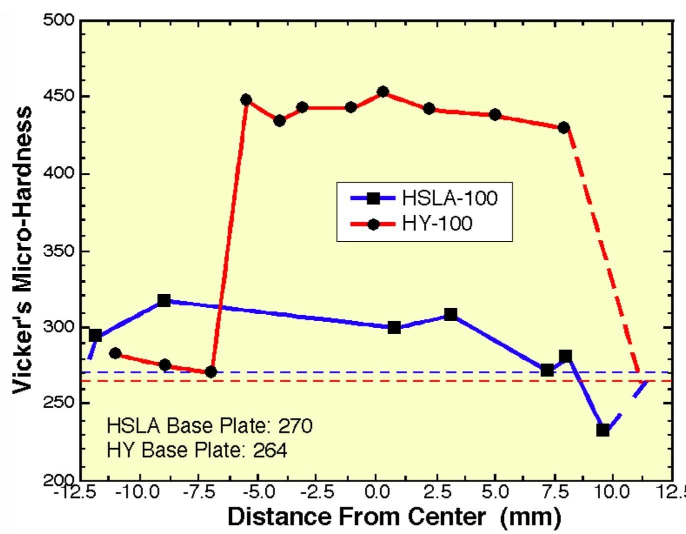
Metallography

Simulated Weld Heat Affected Zone Microstructures









Electrochemical Measurements

Potentiodynamic Polarization Curves

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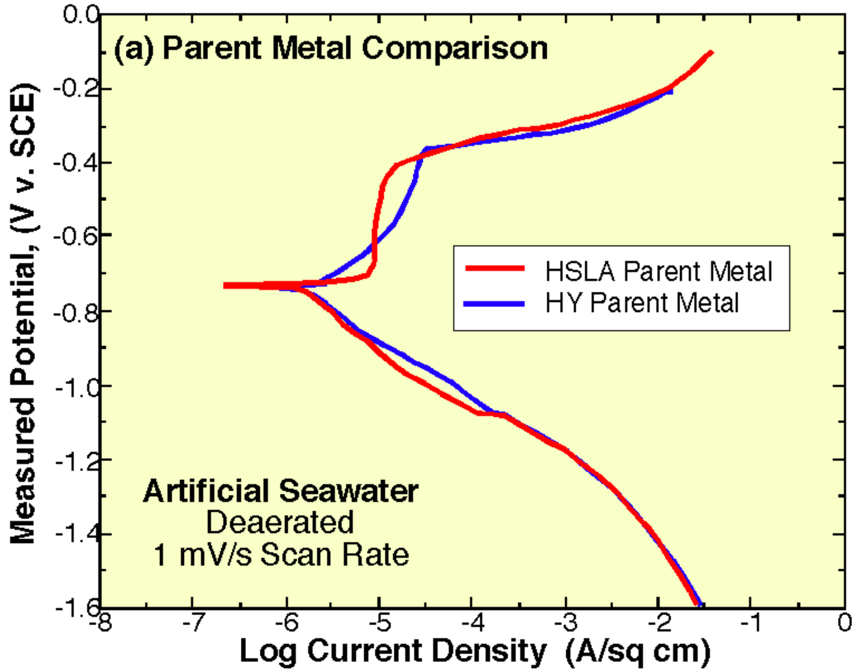
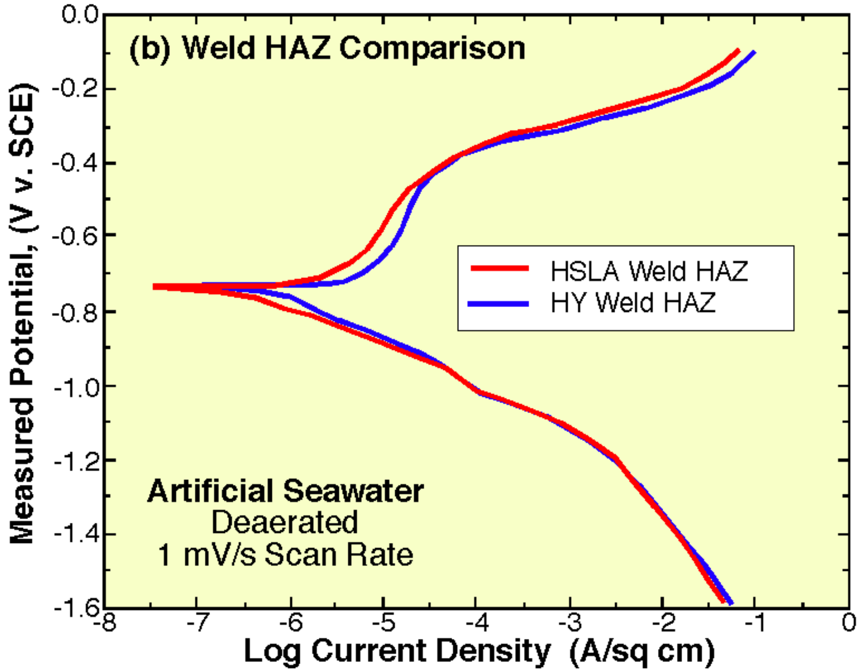
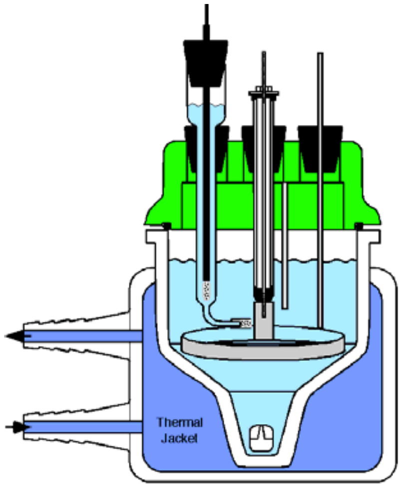




Used to evaluate the current-potential relationships for the different alloys in the cathodic charging solution (artificial seawater)

No differences that would influence H uptake were found.



Electrochemical Absorption and Desorption

To Compare Solubility and Diffusivity

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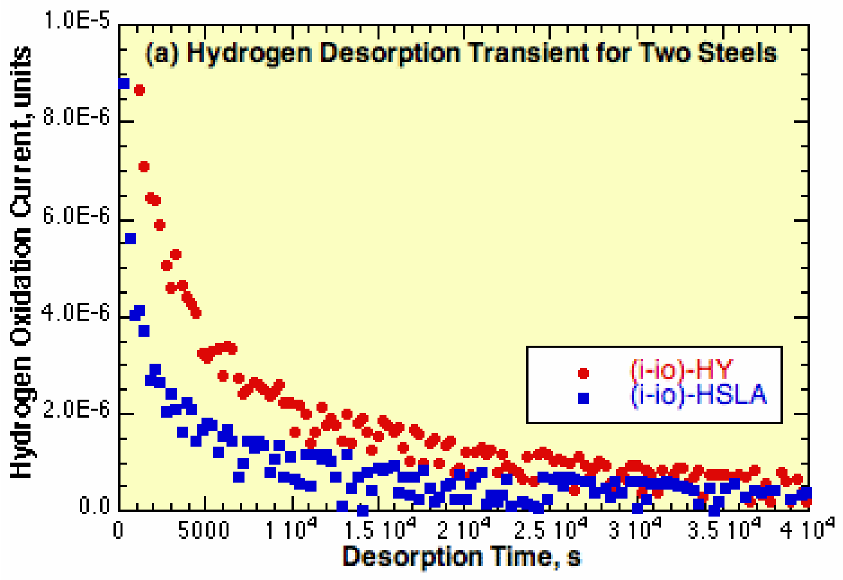
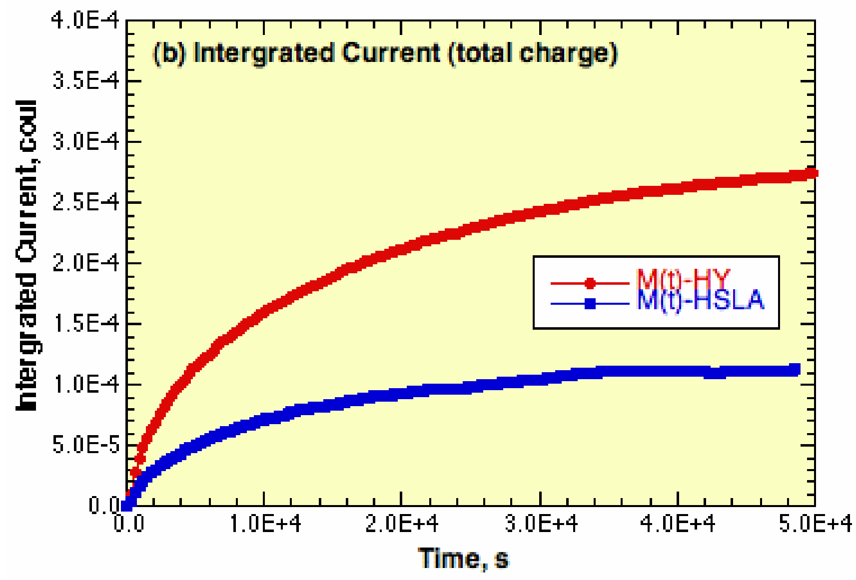
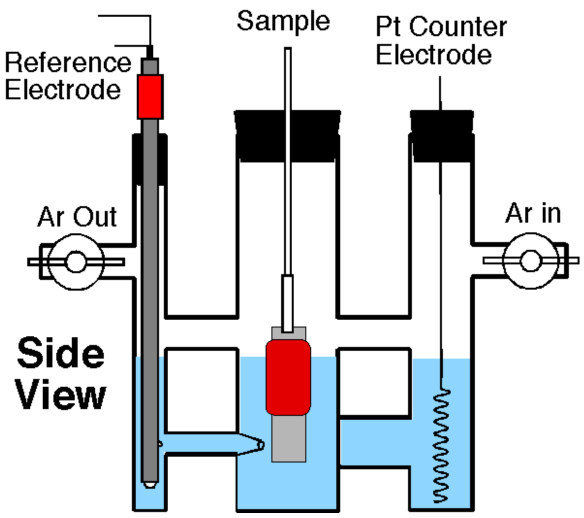




Used to evaluate the H diffusivity and solubility in the parent metal of the alloys

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

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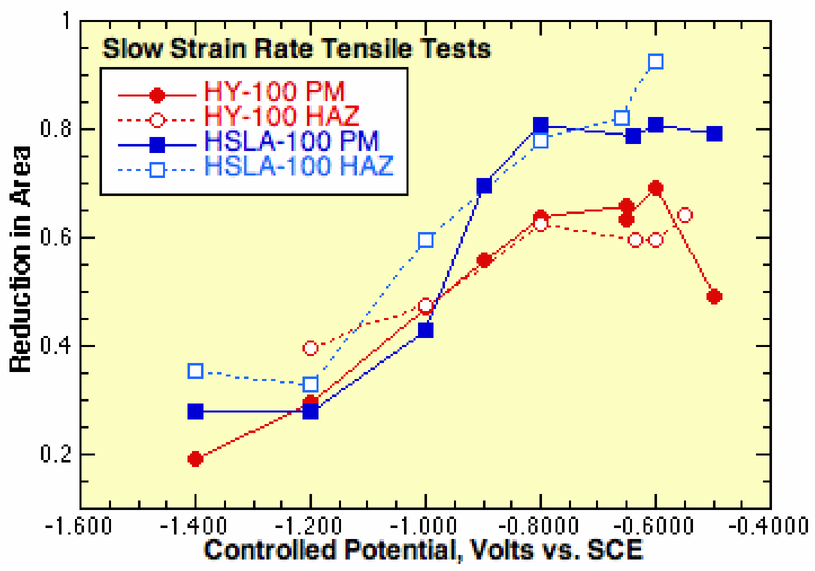
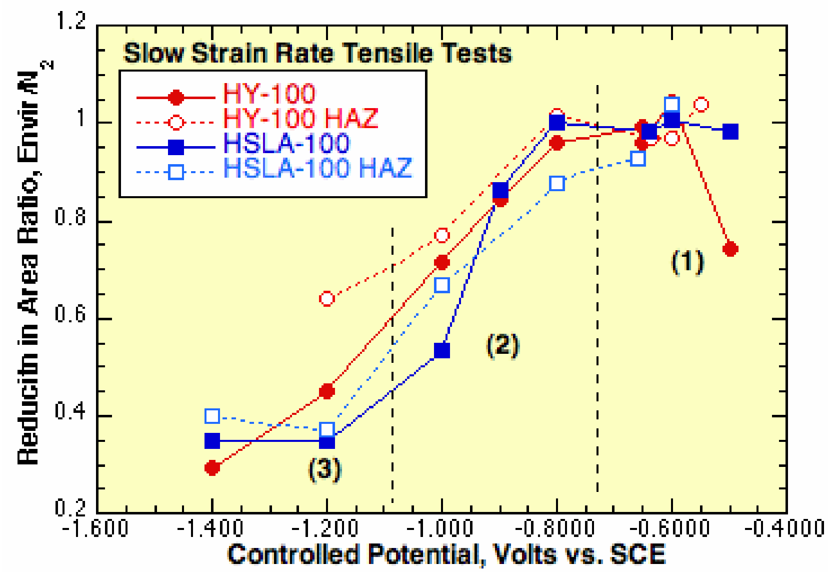
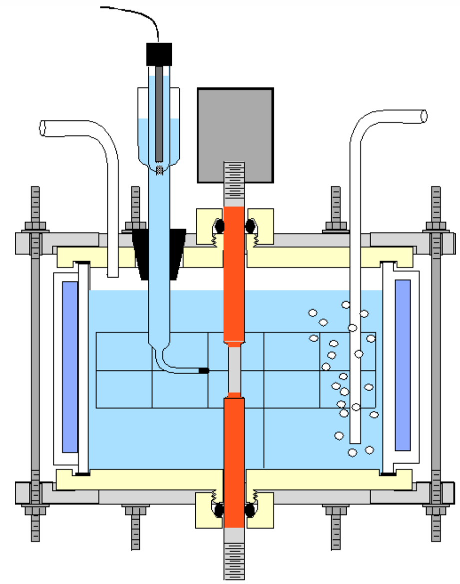




Used to evaluate changes in ductility as the H partial pressure increases

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

The changes were of similar magnitude



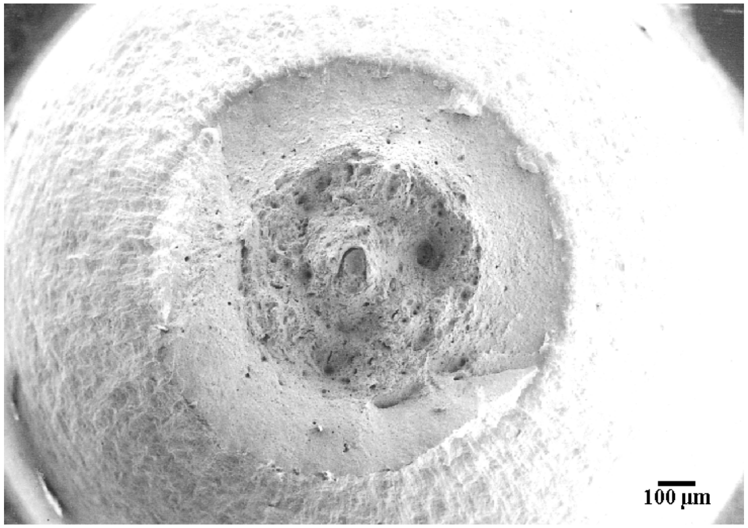
SEM-1

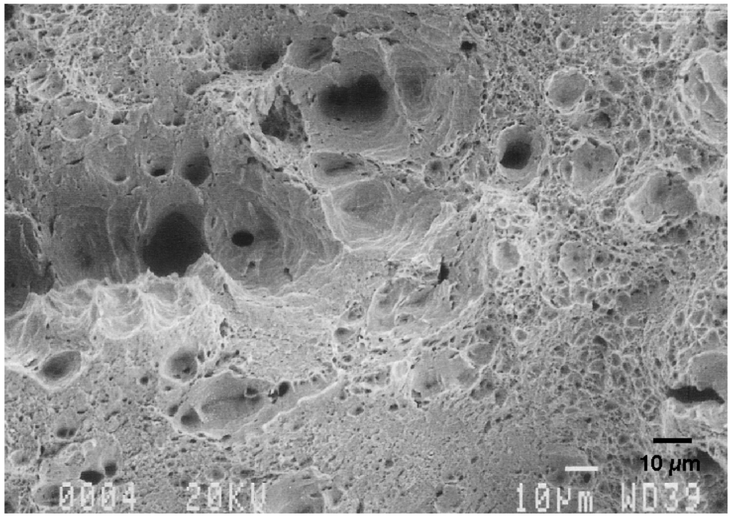
Fractography for Low P(H_2)

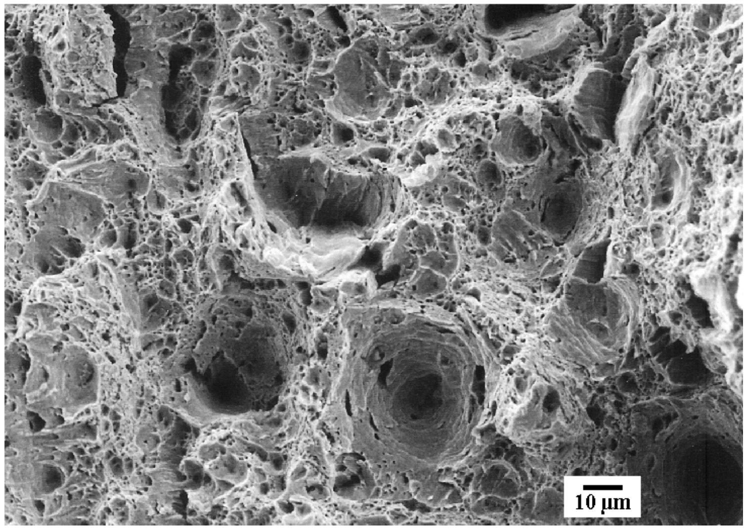
MSEL

HY-100

HSLA-100







SEM-2

Fractography for Medium P(H_2)

MSEL

HY-100

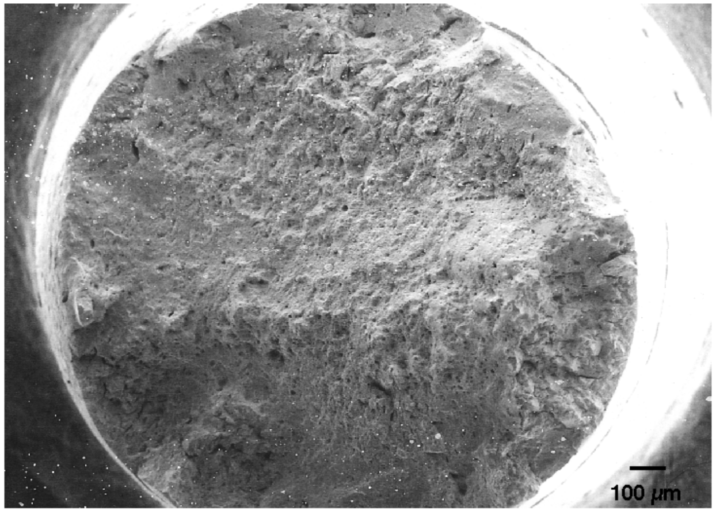
HSLA-100

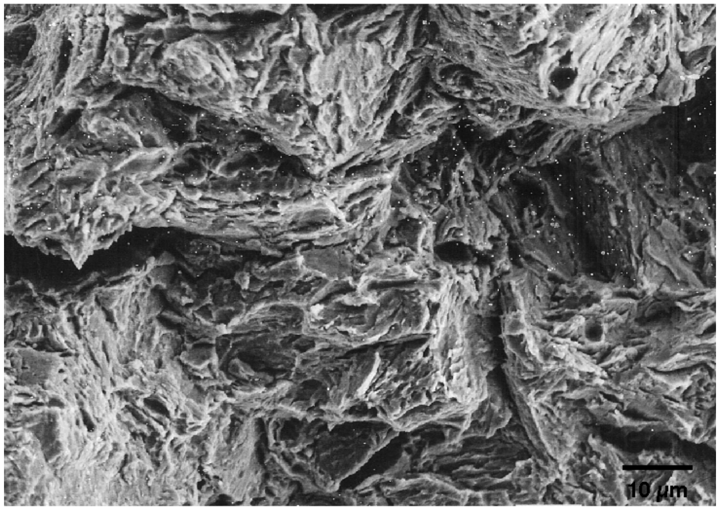
SEM-3

Fractography for High P(H_2)

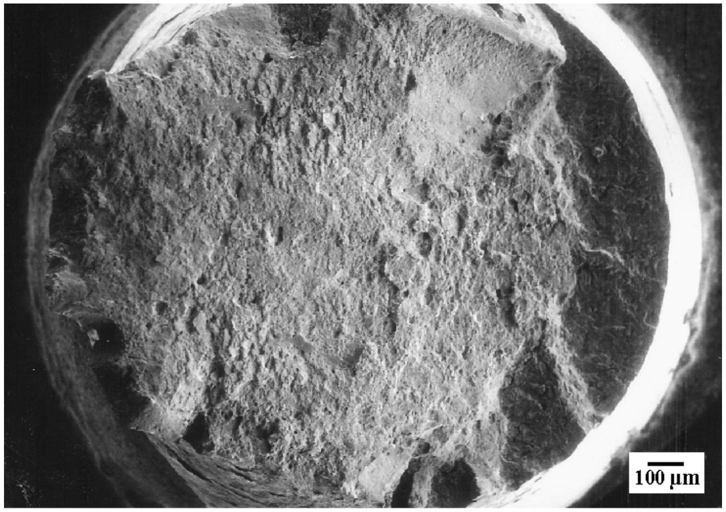
MSEL

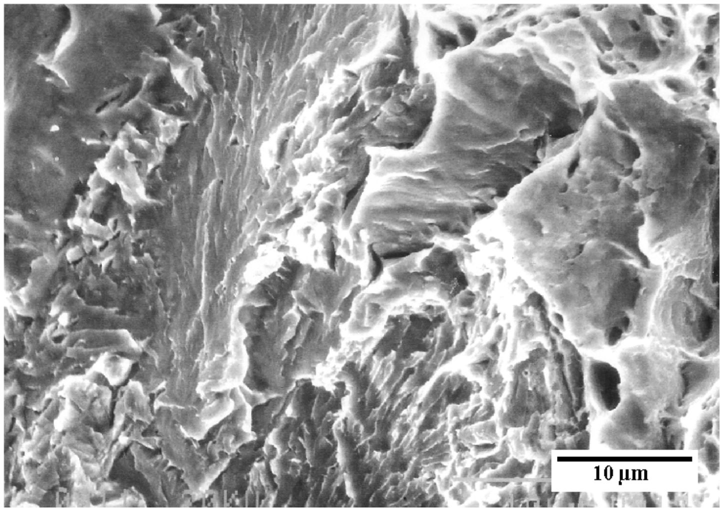
HY-100





HSLA-100

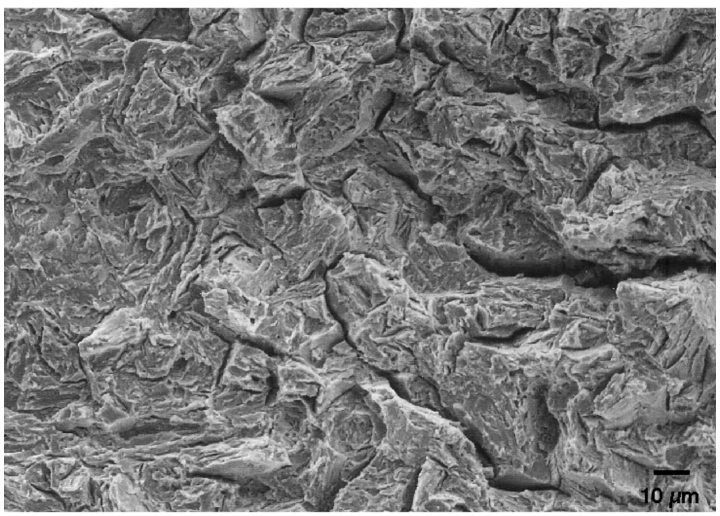




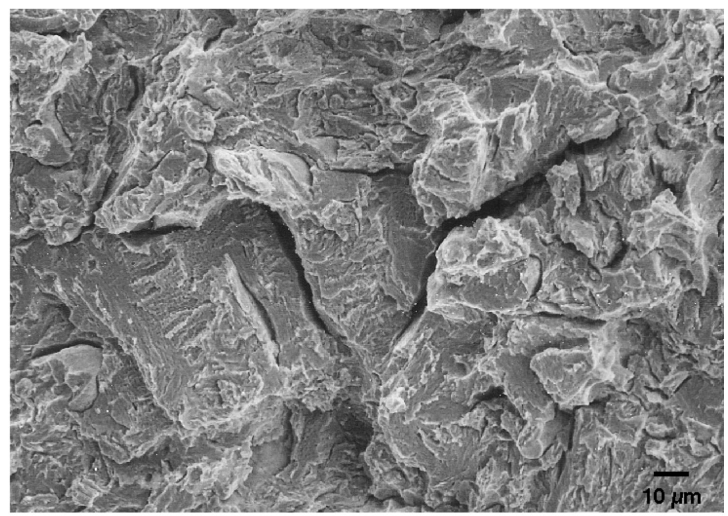
SEM-4

Fractography of Simulated Weld HAZs at High P(H_2)

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)

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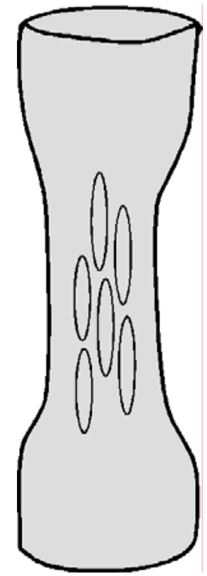
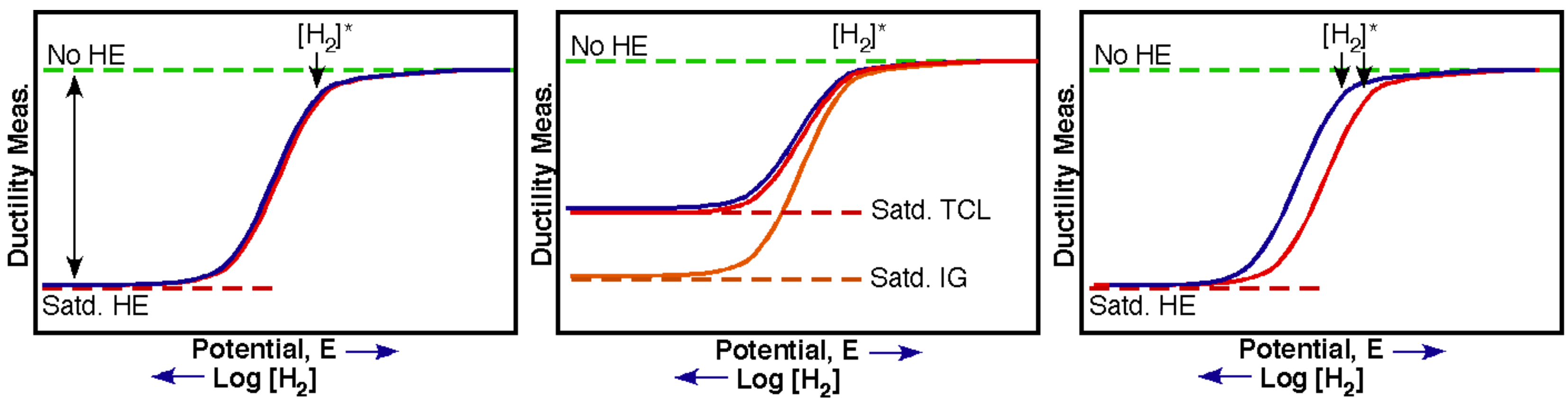
5. Testing in the rolling direction reduces the availability of intergranular and interfacial fracture modes.
6. In this case, TCL fracture may be determining the lower bound of the embrittlement observed in the samples.
7. Uncertainty in the electrochemical testing conditions and reproducibility contribute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





Conclusions

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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.