High strength coiled tubing (CT) can be successfully used in sour environments if properly managed

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Agenda

- Background
  - What is high strength CT?
- Sour Gas Issues
  - Environmental cracking mechanisms
  - Historical operating guidelines
  - Mitigation strategies
- Test Program Development
  - How to test
  - Specialized considerations for CT
  - Experiment design
- Results
- Conclusions

Background

- What is high strength CT?
  - CT with strength levels beyond CT100/110
  - In this case, CT130
    - 130 ksi SMYS (896 MPa)
    - 135 ksi SMUTS (931 MPa)
    - 39 HRC maximum hardness

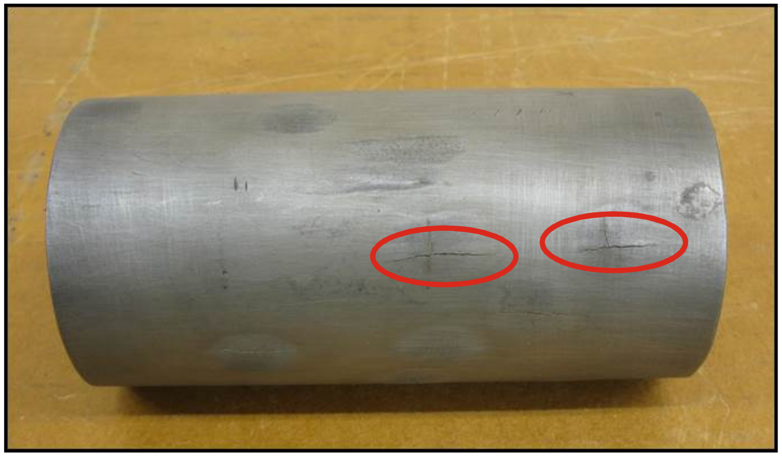
Sour Gas Issues

- Environmental cracking in aqueous sour environments
  - Hydrogen induced cracking (HIC) generally affects lower strength steels with UTS up to 550 MPa (Metals Handbook).
    - HIC is caused by the absorption of hydrogen into the steel (NACE).
    - HIC is not the expected failure mechanism for CT.
  - Sulfide stress cracking (SSC) affects higher strength steels, such as 130 ksi yield strength especially if they are stressed.
    - Since CT is repeatedly bent past the point of plasticity, SSC is the expected failure mechanism for CT.
    - SSC is corrosion caused by cathodic polarization; cathodic protection of CT would worsen the problem.

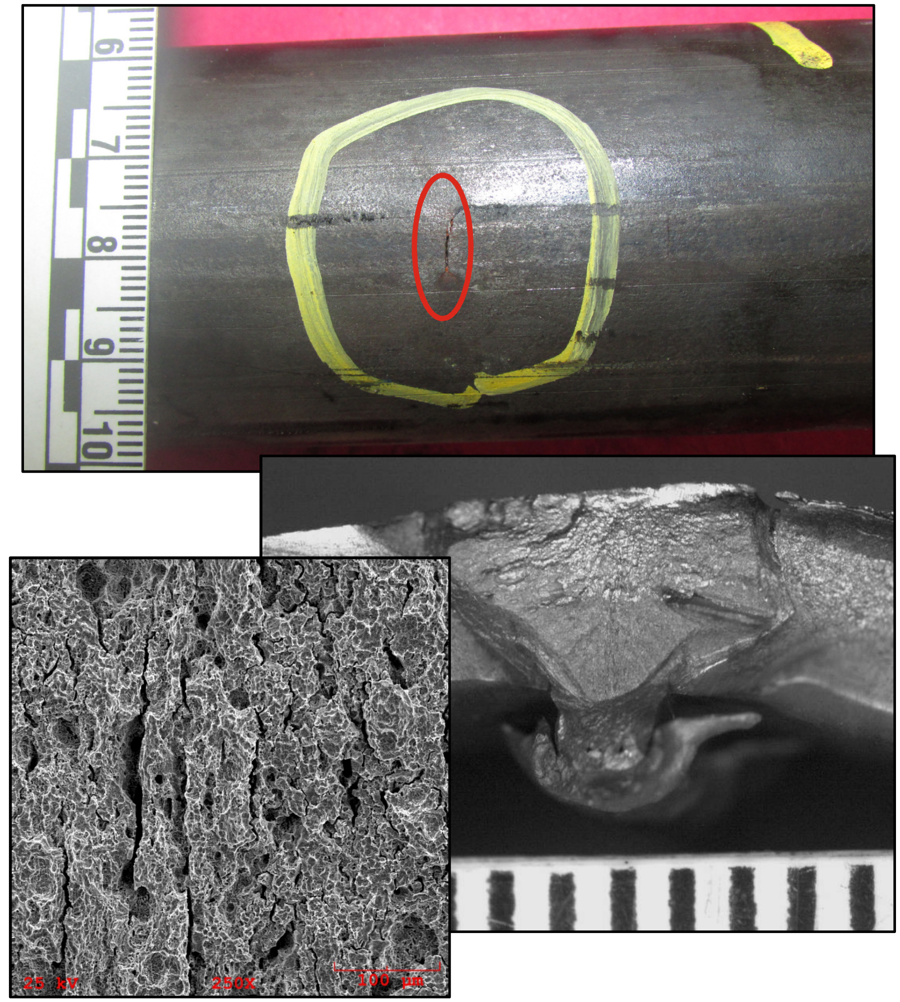
Metals Handbook, 9th Edition, p. 300
NACE TM0284-2011 Foreword

Sour Gas Issues

Environmental cracking in aqueous sour environments (cont.)



- HIC
- Longitudinal



- SSC
- Transverse

Sour Gas Issues

- Historical operating guidelines
  - "A generally accepted rule for resistance of carbon and low-alloy steels to SSC is to maintain the hardness below HRC 22" (Craig).

CT Grade	Minimum Yield Strength (psi [MPa])	Maximum Hardness
CT70	70,000 (483)	22 HRC
CT80	80,000 (551)	22 HRC
CT90	90,000 (620)	22 HRC
CT100	100,000 (689)	28 HRC
CT110	110,000 (758)	30 HRC
CT130	130,000 (896)	39 HRC

  - Higher strength grades are above 22 HRC, so mitigation strategies must be employed to safeguard against SSC.

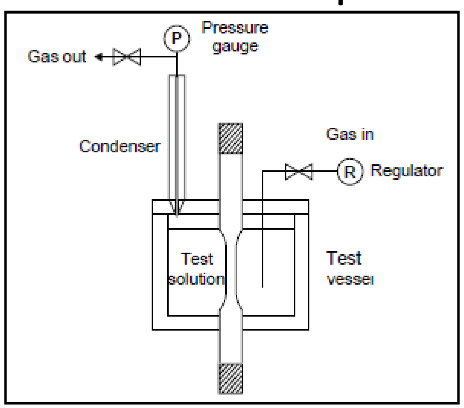
Bruce Craig, Oilfield Metallurgy and Corrosion 4th Edition, p. 172

Sour Gas Issues

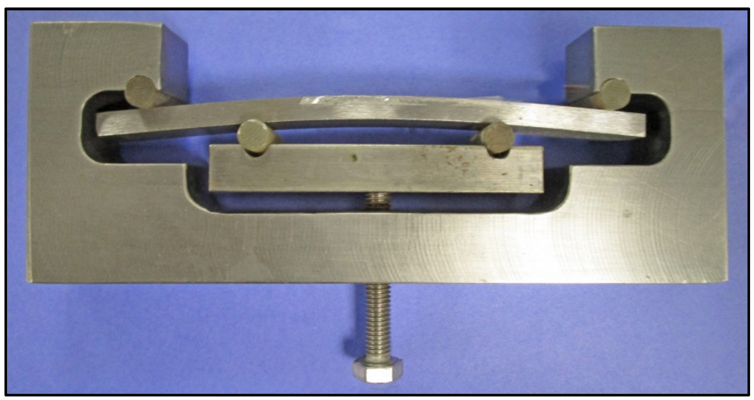
- Mitigation strategies: why CT can be used in sour environments without causing SSC
  - SSC is dependent on time and temperature
    - Time: decreasing exposure time decreases the likelihood of SSC for high-strength coiled tubing
    - Temperature: increasing temperature decreases the likelihood of SSC for high-strength coiled tubing
  - External mitigation – controlling the environment
    - Raise the pH
    - Scavengers
    - Operate overbalanced
    - Inhibitors

Test Program Development

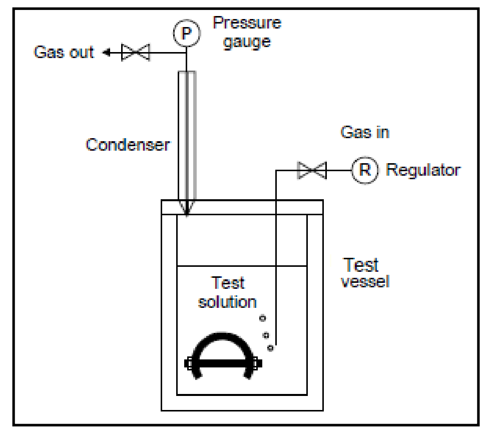
- How to Test
  - Mitigation strategies alone do not provide assurances; best method is to test
  - Laboratory testing method NACE TM0177
    - Machined samples are stressed and placed in an aqueous acidic environment saturated with H_2S for 30 days
    - Three primary sample types: tensile, C-ring, four point bent beam



Tensile, Method A (NACE)



Four point bent beam, Method B (Exova)



C-ring, Method C (NACE)

NACE TM0177-2005
Photo Courtesy of Exova

Test Program Development

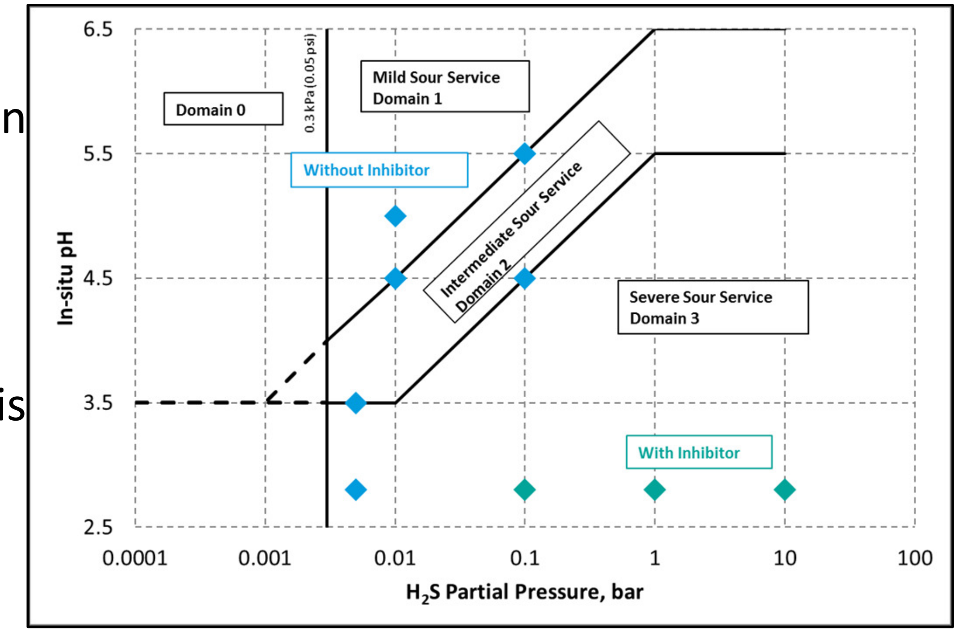
- There is no industry standard for testing CT in sour environments
- SPE 93786 (2005) and 99557 (2006) set the methodology
- Specialized considerations for coiled tubing
  - CT is plastically deformed in operations
  - CT contains both seam and bias welds
  - Test program considerations:
    - Half of samples should not be fatigued
    - Half of samples should be fatigued to approximately ½ of fatigue life
    - Samples should include the parent tubing, seam weld, and bias weld
    - Samples should be tested in duplicate
- Each environment should have 12 samples!

Specimen Type	QTY	Condition
Parent Tubing	2	No Fatigue
Seam Weld	2	
Bias Weld	2	
Parent Tubing	2	Pre-Fatigued
Seam Weld	2	
Bias Weld	2	

Test Program Development

- Experiment design
  - Key variables
    - pH
    - H_2S partial pressure
    - With and without inhibition
  - Inhibitor
    - Identified as "CG"
    - 0.2% by volume in aqueous solution
  - The rules
    - Environment "passes" only if all 12 samples pass
    - If any sample fails, a 3-for-1 retest is undertaken
    - Test at room temperature for 30 days to be more conservative

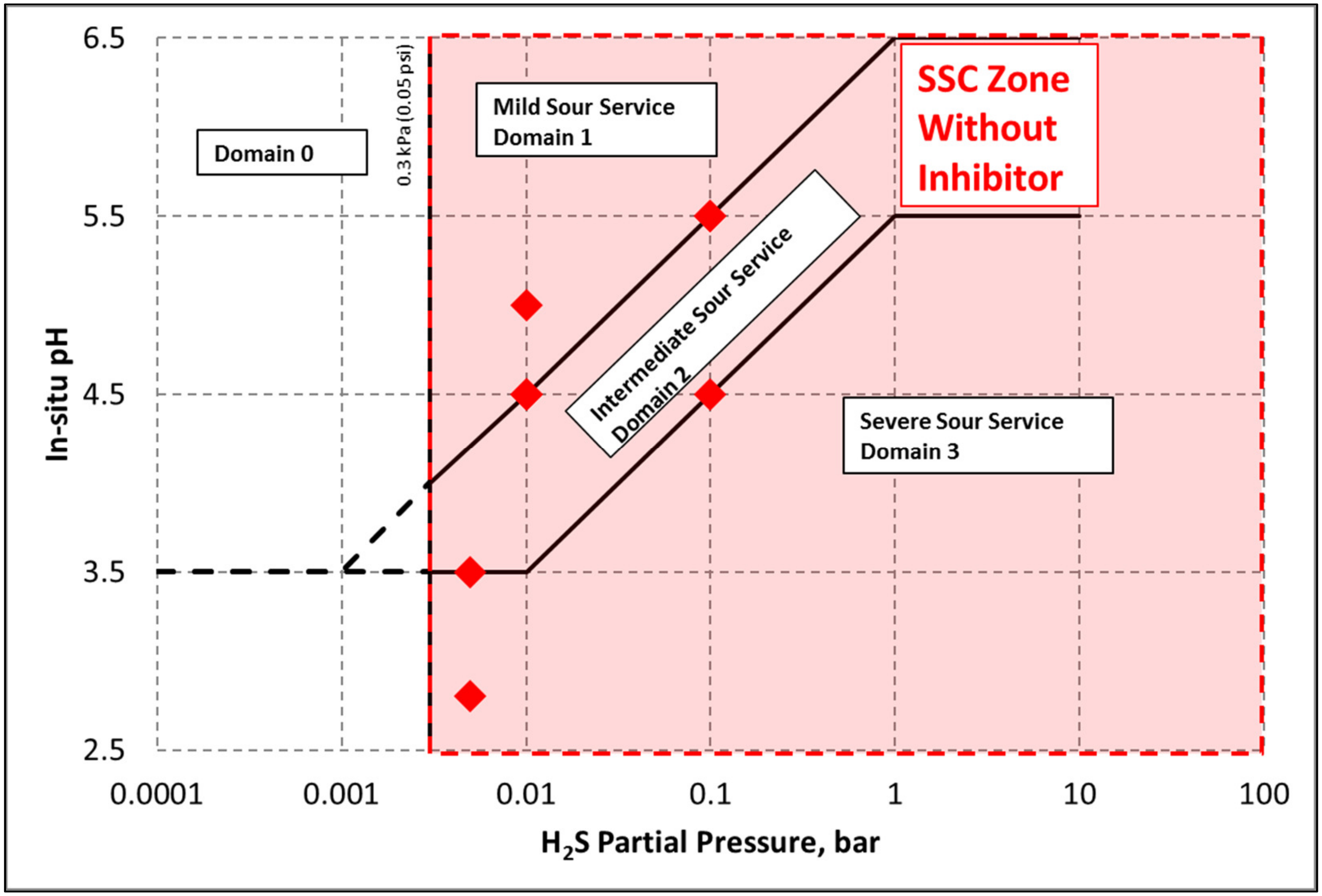
Sour Service Criteria (SPE 121294)	
Pressure, MPa (ksi)	H_2S Concentration (ppm)
6.89 (1)	>50
20.68 (3)	>15
34.47 (5)	>10
68.95 (10)	>5
103.42 (15)	>3



SPE 121294

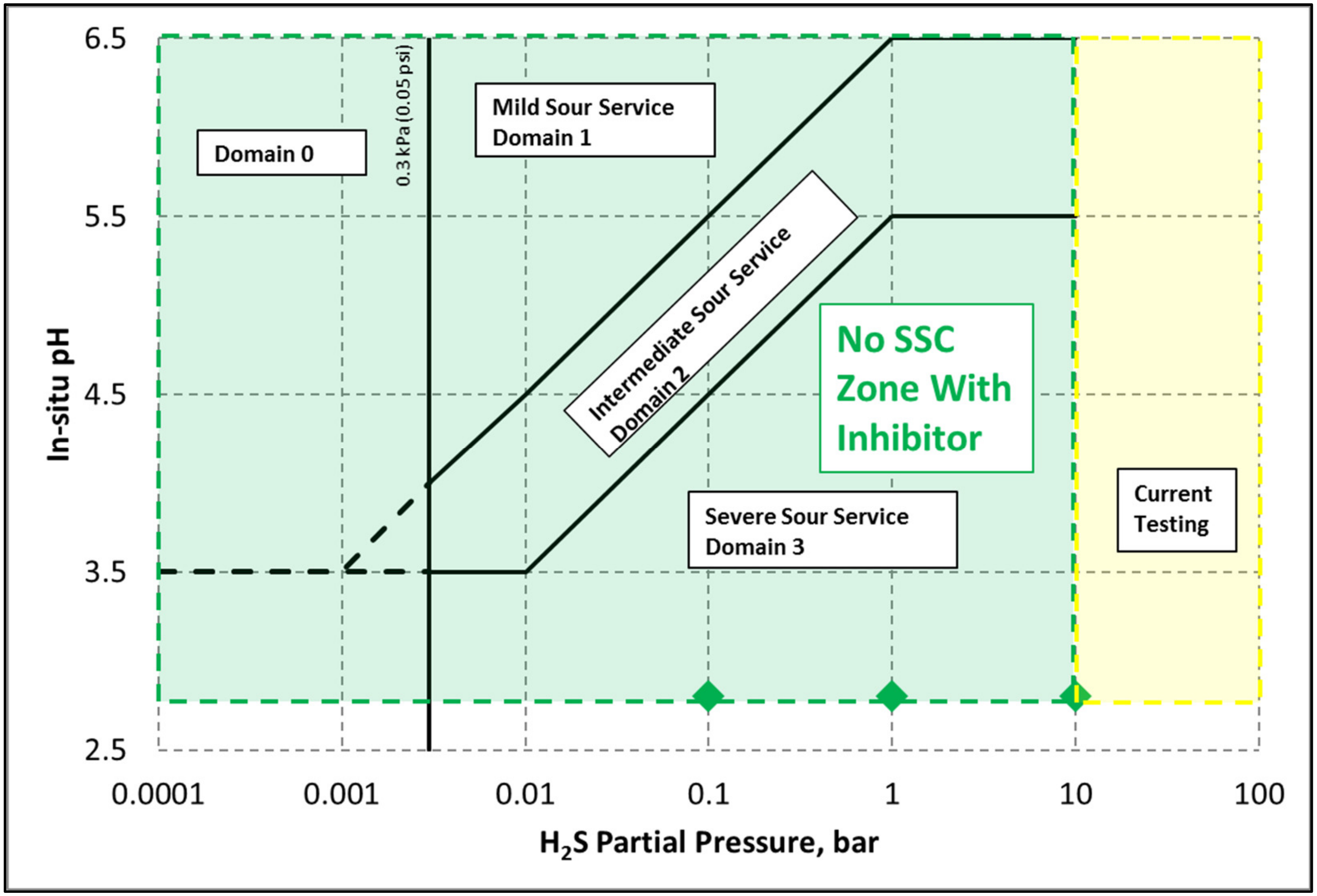
Results

- All sample sets failed when no inhibition was used.
  - It is possible that over-straining occurred.



Results

- All sample sets passed when inhibition was used, with the need for one 3-for-1 retest.



Conclusions

- *A "safe operating zone" exists for CT130 (and all lower-strength coiled tubing grades) as low as 2.8 pH and 10 bar H_2S partial pressure when inhibitor CG is used.*
- *CT130 can be treated the same as CT100 and CT110 when operating in sour and non-sour environments when inhibition is used.*
- *Lesson learned: Always make extra test samples.*
- *Additional testing in progress:*
  - Testing up to 100 bar H_2S partial pressure with inhibitor CG.
  - More testing is necessary to develop a no-inhibition "safe zone" for CT130.

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