An update of sour performance testing and field performance

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Tenaris Coiled Tubes

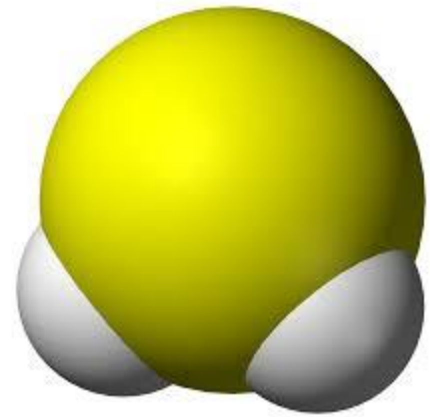
Tenaris

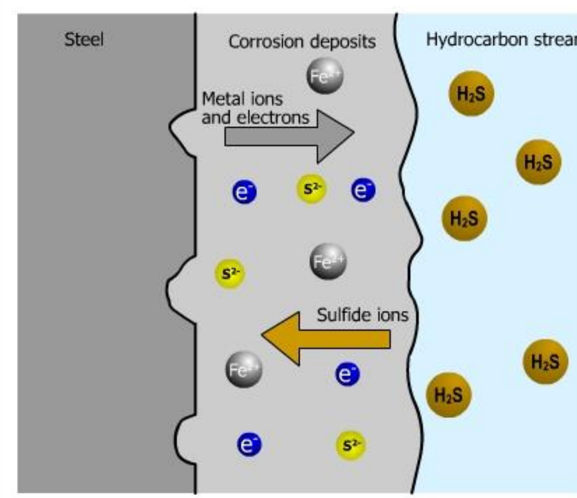
Overview

- Damage Mechanisms
- Industry Standards
- Governing Parameters
- Mitigation Methods
- Testing and Results
- Conclusions

H_2S Corrosion

- Iron becomes anode and H_2S becomes cathode
- $Fe + H_2S + H_2O \rightarrow FeS + 2H + H_2O$
- Normally atomic hydrogen will recombine to molecular hydrogen H_2
- Sulfur restricts recombination of hydrogen

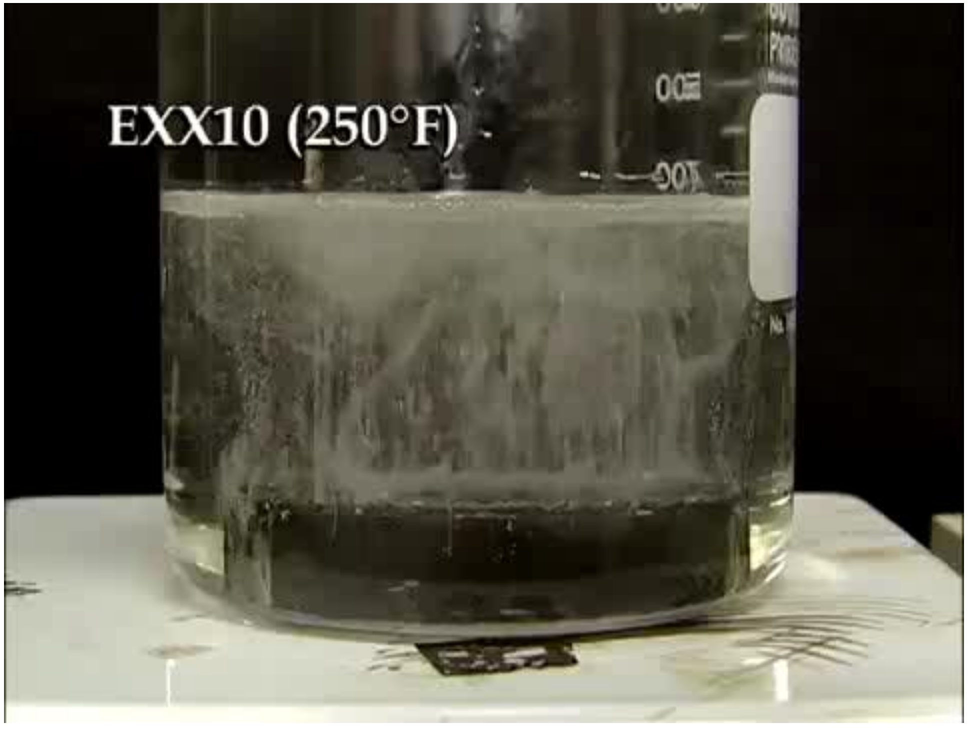




Mechanism of sulfide stress corrosion cracking.

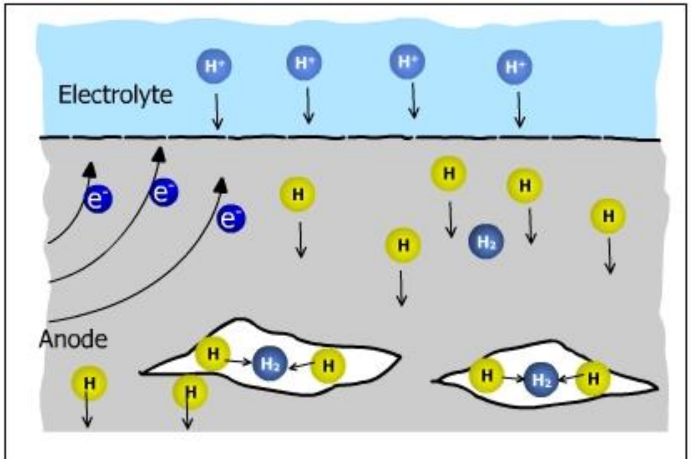
Hydrogen Absorption and Diffusion

- Monatomic hydrogen is absorbed into the steel
- Hydrogen diffuses through steel and concentrates in areas of high stress in the iron lattice (SSC) or weak internal interfaces (HIC)



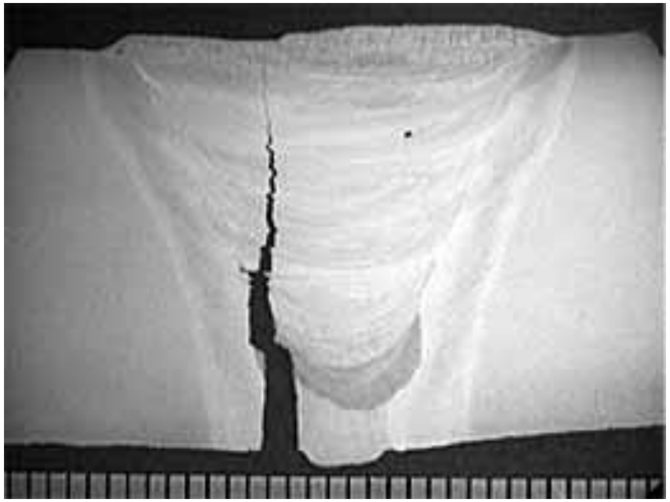
Hydrogen Induced Cracking (HIC)

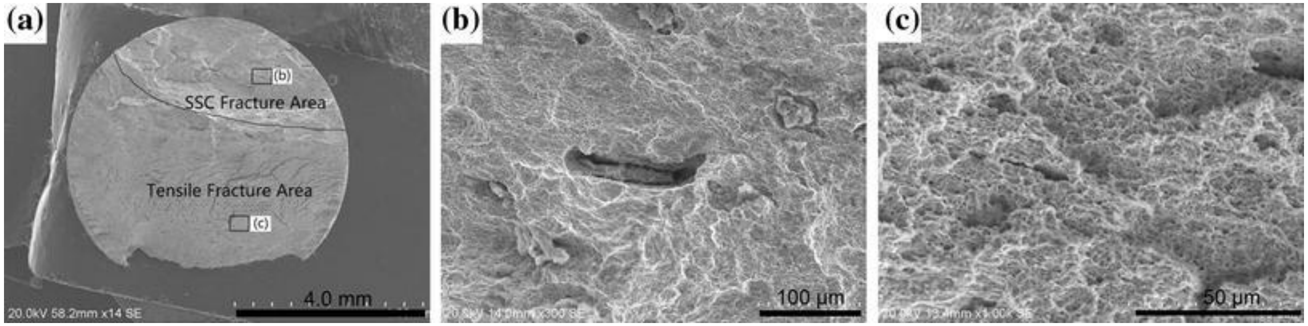
- Hydrogen recombines at weak internal interfaces (inclusions, laminations, etc.)
- Does not require stress
- Hydrogen recombines into molecular hydrogen
- More common in steels with yield strength <100 ksi
- Steels containing sulfur and phosphorus are more susceptible



Sulfide Stress Cracking

- Monatomic hydrogen remains in iron lattice
- Requires tensile stress
- Produced brittle fracture oriented transverse to stress
- Fractures occur as stress levels below yield
- More common in higher strength steels

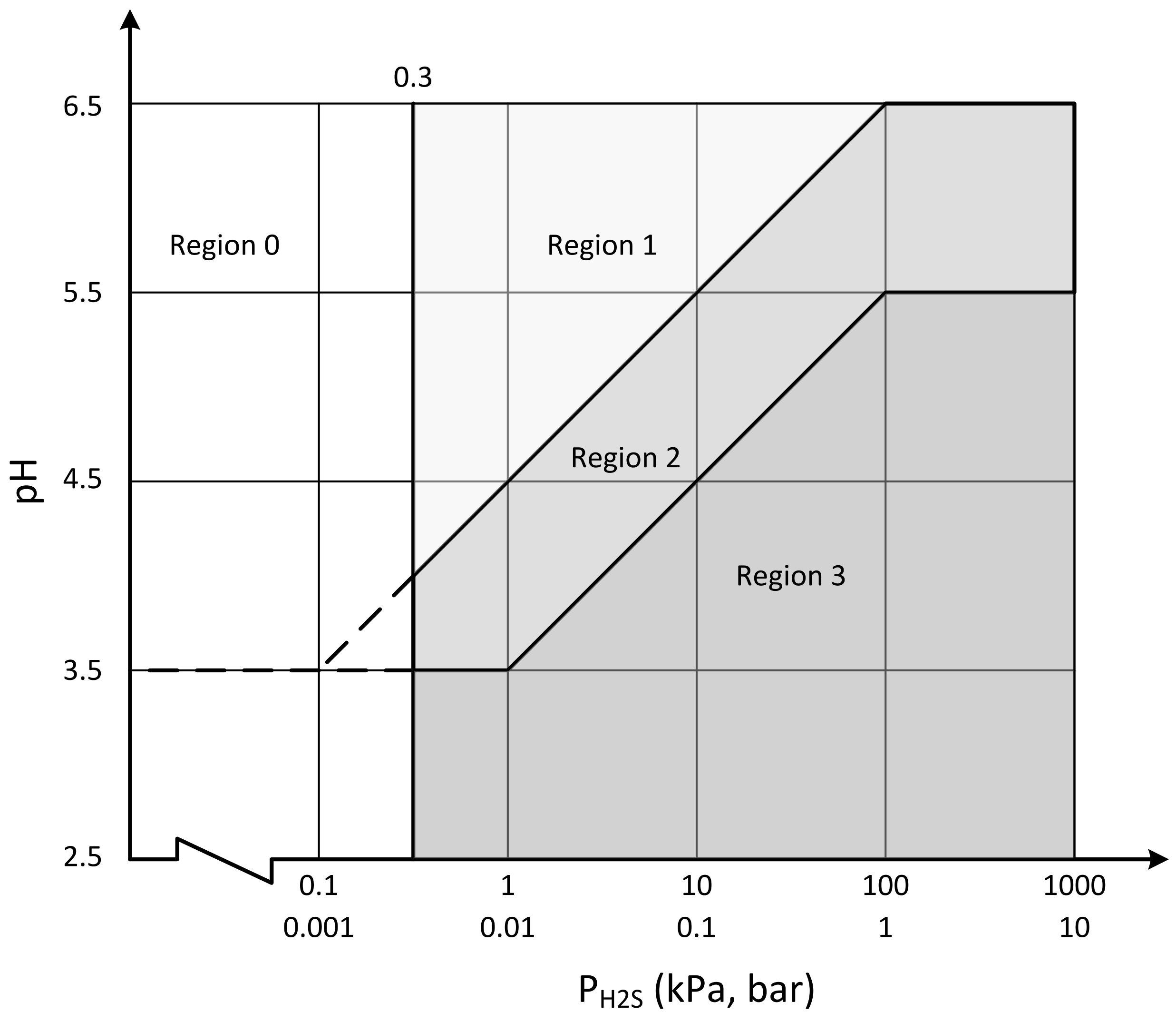




NACE MR0175/ISO 15156 – Option 1

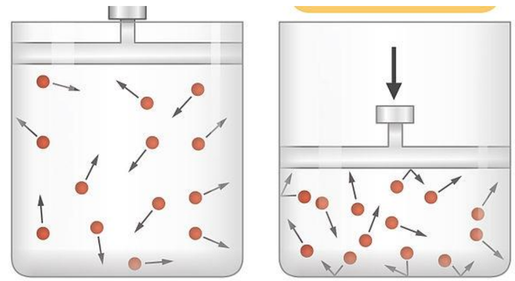
- Doesn't apply to coiled tubing, but .....
- For $P_{H_2S} < 0.3 \text{ kPa } (0.05 \text{ psi})$ "… no special precautions are required …"
- For $P_{H_2S} \geq 0.3 \text{ kPa } (0.05 \text{ psi})$
  - Heat treatment condition
  - max hardness 22 HRC
  - <1% Ni
  - >1100 F stress relief ($\varepsilon > 5\%$)

NACE MR0175/ISO 15156 – Option 2

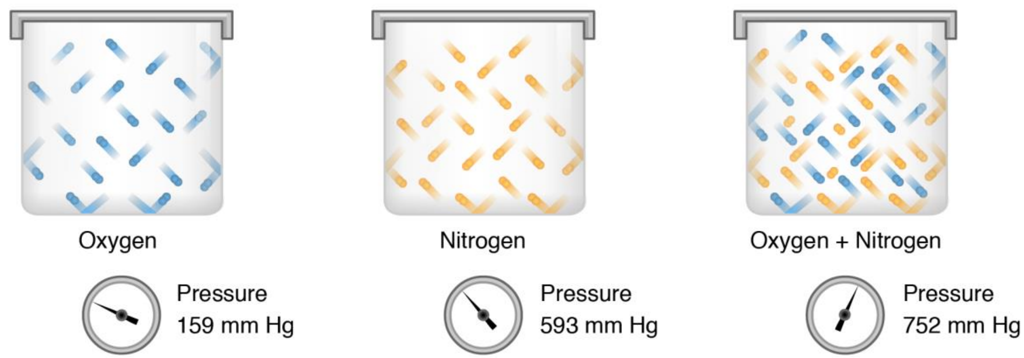


Partial Pressure

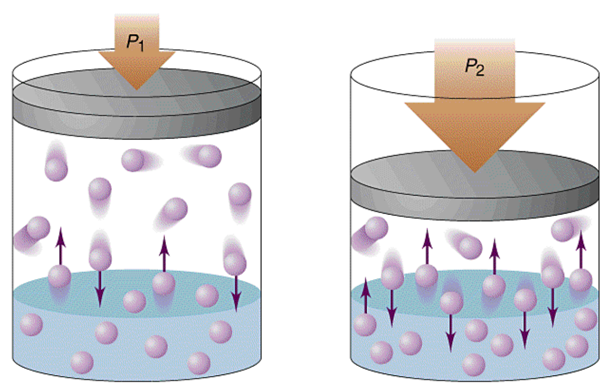
- Boyle's law: $PV = C$ The higher the pressure, the more gas molecules per volume



- Dalton's law $\frac{P_i}{P} = \frac{n_i}{n}$ The partial pressure of a gas component is proportional to it's concentration

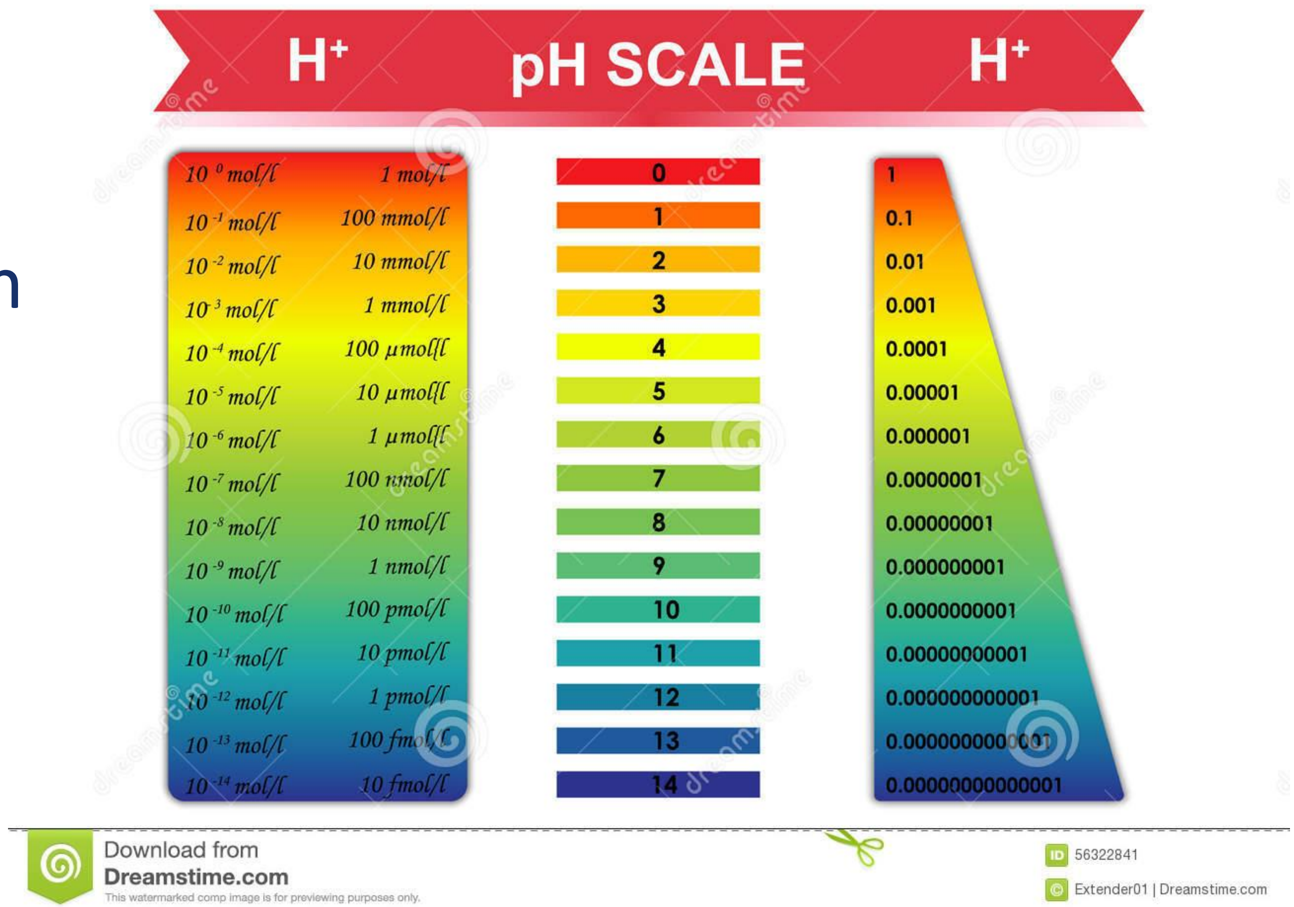


- Henry's law - the amount of dissolved gas is proportional to its partial pressure in the gas phase



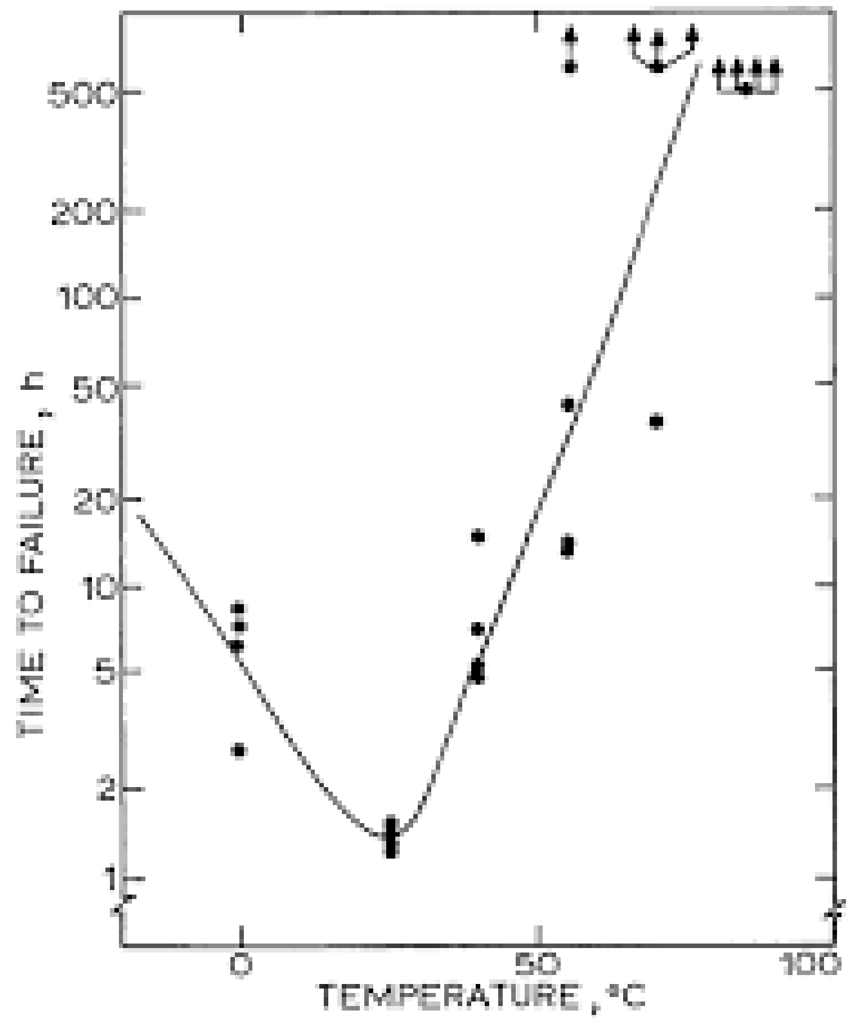
pH

- Logarithmic measure of hydrogen ion concentration
- Provides source of monatomic hydrogen if sulfur is present



Temperature

- Maximum susceptibility to SSC and HIC occurs at ambient temperature
- This appears contradictory with the fact that the hydrogen diffusion rate increases with temperature
- At higher temperatures the surface film may be reducing hydrogen adsorption rate

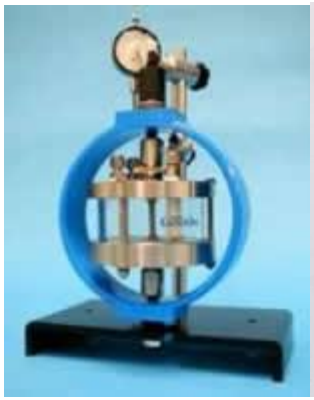


Inhibitors and Scavengers

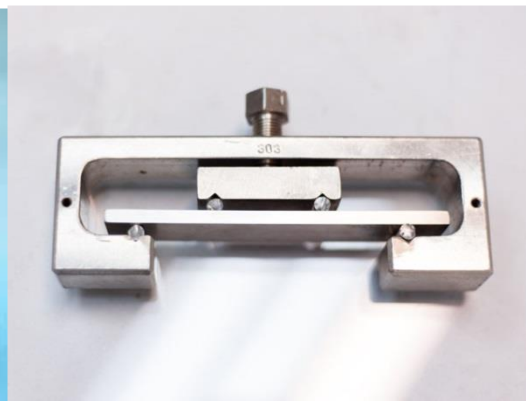
- Inhibitors have, in general, proven effective in reducing H_2S corrosion, but what about SSC and HIC?
- Inhibitors are typically fatty amine based and attach to the FeS film layer on the tube surface
- Surface film becomes hydrophobic, significantly decreasing water activity and hydrogen ion concentration
- Scavengers can reduce H_2S concentration

SSC Testing and Results

NACE TM0177



Method A
UT



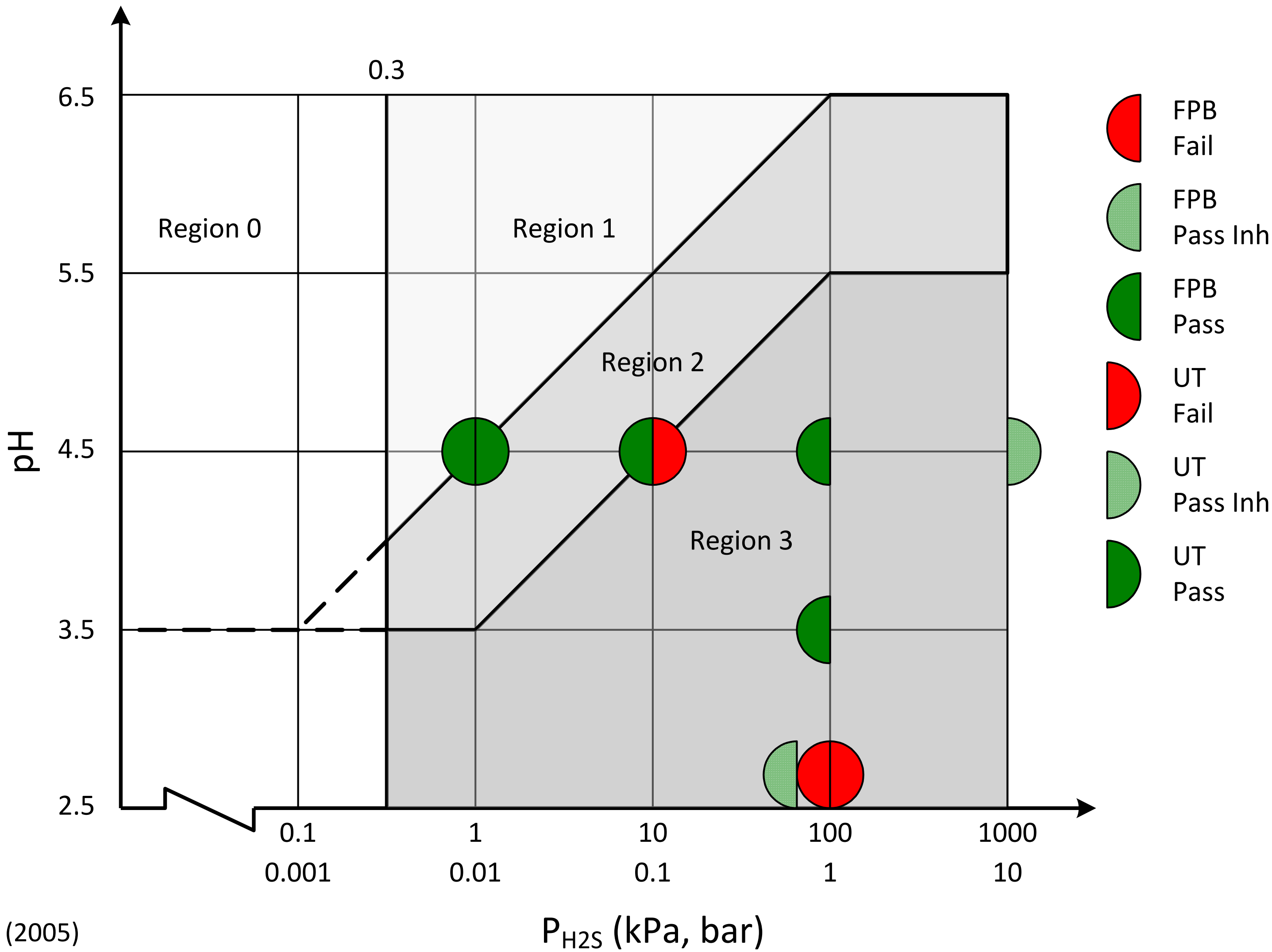
Method B
FPB

Method C
CR

Method D
DCB

- Applied stress (usually % of SMYS or AYS)
- 30 day duration
- Typically ambient temperature and pressure
- Solution A – pH 2.6 to 2.8, 1 bar H_2S
- Solution B - pH 3.4 to 3.6, 1 bar H_2S

SSC Testing With and Without Inhibitor



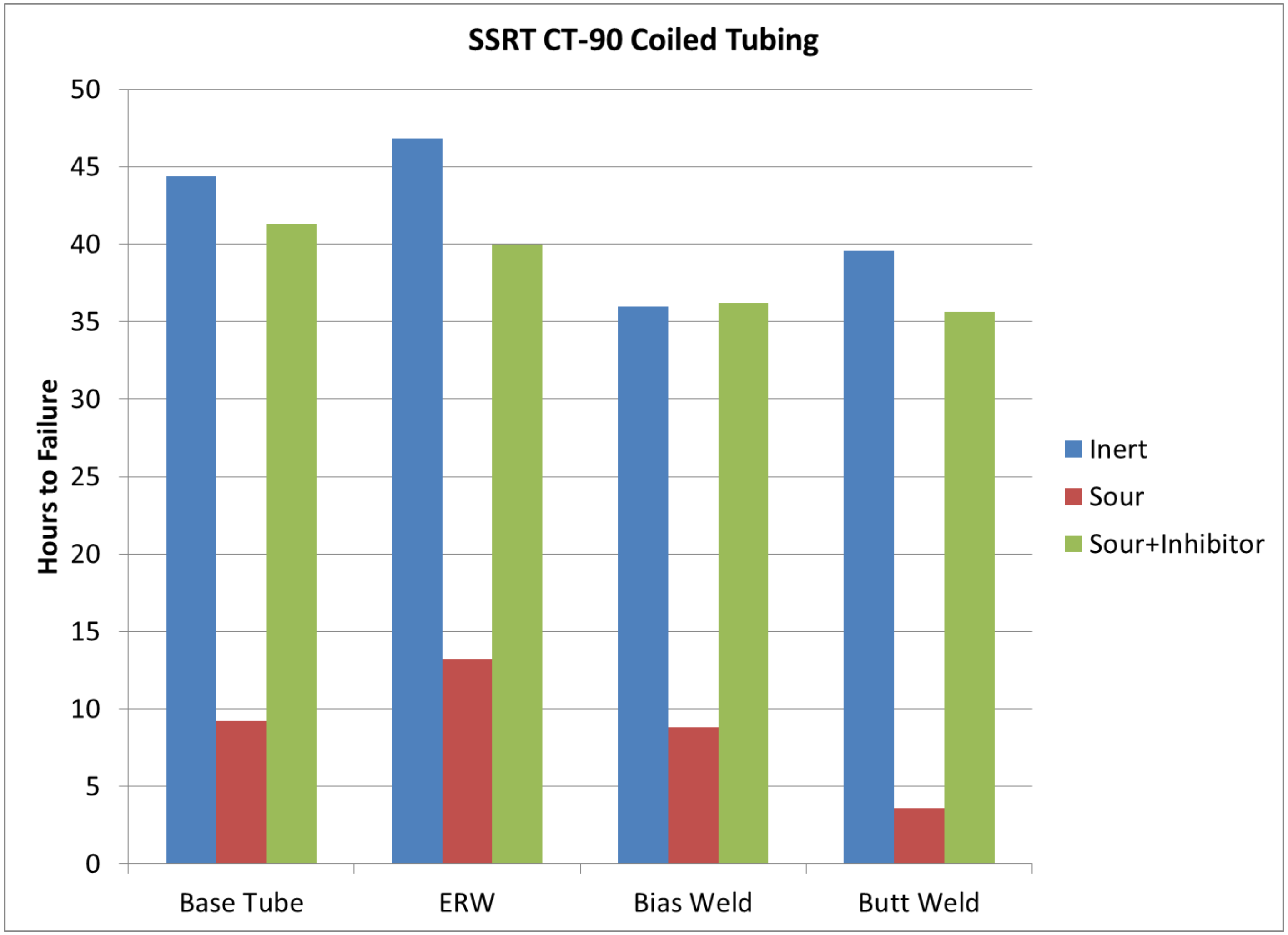
Source: McCoy (2005)

SSR Testing and Results

Slow Strain Rate Testing (SSRT)

- Strain rate of 1 X 10^{-6}
- Strain continues to failure
- Compare time to failure in inert and sour environments

SSRT With and Without Inhibitor



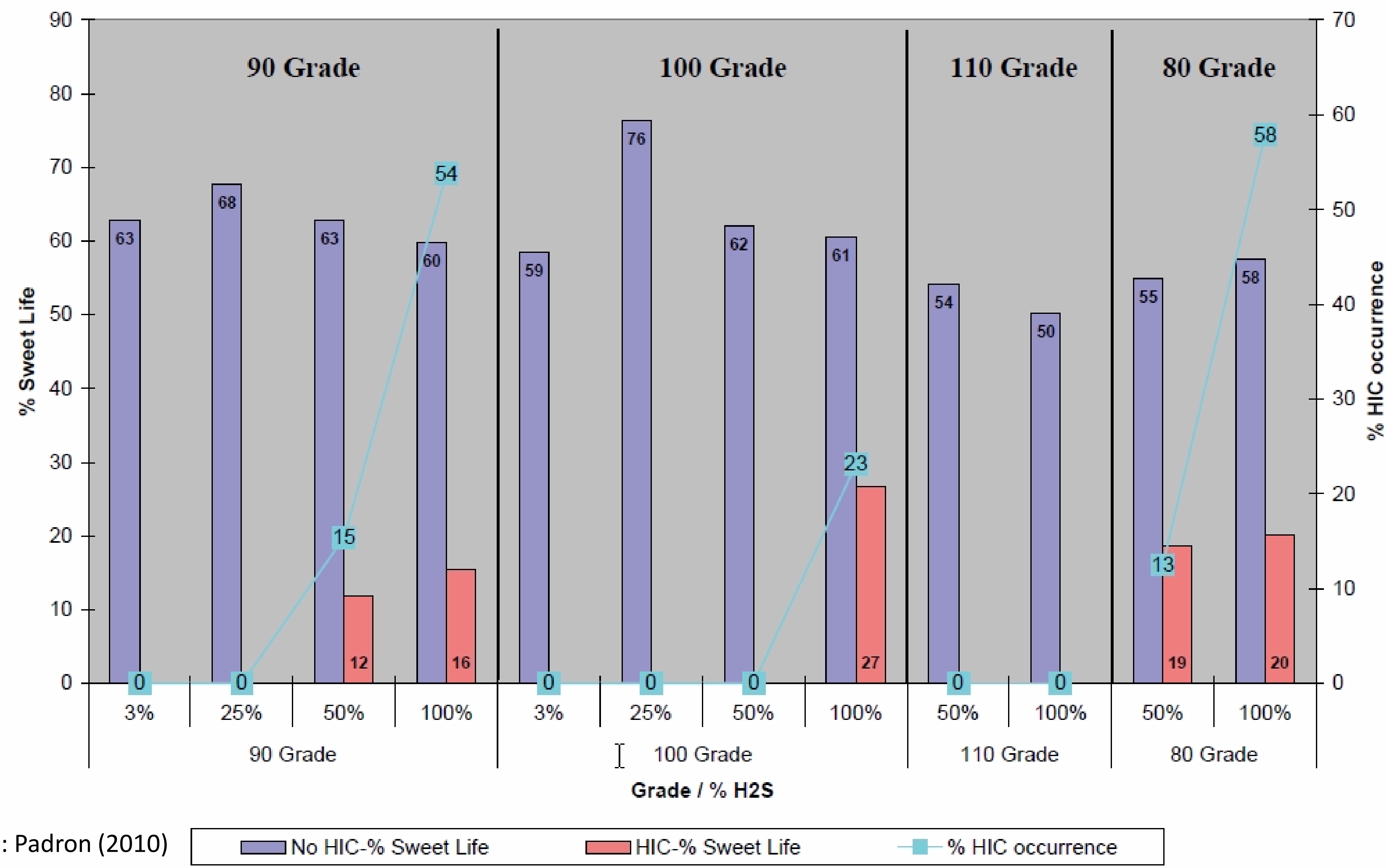
Source: McCoy (2005)

Sour Fatigue Testing and Results

- Full size bend fatigue samples are exposed in sour environment for 4 to 7 days
- Samples are transported on dry ice to bend fatigue machine

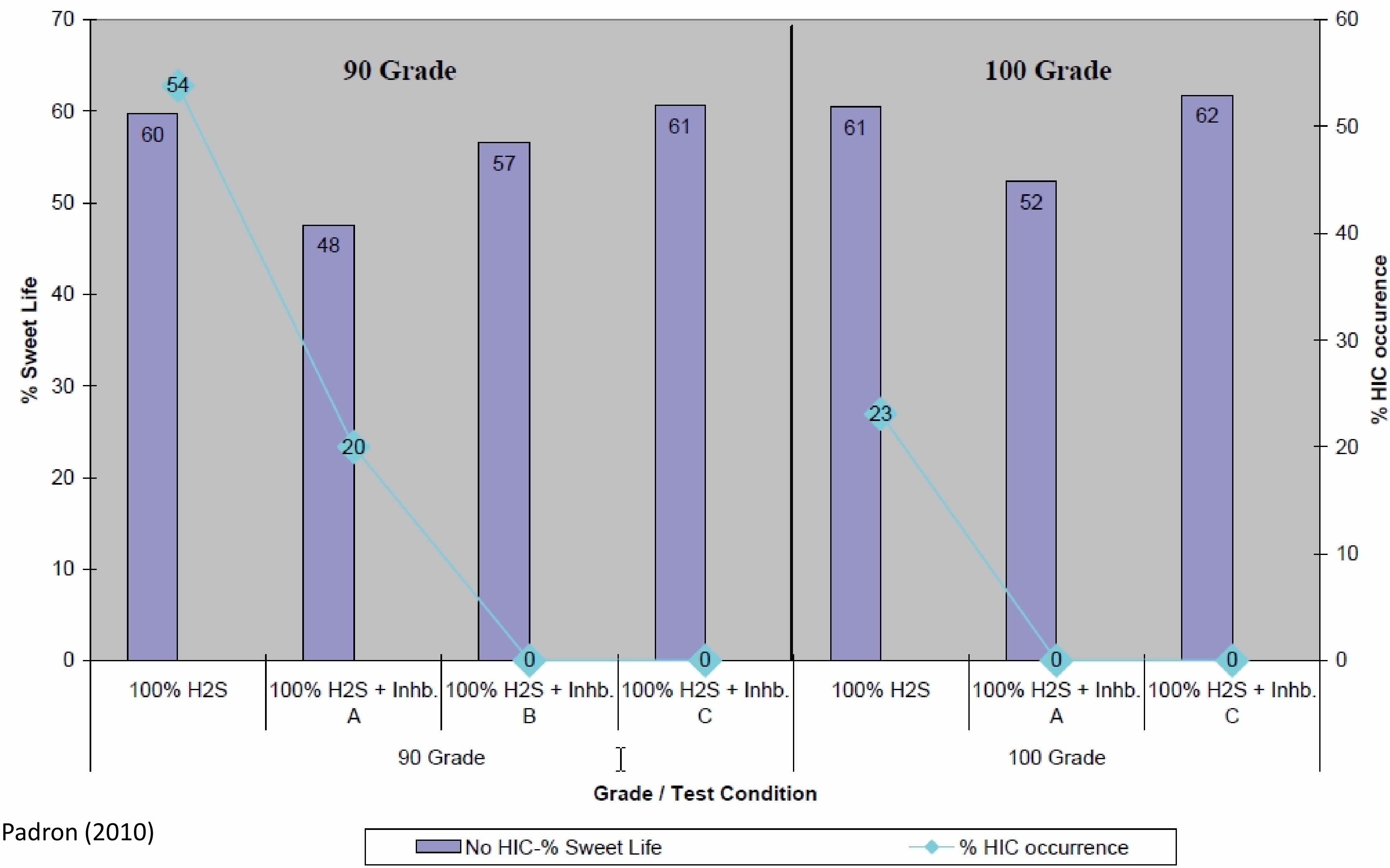
- Samples are repeatedly bent at straightened with internal pressure until fracture occurs
- Comparison made of fatigue life with and without sour exposure

Base Tube Sour Fatigue Without Inhibitor



Source: Padron (2010)

Base Tube Sour Fatigue With Inhibitor



Source: Padron (2010)

Bias Weld Sour Fatigue Without Inhibitor

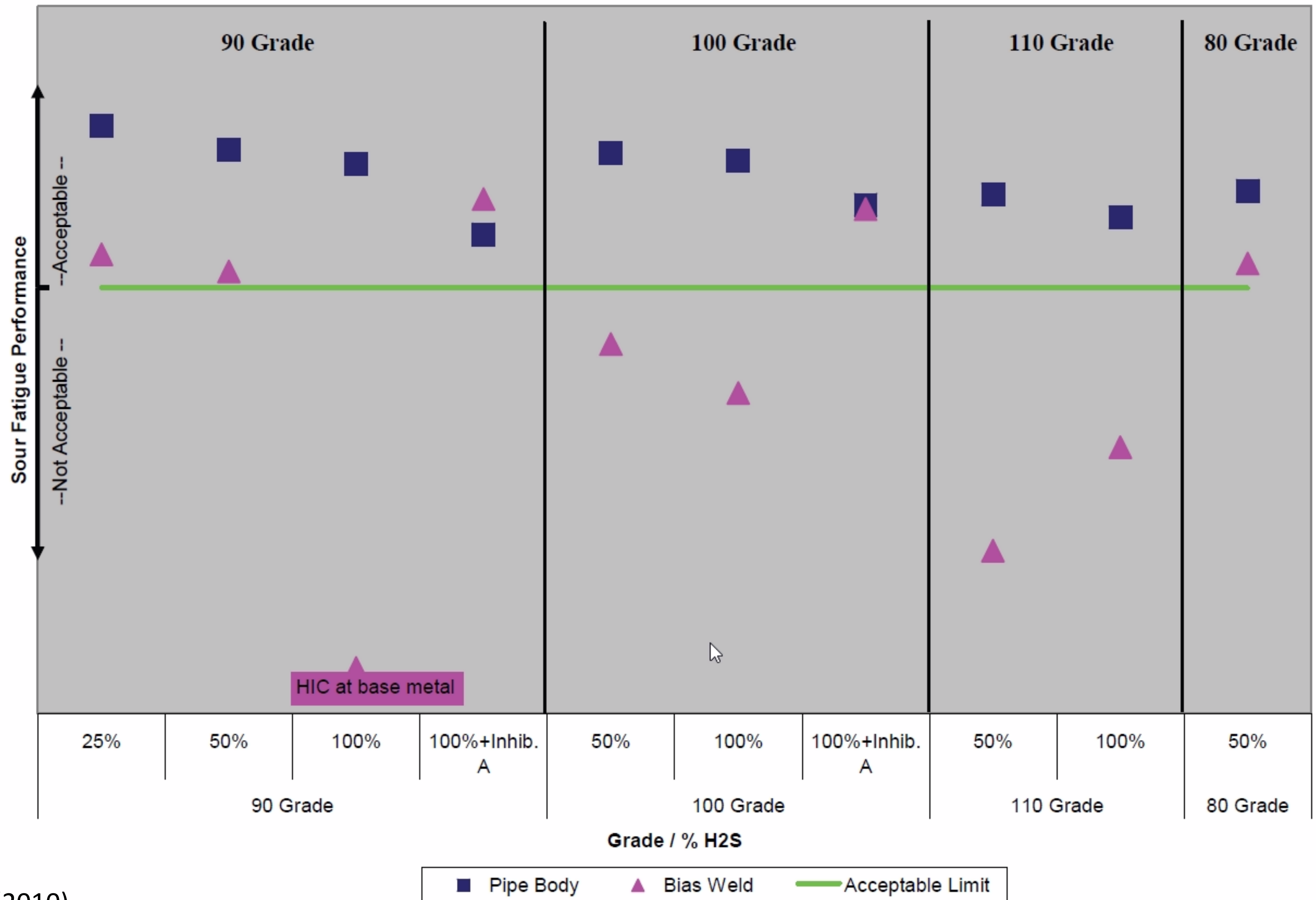


Figure 13. Bias welds sour fatigue performance

Source: Padron (2010)

Bias Weld Sour Fatigue Without Inhibitor

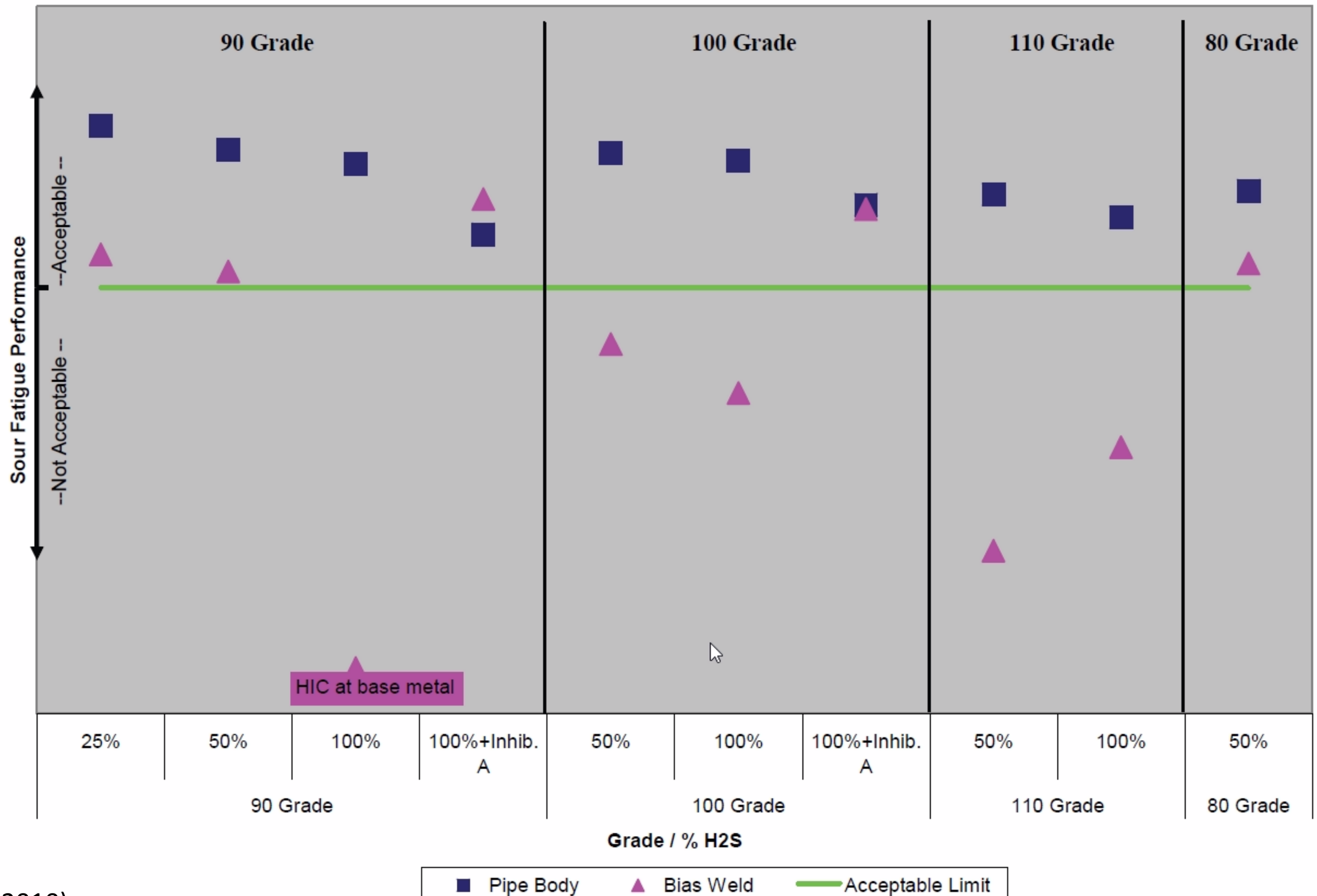
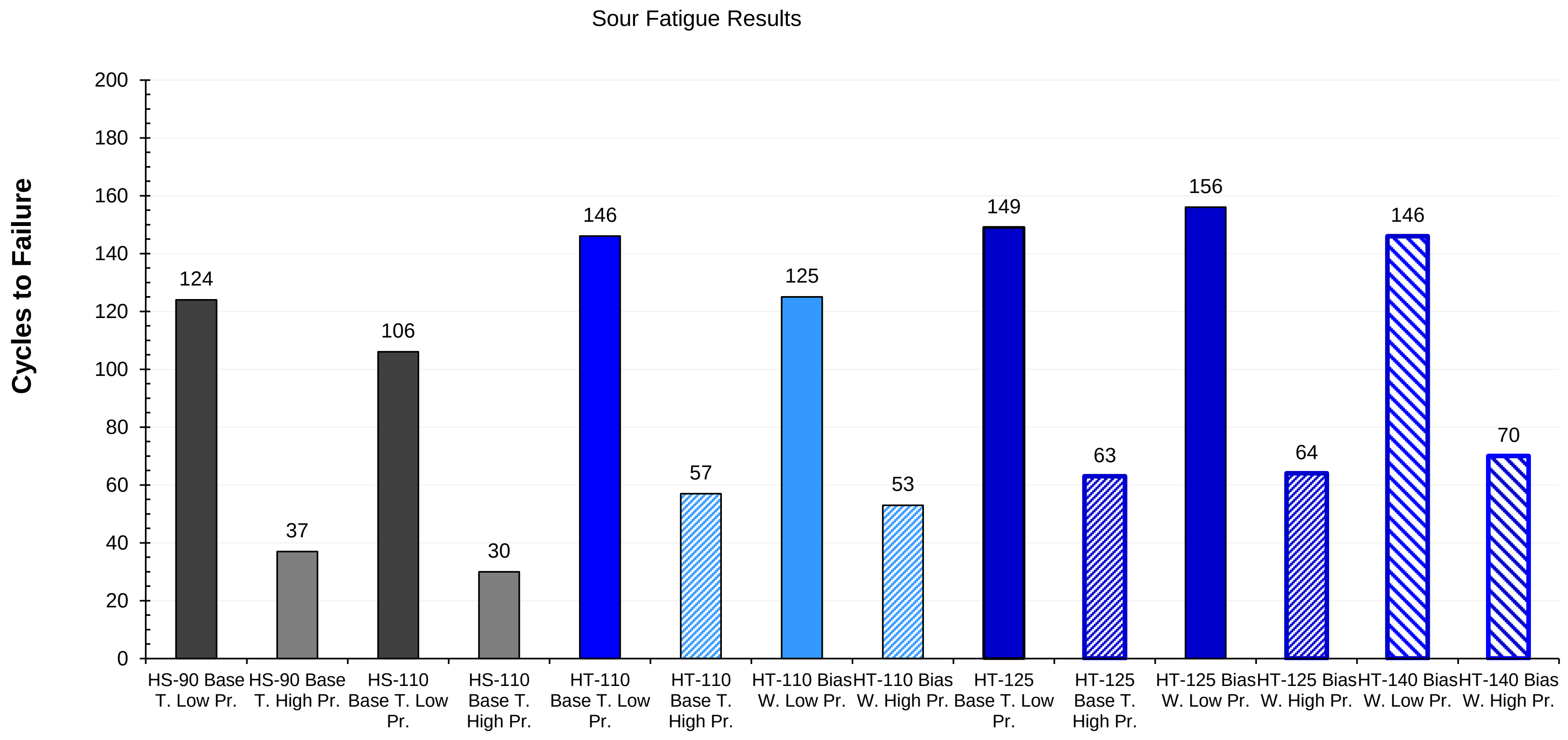


Figure 13. Bias welds sour fatigue performance

Source: Padron (2010)

BlueCoil Sour Fatigue Life Without Inhibitor



Conclusions

- Time to SSC failure in sour environments were typically <10 hours
- Inhibitors proved effective at reducing susceptibility to SSC
- Cumulative fatigue prior to testing did not significantly increase susceptibility to SSC
- Ignoring HIC failures, the sour fatigue life was essentially constant (50%-60%) and independent of grade and H_2S partial pressure (within the range tested)
- HIC will significantly reduce sour fatigue life
- HIC failures increased with H_2S partial pressure and decreased with increasing tube SMYS
- Inhibition does not extend sour fatigue life, except for avoiding HIC
- Bias weld sour fatigue life is significantly lower than base tube sour fatigue life

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