



Impact of Carbon Steel Metallurgy on Sour System  
Corrosion  
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**NACE Calgary Section  
Elemental Sulfur Mini-symposium**

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# The Age Old Question

- Does pipeline material chemistry and metallurgical structures make a difference in the corrosion of sour systems and systems with elemental sulfur?



# Possible Impacts on Corrosion Susceptibility

- Micro Alloy
  - Can they create anode/cathode differences and result in pit initiation?
  - Do they effect FeS scale formation?
- Cold Work or Heat Treatment
  - Cold work creates a higher energy state. Does this affect corrosion in sour systems?
  - Do heat treatments that create metallurgical differences affect corrosion?
- Welding
  - Under some conditions welds will preferentially corrode. Are welds a factor in corrosion of sour system?



# To Find the Answer

- Literature Search
  - High level search, not exhaustive
  - Papers written in the mid 80's and earlier have more information. These papers are not readily available
- Failure review
  - Talked with the senior people at Alberta failure analysis labs about the sour system and systems with elemental sulfur failures

# To Find the Answer

- Talked with “corrosion wizards”. The wise men and women with years of experience





# Carbon Steel Metallurgical Considerations

- Micro alloy elements and impurities in common pipeline steels.
- Cold Work/Heat Treatment
  - Cold working of ERW pipe
  - Field bending
  - Heat Treatment
- Welds
  - Circumferential pipeline welds
  - ERW seam welds

# Scope: Sour System Corrosion

- The mechanisms of sour system and elemental sulfur corrosion are not included in this presentation
- Cracking mechanisms are not addressed
- Corrosion of alloy materials is not addressed

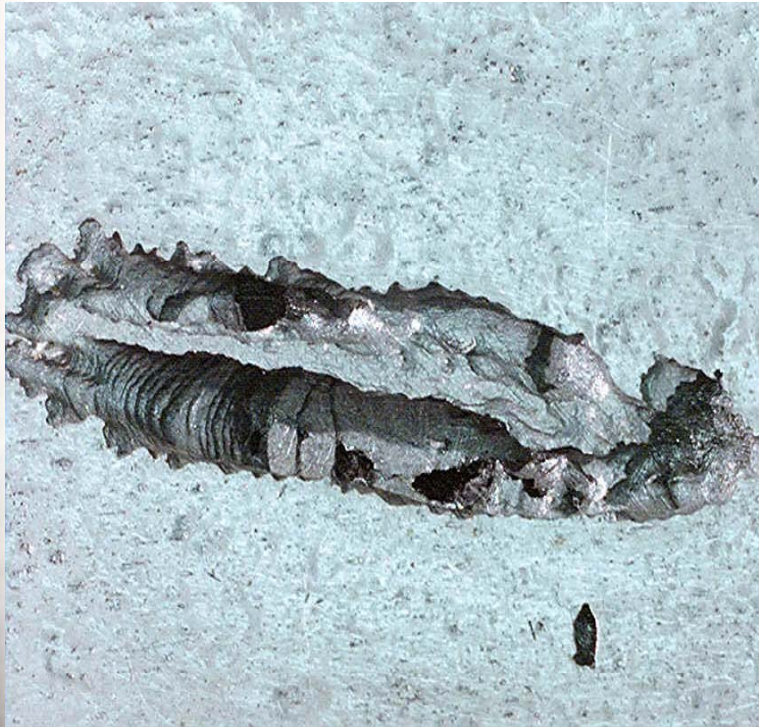
# Sour System Corrosion

Pitting can be:

- Extensive
- Isolated



# Sour System Corrosion



Flow Effects



Active and Passive Pits

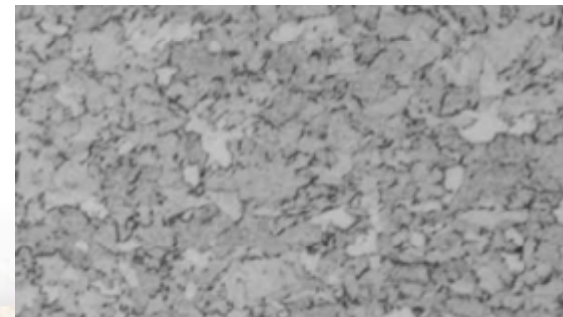
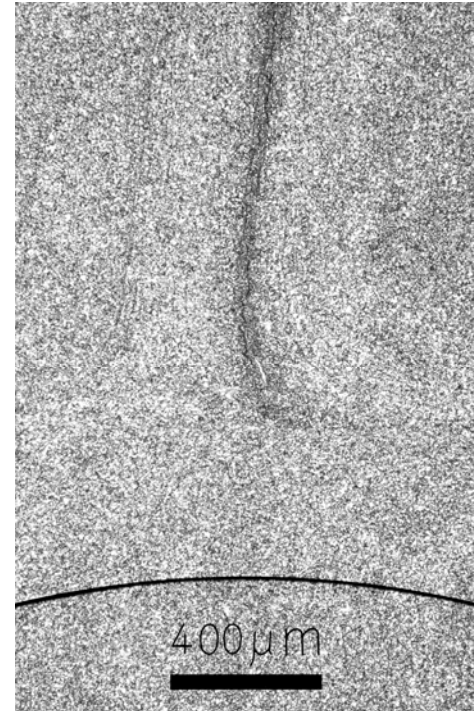
# “Road Runner” Corrosion

- This internal pit in a wet sour gas pipeline grew in 5 directions!



# 1. Micro Alloy's and Impurities

- Can they create anode/cathode differences and result in pit initiation?
- Do they effect FeS scale formation?
- Micro alloys are in typically in solid solution
- More recent pipeline steels are primarily low carbon with a fine grained micro structure dominated by Ferrite



# Micro Alloy Elements

- Pipeline steels have changed; old 70's and earlier had higher C,Mn
- Typical pipeline steels have varying degrees of micro alloy elements
- Some are added intentionally to improve strength
  - Elements niobium, vanadium and titanium added either singly or in combination to increase strength
  - micro alloying elements are sometimes used in conjunction with other strengtheners such as boron, molybdenum and chromium, nickel and copper
  - Strengthening by micro alloying allows reduction in carbon content to improves weld ability and notch toughness.

# Micro Alloy Elements

- Others are remnants from the steel source
  - Impurities such as sulfur, oxygen, nitrogen and phosphorus
  - Skelp made from electrical arc furnaces can have more contaminants than skelp made from iron ore

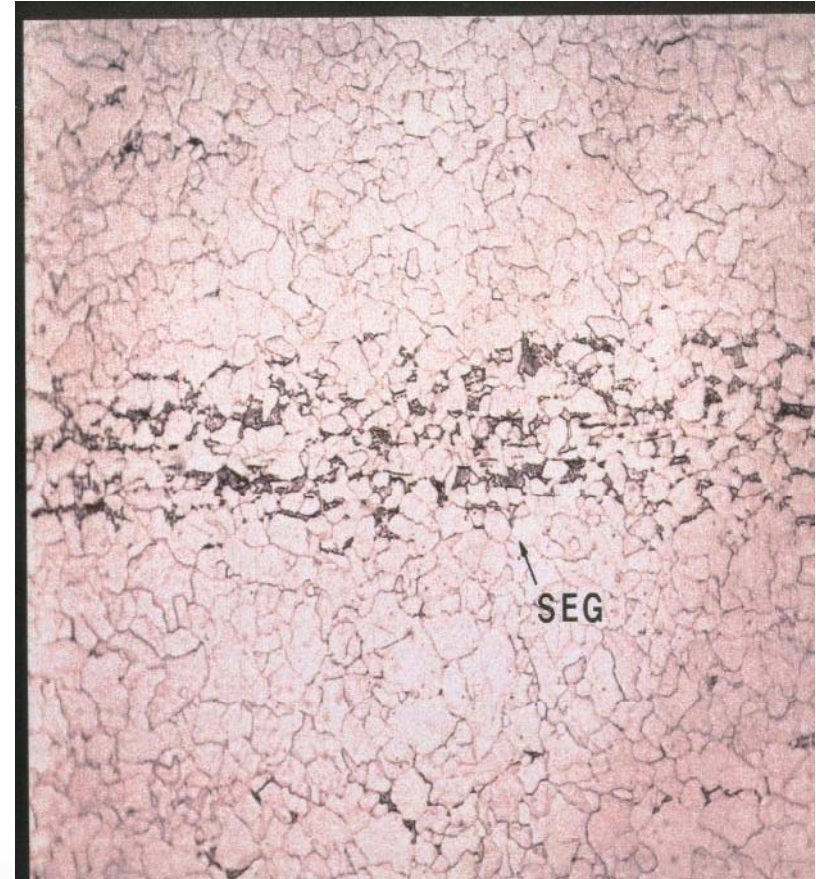
# Typical Elements in Pipeline Steel

The actual amounts and allowable maximums vary

- Carbon (C) 0.05-0.10% .
- Manganese (Mn) Per API 5L 3.1\* Per API 5L 3.1\*
- Silicon (Si) 0.35% max.
- Sulfur (S) 0.003% max.
- Phosphorus (P) 0.012% max.
- Nickel (Ni) 0.20% max.
- Chromium (Cr) 0.20% max.
- Molybdenum (Mo) 0.20% max.
- Copper (Cu) 0.35% max.
- Aluminum (Al) 0.05% max.
- Calcium (Ca) 2X Sulfur mi. / 0.006% max.
- Nitrogen (N) 0.012% max.
- Niobium (Nb) 0.08% max.
- Titanium (Ti) 0.025% max.
- Vanadium (V) 0.08% max.

# Example of Impurity

- This is a non-typical ERW pipeline steel with a high concentration of carbon, manganese, sulfur and phosphorous at the center line
- This effects HIC resistance but what about corrosion?



# Example from an Alkylation Unit

- This acid corrosion occurred in Alkylation Unit
- Small differences in metallurgy can result in preferential corrosion
- The carbon steel flange and weld were not corroded but the carbon steel nozzle was severely attacked



Photo Courtesy of Acuren



## Do Micro Alloys and Impurities have an Effect?

- A review of industry papers did not reveal any reports of micro alloy's, or steel impurities effecting corrosion in sour systems or systems with elemental sulfur
  - Note that this was a high level review and not an exhaust search
  - Does anyone have other knowledge or experience?



## Do Micro Alloys and Impurities have an Effect?

- Discussion with companies who specialize in failure analysis
  - Corrosion failures have not been attributed to the carbon steel material chemistry
- Discussion with industry experts with years of experience in sour systems
  - No evidence of micro alloy's increasing likelihood of corrosion

## 2. Cold Work/Heat Treatment

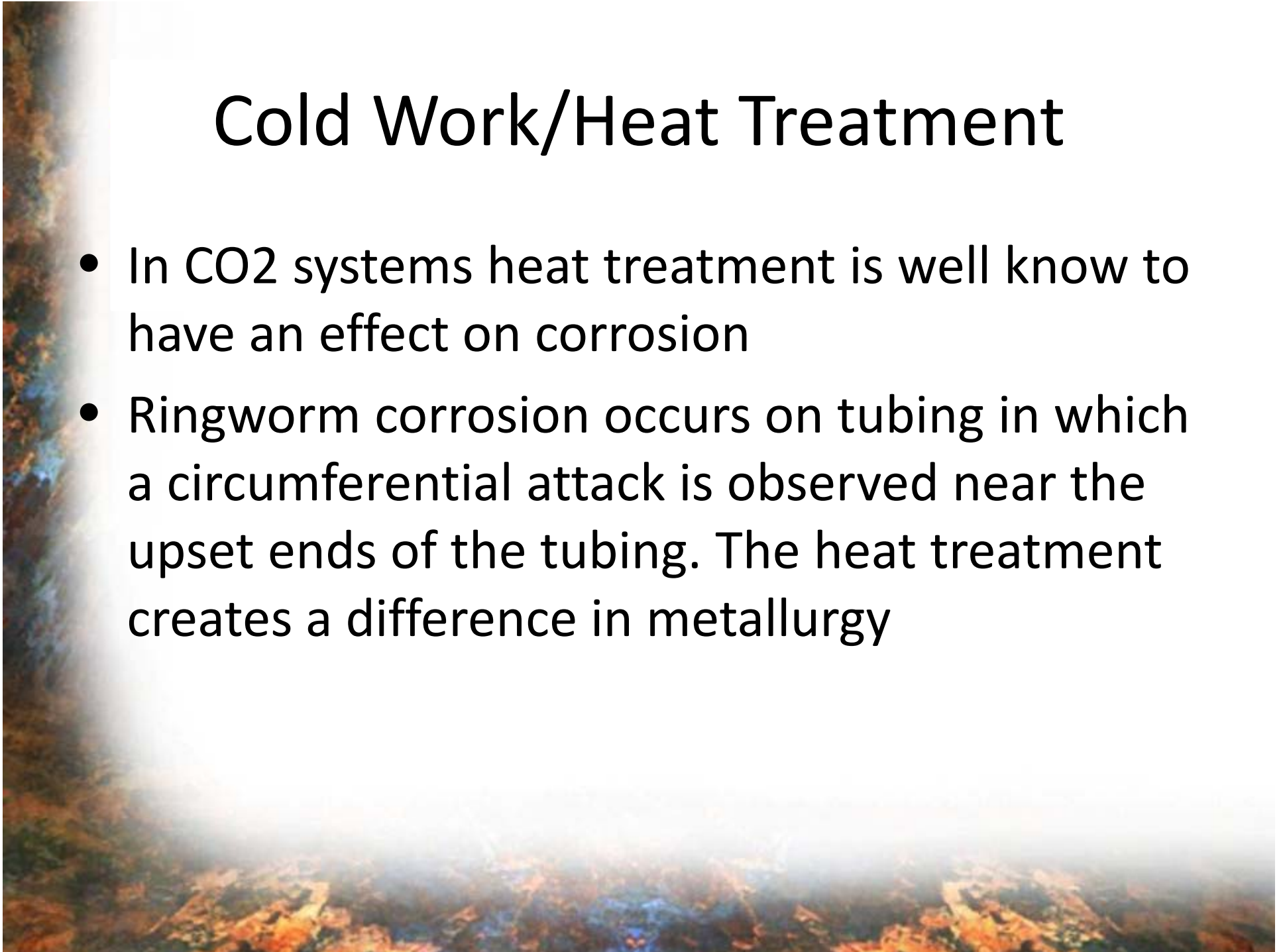
- Does cold work or heat treatment have an Effect?
- Cold work and heat treatment can change the energy state of the material. Examples for carbon steel pipelines are:
  - Cold working of ERW pipe
  - Field Bending of Pipelines
  - Heat treatment of welds
  - As manufactured heat treatment

# Field Cold Bending Pipelines



# Cold Work/Heat Treatment

- In CO<sub>2</sub> systems heat treatment is well known to have an effect on corrosion
- Ringworm corrosion occurs on tubing in which a circumferential attack is observed near the upset ends of the tubing. The heat treatment creates a difference in metallurgy



# Cold Work/Heat Treatment

- Pat Teevens conducted work on a sour gas system with elemental sulfur in the mid 80's.
- There was a difference in corrosion inhibitor performance with downhole tubular's that had different heat treatments


– CORROSION CONTROL CONSIDERATIONS FOR THE PRODUCTION OF VERY (SUPER) SOUR GAS WELLS (H<sub>2</sub>S ~ 60 mol%)-  
Patrick J. Teevens

# Literature Search

- Increased corrosion attributed to cold work
- Higher corrosion rates on API 5L X52.

“ The characteristics of the initial sulfide layer formed for both steels must have been somewhat different probably due to differences in the substrates. From a metallurgical point of view, both steels are very similar in terms of chemical composition (see Table I) other than Mn and S, which are slightly larger for the X52 grade steel. However, X52 has undergone plastic deformation to improve its yield strength and hardness. These two differences might account somehow for the formation of a less compact and less uniform sulfide iron layer which did not act as a barrier to the species at all.”

CO<sub>2</sub> AND H<sub>2</sub>S CORROSION OF API 5L-B AND 5L-X52 GRADE STEELS J.J. Perdomo, et al PDVSA INTEVEP S.A. NACE 2000 Paper 00042



# Does Cold Work/Heat Treatment have an Effect?

- A review of industry papers did find examples of both heat treatment and cold work having an effect in sour systems
- Discussion with companies who specialize in failure analysis
  - Corrosion failures in pipelines have not been attributed to heat treatment or cold work
- Discussion with industry experts with years of experience in sour systems
  - Heat treatment can have an effect on corrosion but it is not typically a consideration in sour or elemental sulfur service
  - Heat treatment and cold work effects on cracking are the key considerations

## 3. Welding

- Can welding have an effect on sour system corrosion?
- Welding
  - Under some conditions welds preferentially corrode.
  - Welds have complex metallurgical structures and heat affected zones

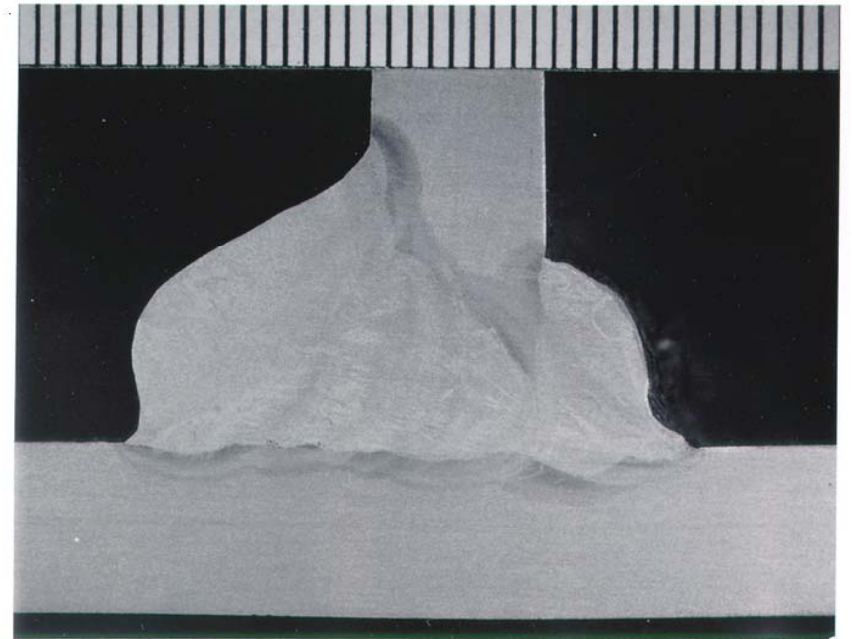


# Effect of Welds

- Welds
  - Circumferential pipeline welds
  - ERW seam welds
- Welding creates a metallurgical difference and a higher energy state (residual stress)
- Preferential weld corrosion is known to occur in pipelines, piping and pressure vessels

# Effect of Welds

- Preferential weld corrosion is the result of galvanic coupling, whereby the weld metal acts as an anode and the pipe material as a cathode
  - different metallurgical zones due to different microstructures



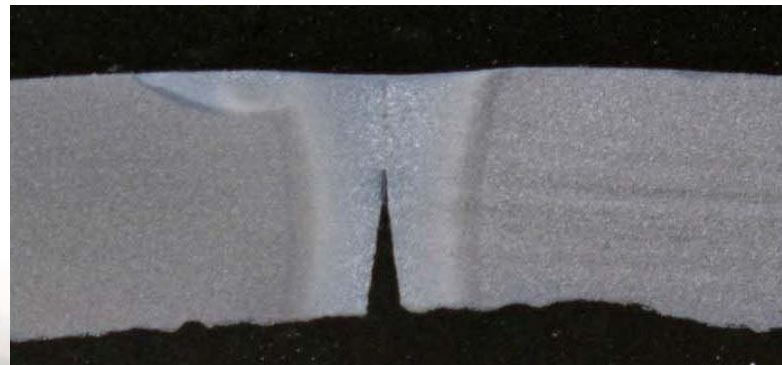
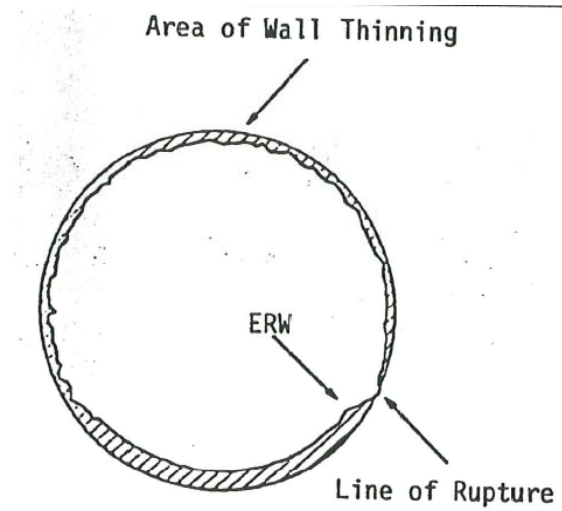
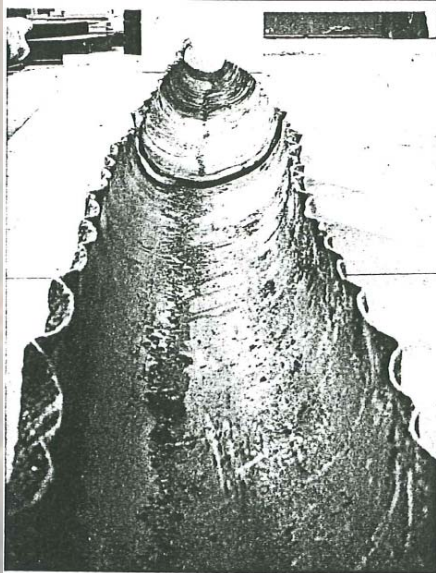
Weld for a Hot Tap on a Sour Gas Pipeline

# Literature Survey

- A wet sour gas field with 5% CO<sub>2</sub> and 0.2% H<sub>2</sub>S had preferential weld attack on the ERW seam.
- High rates of methanol injection and a CO<sub>2</sub> dominated corrosion mechanism resulted in top of the line acid attack of the pipeline and the ERW weld.

Analysis of a Gas Field Corrosion Failure at Crossfield- Nguyen Bich, Karol Szklarz, Materials Performance 1989

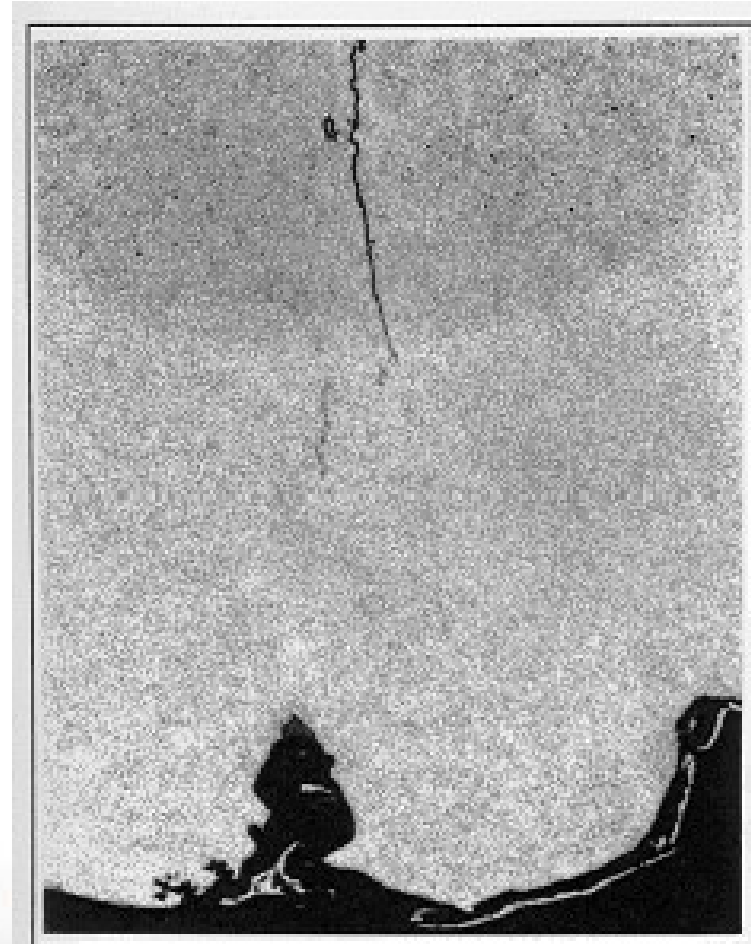
# Crossfield Failure



Example of ERW seam  
corrosion and cracking  
Photo Courtesy of Acuren

# Weld defects

- Welding
  - Root bead defects have been known to initiate pitting.
  - Cracking, such as the SOHIC in this photo is the main concern in a sour system.





# Can Welding have an Effect on Sour System Corrosion?

- A review of industry papers on welds in sour systems
  - Corrosion failures in pipeline ERW welds have been attributed to conditions where acid attack occurs
- Discussion with companies who specialize in failure analysis
  - Corrosion does occur at circumferential welds and is attributed to weld defects that result in pit initiation
- Discussion with industry experts with years of experience in sour systems
  - Welds typically do not result in preferential corrosion
  - Welding effects on cracking are the key considerations

# Summary

- In other corrosive systems micro alloy's, heat treatment, cold work and welding can lead to accelerated corrosion.
- In sour systems and systems with elemental sulfur these metallurgical variations do not play a significant role.
- The formation of FeS scales may prevent these types of localize attack.

# Summary

- The rate of corrosion in sour gas systems with elemental sulfur can be so high that minor metallurgical differences are not relevant.
- This 2" line was in H<sub>2</sub>S, S, Cl<sup>-</sup> service for only 40 days!

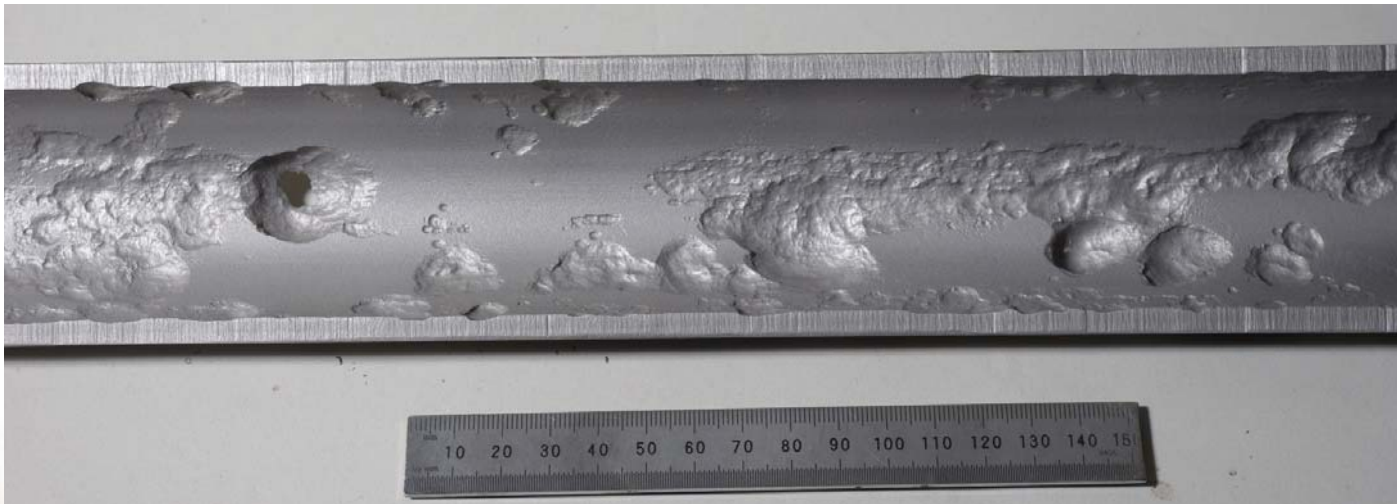


Photo Courtesy of Acuren