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Flexible pipes-Corrosion of armour wires in confined environment

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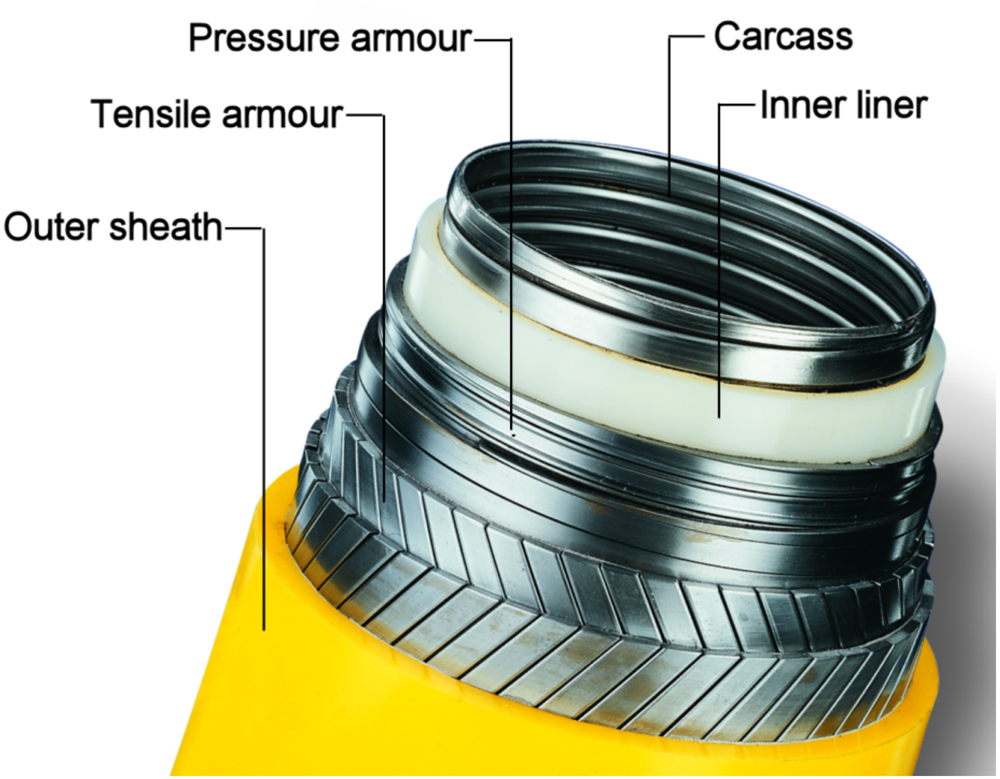
Presentation Outline

- Flexible pipe design
- Confined environment concept
    - Formation of protective corrosion product (FeCO3) films
    - Disturbing factors
- Oxygen ingress and reformation of protective $FeCO_3$ film

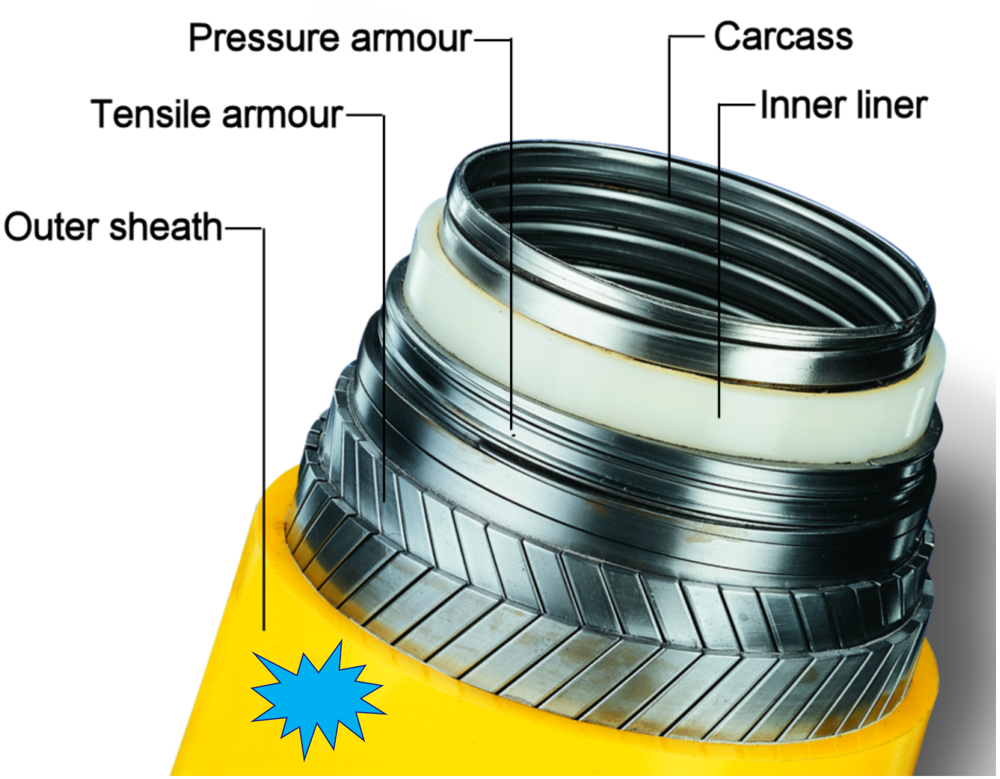
Cross section of a flexible pipe



Diffusion:
- H_2O
- CO_2
- H_2S
- CH_4 +++

Confined environment:
Low ratio of free volume (V) to steel surface area (S), **V/S < 0.1 ml/cm²**

Cross section of a flexible pipe



Diffusion:

- H_2O
- CO_2
- H_2S
- CH_4 +++

Damaged outer sheath:

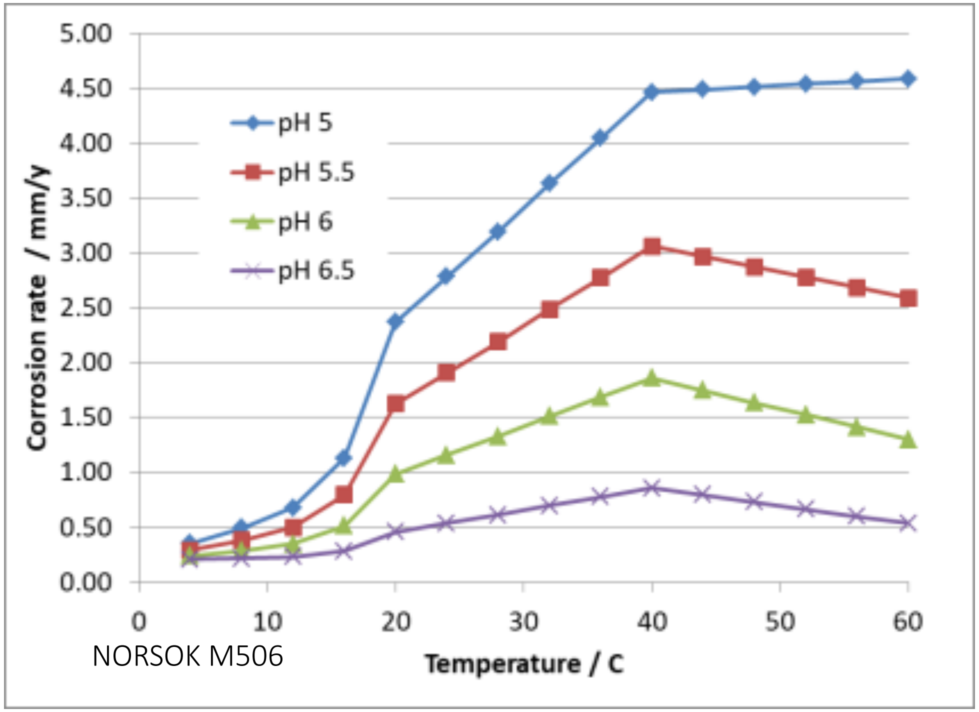
- air (O_2)
- sea water

Air through vent port

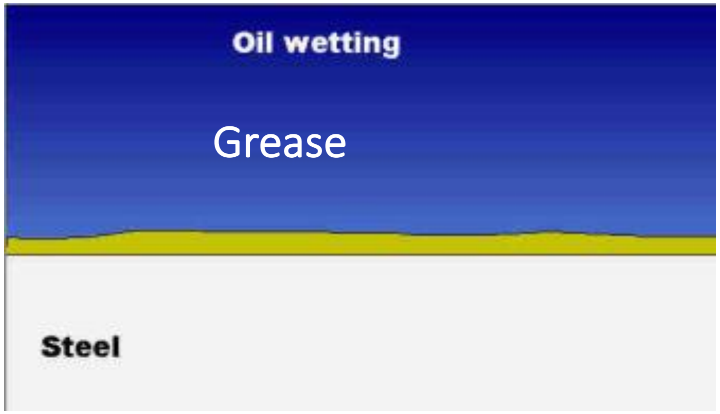
Confined environment:
Low ratio of free volume (V) to steel surface area (S), **V/S < 0.1 ml/cm²**

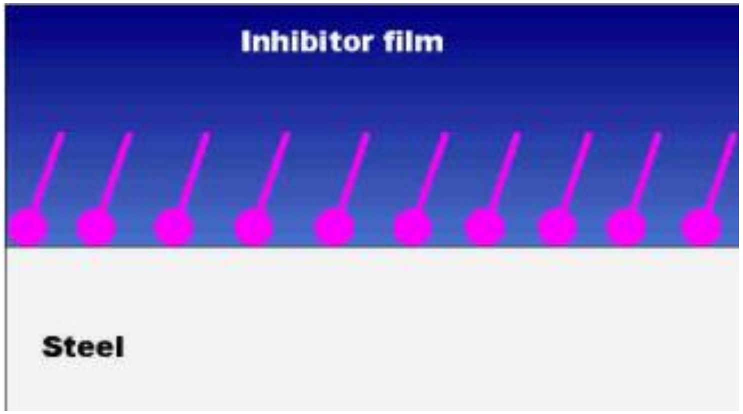
No protection- high corrosion rates

CO_2 corrosion, fCO_2=1 bar



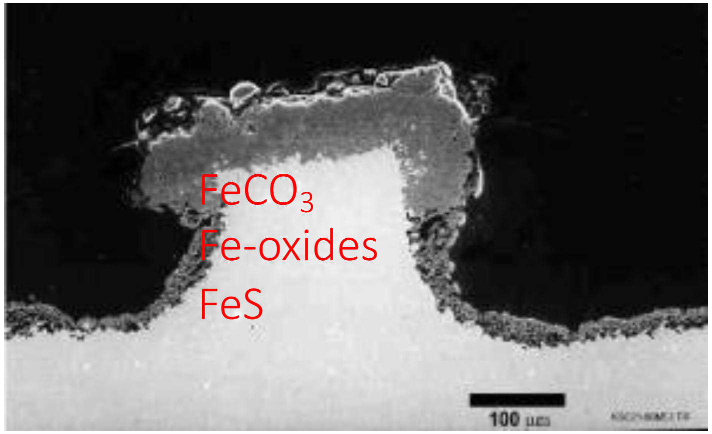
Carbon steel exposed to water + CO_2/H_2S/O_2 in the annulus corrodes unless it achieves a protective layer on the surface





CP?

Tape



Acceptable corrosion rates

~~0.1 mm/year (oil and gas pipelines)~~

<0.01 mm/year

↓

Good protective corrosion product films!

pH and SR dependent on the dissolved corrosion product concentration

$$Fe + 2H_2CO_3 \rightarrow Fe^{2+} + 2HCO_3^- + H_2$$

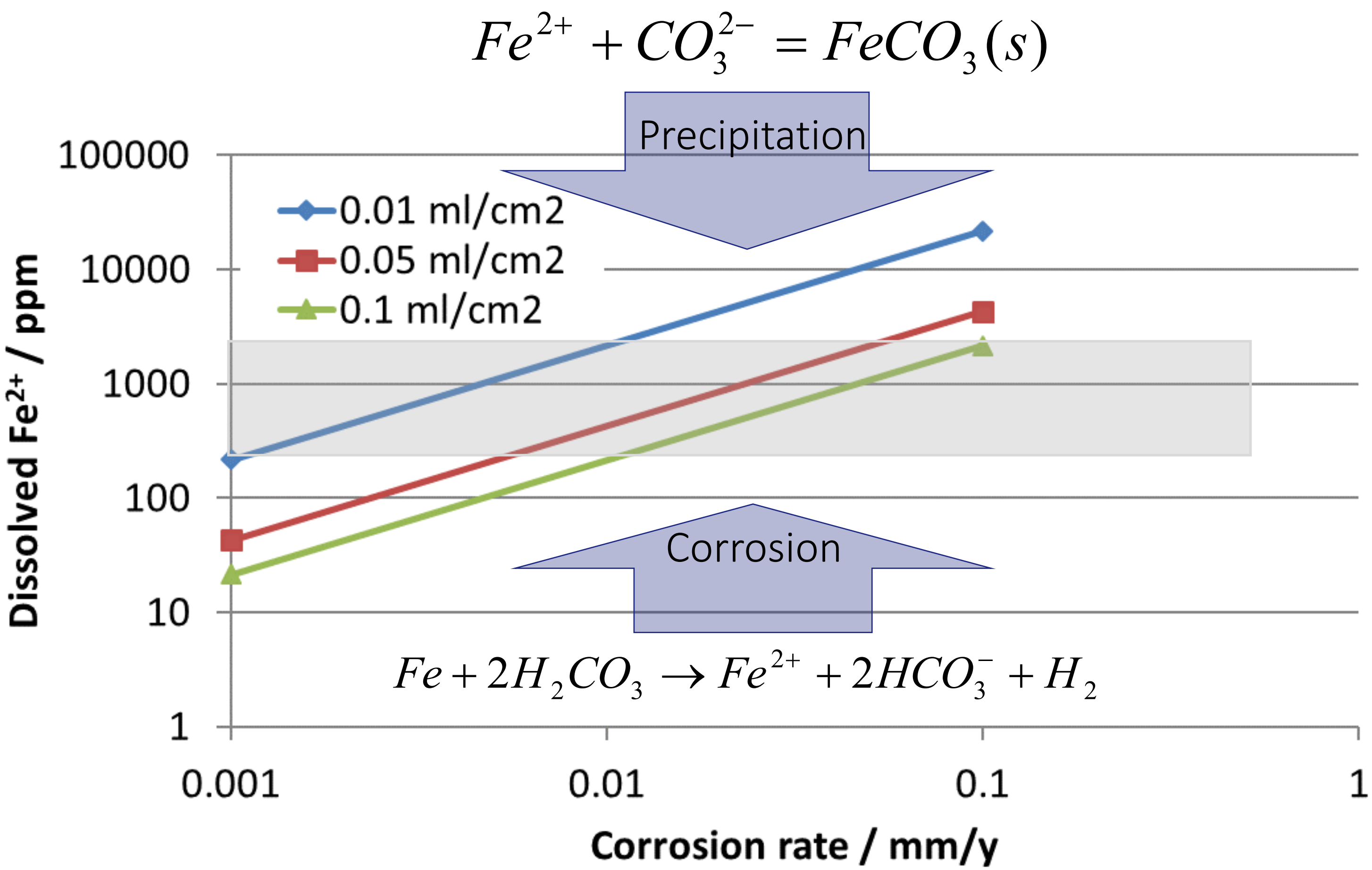
$\uparrow$ pH, SR_{FeCO3}

$$SR_{FeCO3} = \frac{c_{Fe^{2+}} \cdot c_{CO_3^{2-}}}{K_{sp}} > 1$$

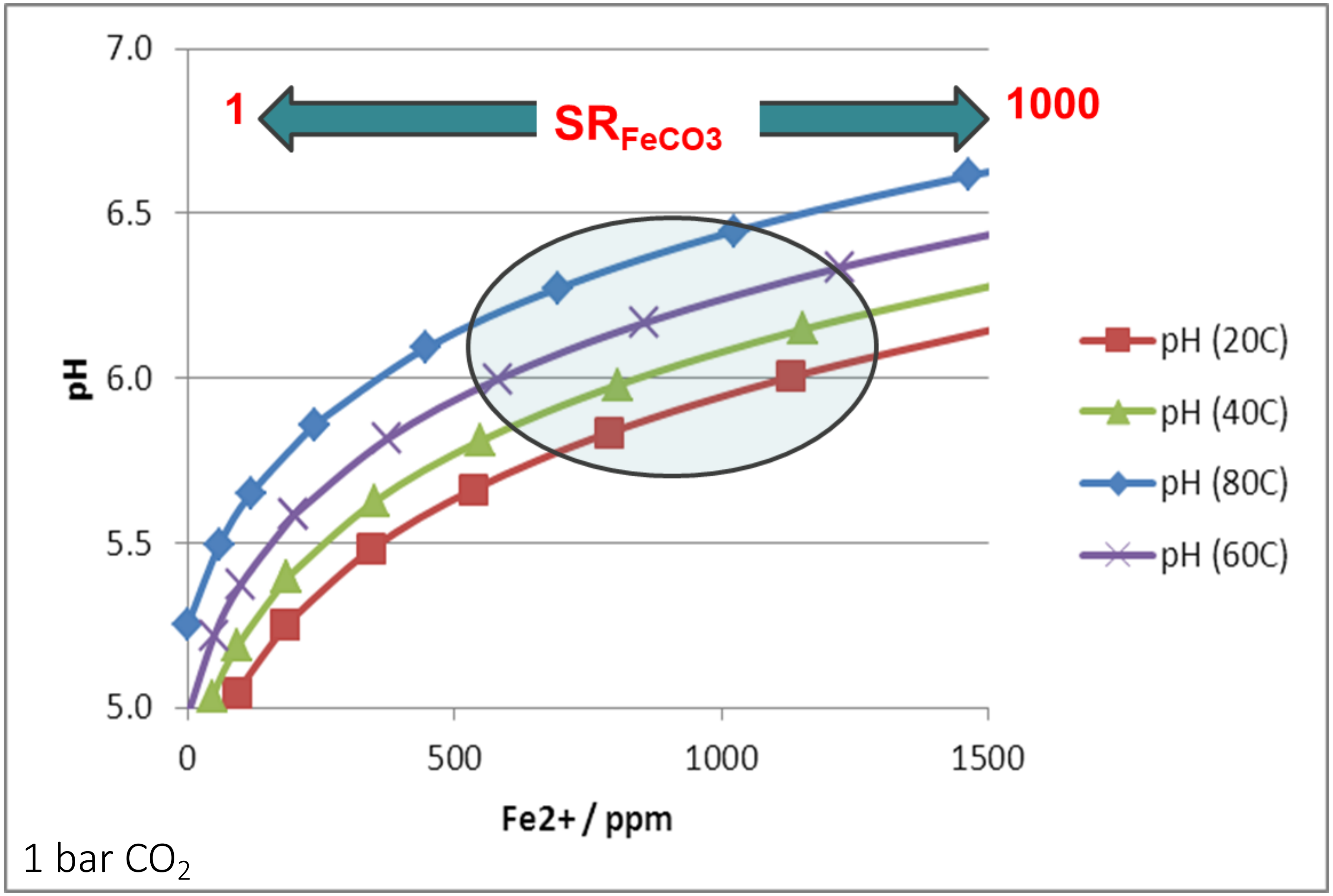
$$Fe^{2+} + CO_3^{2-} = FeCO_3(s)$$

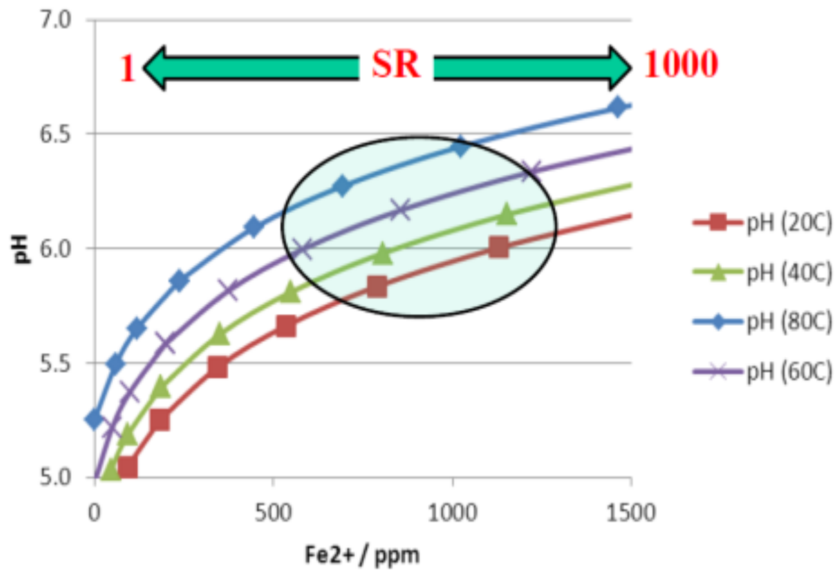
$\downarrow$ pH

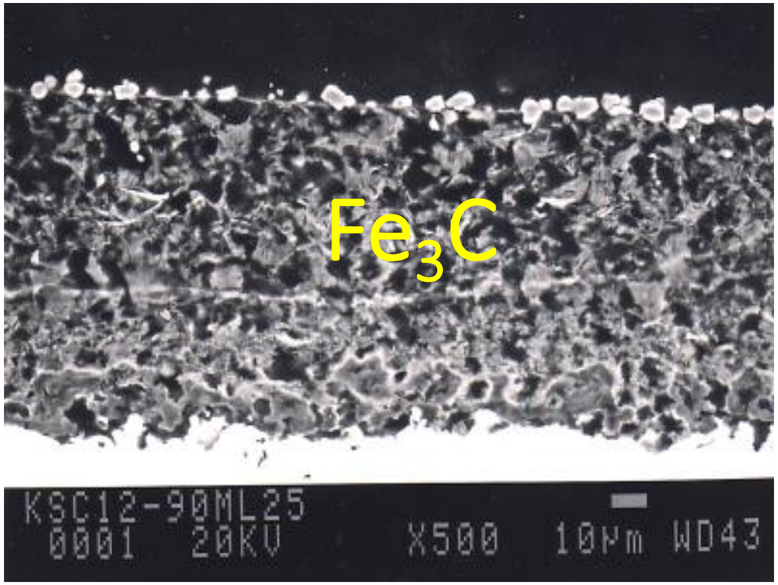
Accumulation of corrosion products

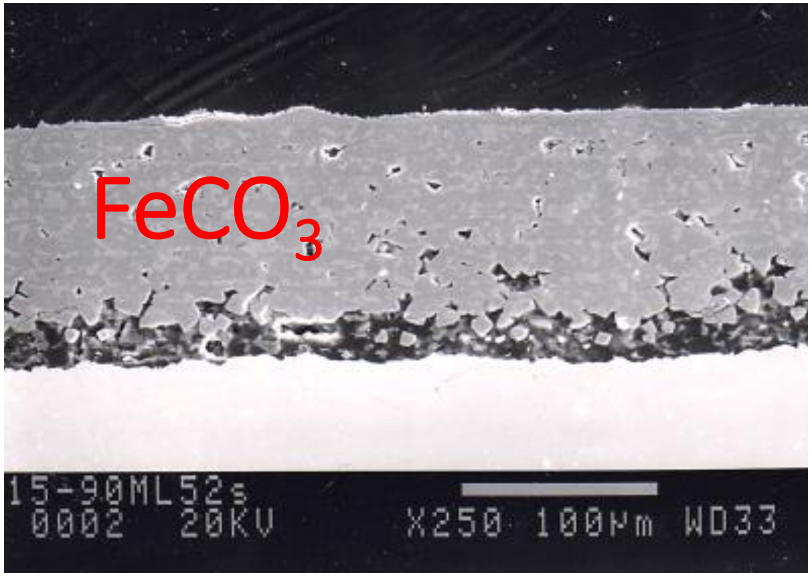


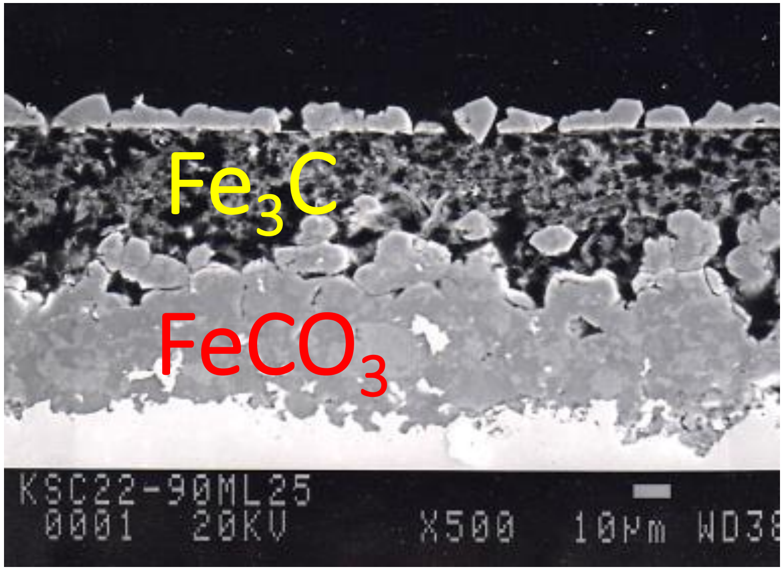
pH vs. Fe^{2+} in annulus




1
SR
1000
7.0
6.5
6.0
5.5
5.0
pH
0
500
1000
1500
Fe2+ / ppm
pH (20C)
pH (40C)
pH (80C)
pH (60C)


Fe3C
KSC12-90ML25
0001 20KV X500 10µm WD43


FeCO3
15-90ML52s
0002 20KV X250 100µm WD33


Fe3C
FeCO3
KSC22-90ML25
0001 20KV X500 10µm

Annulus vs. pipe line corrosion- what is different?

- Similarities
  - CO_2 content can be high, worst case corrosion rates (>>1 mm/y)
- Differences
  - Damaged outer sheath gives O_2 contamination
  - Low H_2S concentration if present, diffusion and consumption
  - Low ratio of free volume (V) to steel surface area (S). $V/S < 0.1$ ml/cm^2
  - Fast accumulation of dissolved corrosion products (*no escape*)
  - Liquid flow rates are very low, slow replacement of electrolyte

Confined environment and high SR_{FeCO3}

Will protective corrosion product films always form in confined environment?

- Armour wire steels respond differently to CO_2
- Natural inhibition (soft material, grease...), partial protection
- Non homogeneous distribution of corrosive gases and dissolved corrosion products
- Consumption of CO_2 and H2S
- Changes in operational conditions (temp., bore fluid, shut down)
- Damaged outer sheath, sea water floding, oxygen ingress
- Corrosion history - oxygen exposure prior to protective film formation

O_2 destabilizes protective $FeCO_3$ films

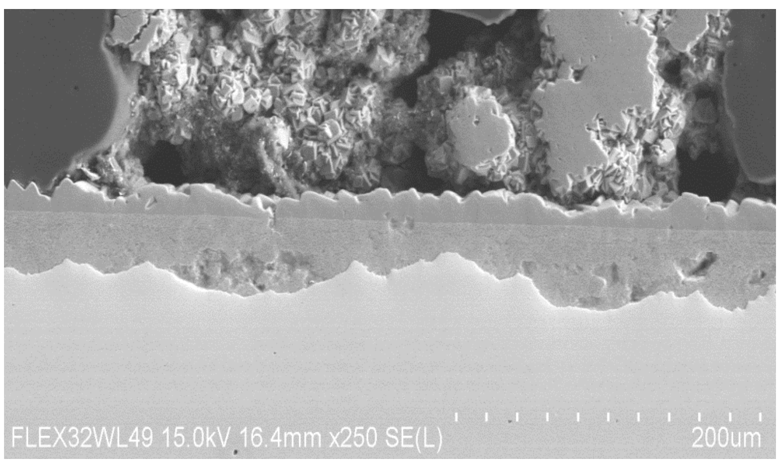
$$4\,Fe^{2+}(aq) + 4\,H^{+}(aq) + O_2(aq) \rightarrow 4\,Fe^{3+}(aq) + 2\,H_2O(l)$$

$$Fe^{3+}(aq) + 3\,OH^{-}(aq) \rightarrow Fe(OH)_3(s)$$

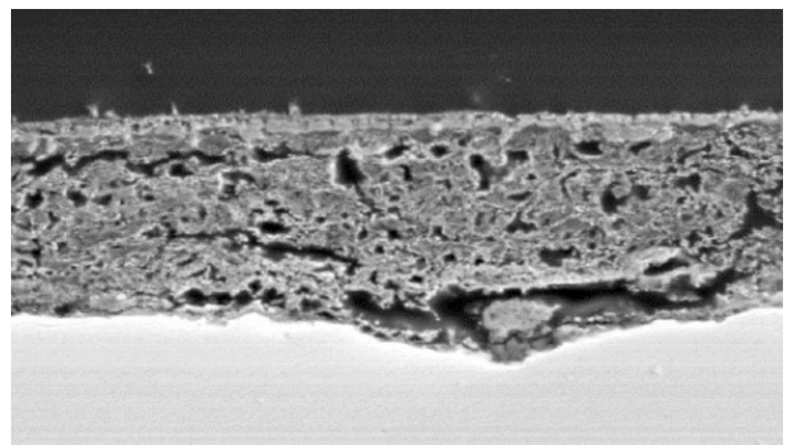
$$FeCO_3 \rightarrow Fe^{2+} + CO_3^{2-}$$

pH

Fe^{2+}



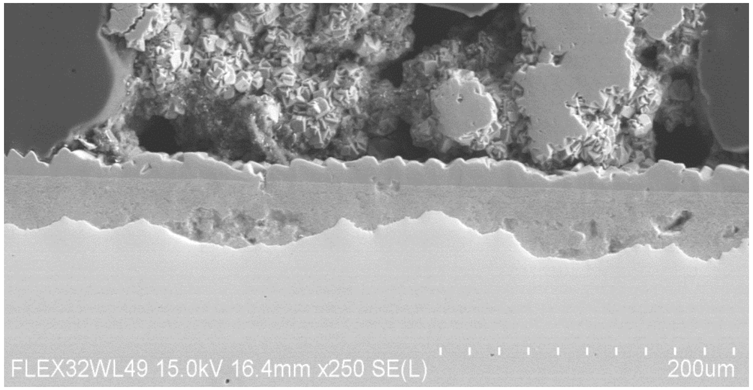
Low corrosion rate



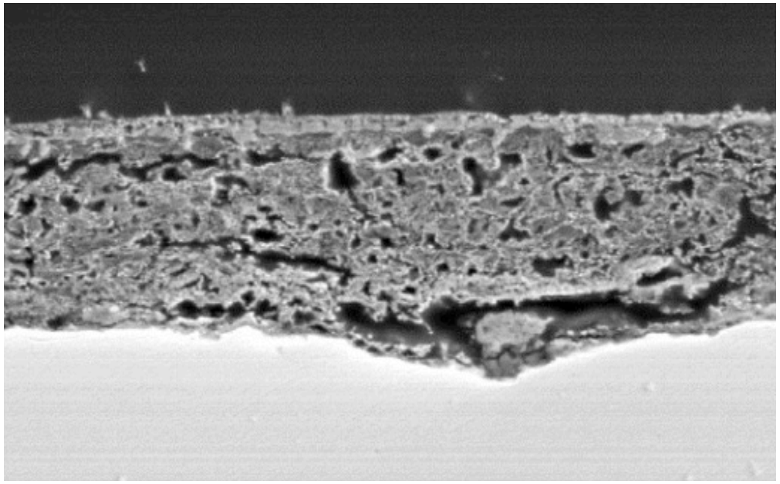
High corrosion rate

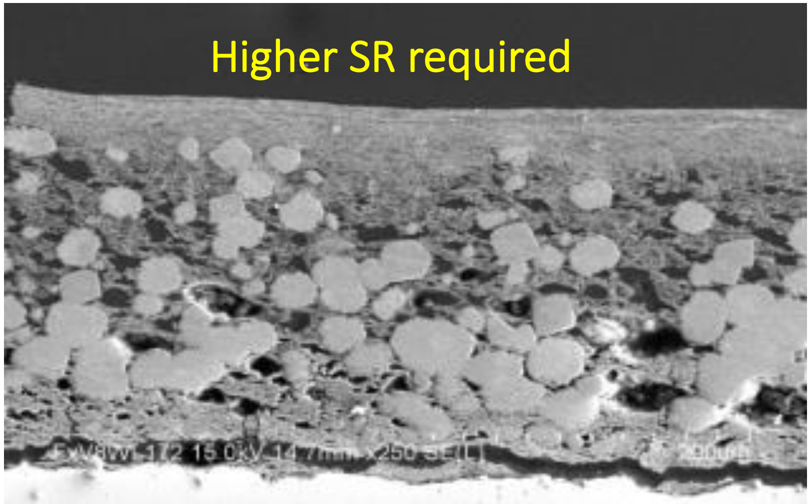
The required SR_{FeCO3} to achieve and maintain protection is «history» dependent

CO_2-exposure

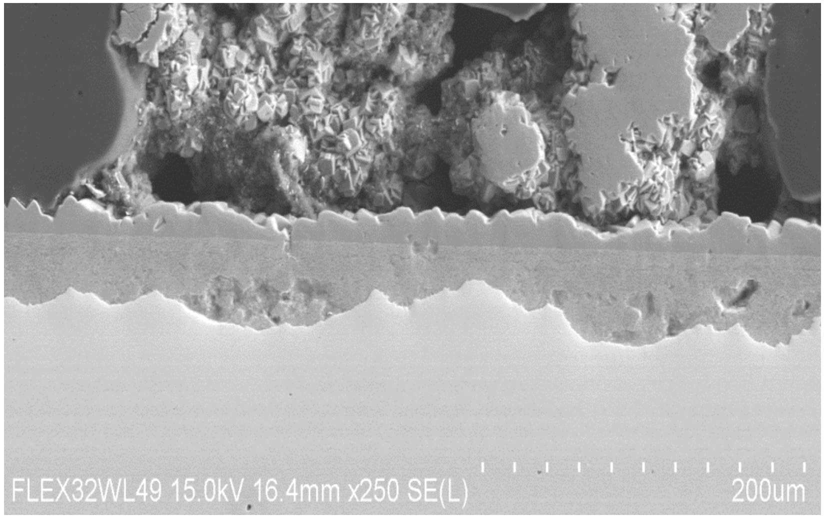


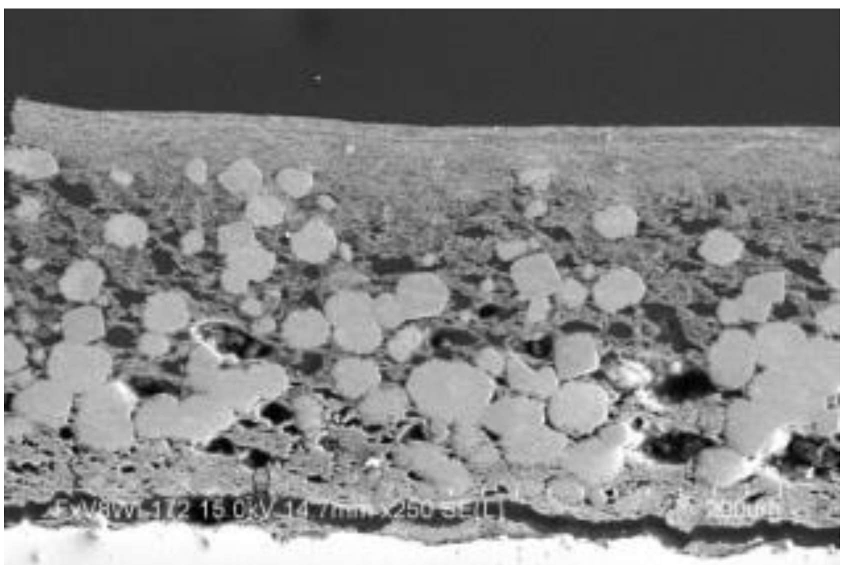
CO_2 exposure + failure/flooding–O_2 exposure + repair-CO_2 exposure



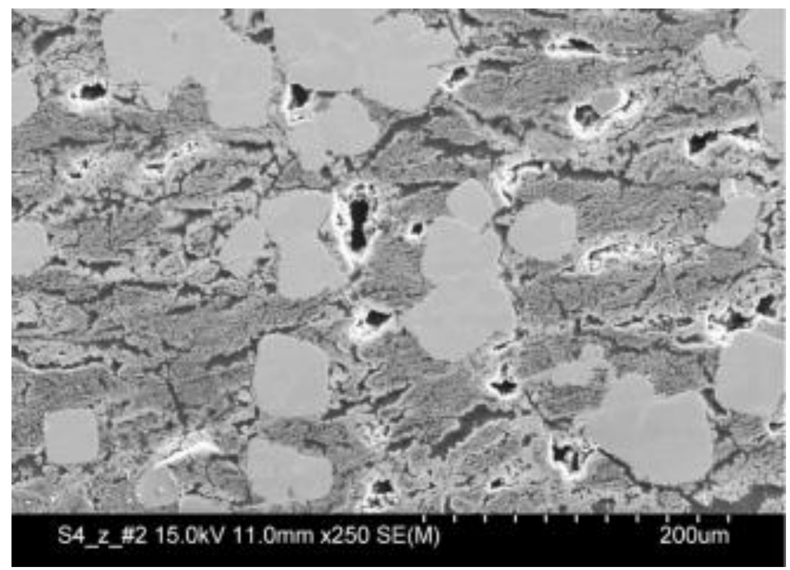


Experiments





Field case



Summary

- Most flexibles perform as expected, i.e. corrosion rates < 0.01 mm/y, no cracking
- The confined environment in the annulus does not always give corrosion product films with sufficient protectiveness
- Damaged outer sheath and sea water flooding might be a challenge
- Oxygen ingress destabilize protective $FeCO_3$ film and gives higher corrosion rates and pitting
- The annulus chemistry is complex, like a clockwork depending a large number of time dependent parameters

Sea water ingress

O_2 ingress

Pressure

Temp

O_2