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Evaluation of test methodologies for assessing SCC-CO2 in flexible pipes.

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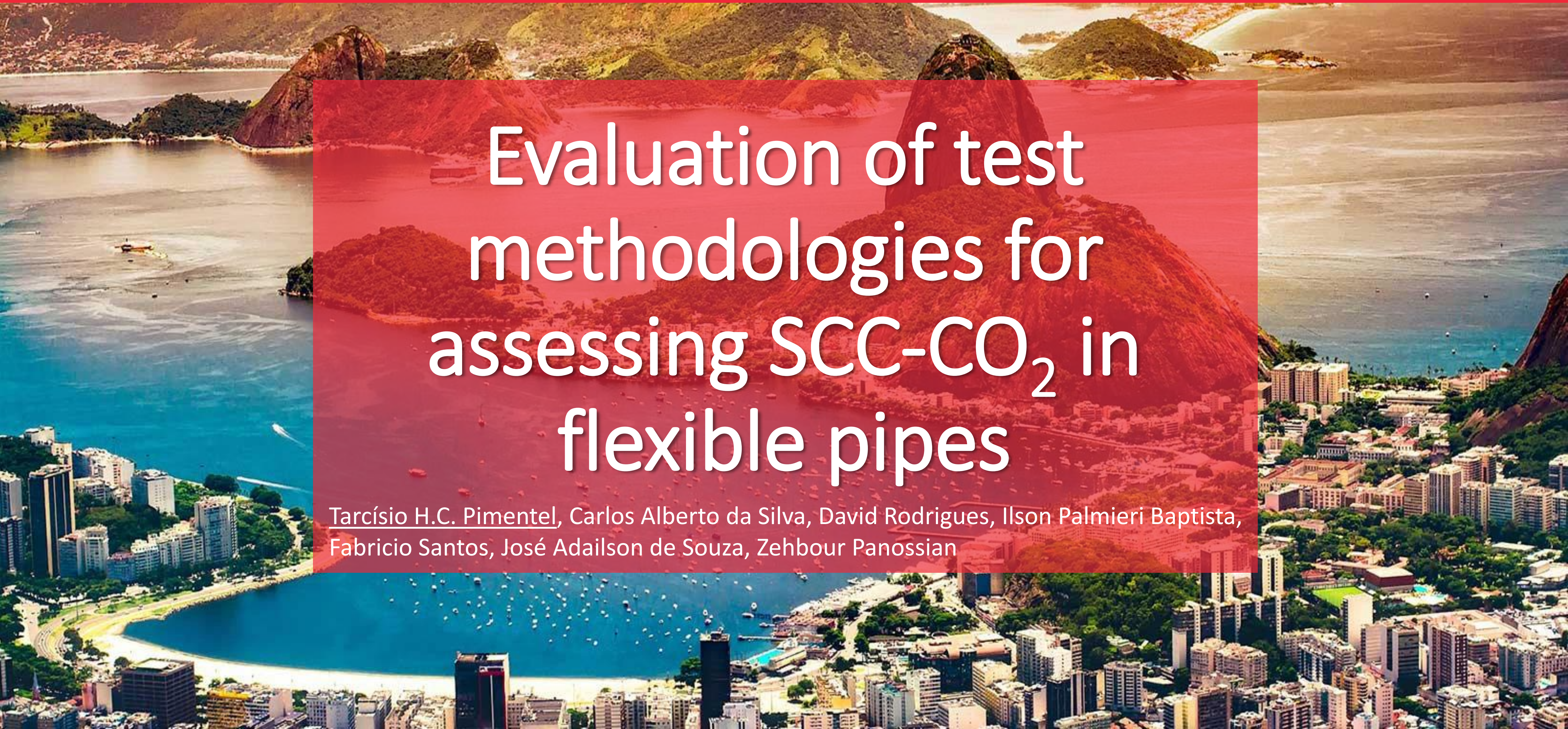
ABRACO
ASSOCIAÇÃO BRASILEIRA DE CORROSÃO

LatinCORR & InterCorr 2023

November 5-8, 2023 | Rio de Janeiro, Brazil

AMPP



Evaluation of test methodologies for assessing SCC-CO_2 in flexible pipes

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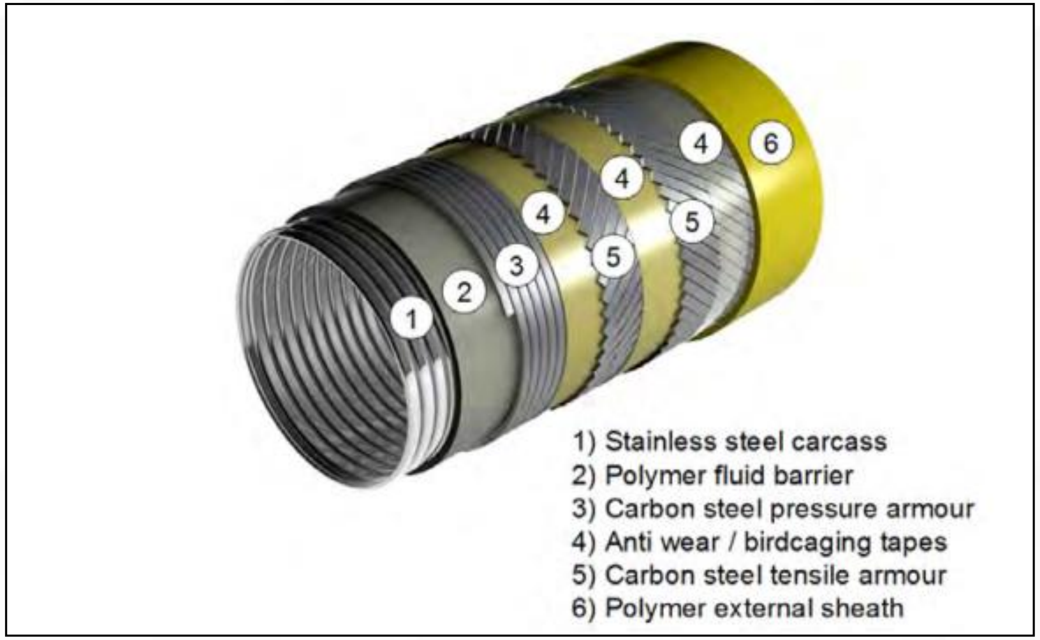
- Conclusion

Methodology + Results

• Flexible Pipes

- Configurable pipe composed of multiple independent layers
- Applications: *riser*, *flowlines*, fluid injection, gas and oil transport (with CO_2)



Benefits

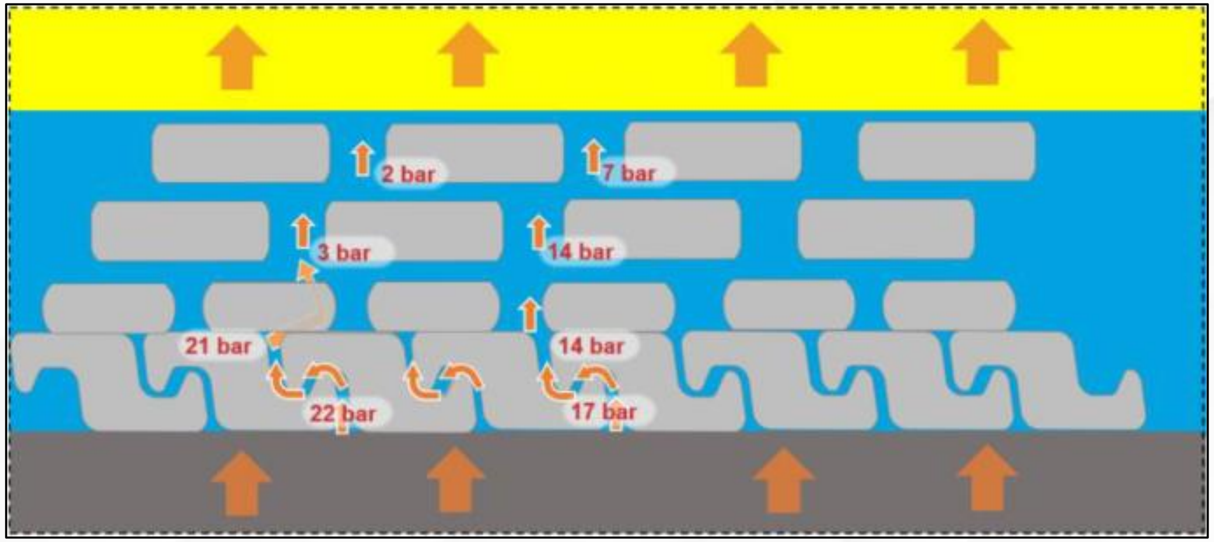
- ✓ Applied in deep marine environments (up to 3 km)
- ✓ Operation at high pressures (120 bar) and temperatures (120 °C)
- ✓ Ease and safety of installation
- ✓ Little maintenance throughout its lifespan
- ✓ High fatigue resistance
- ✓ High corrosion resistance

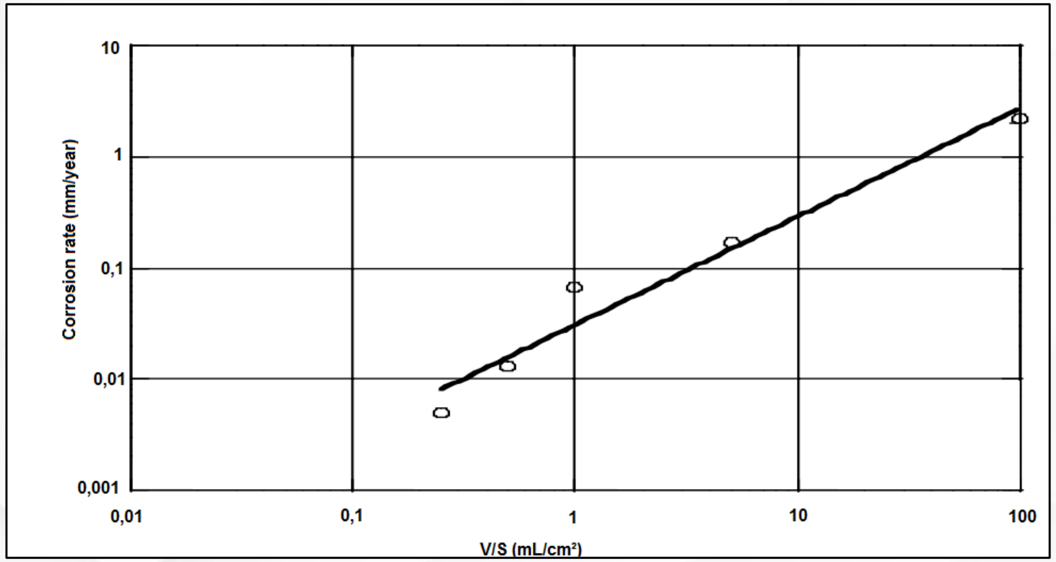
Disavantages

- ❑ Higher cost than an rigid pipe

FERGESTAD, D.; LØTVEIT, S. A. **Handbook on Design and Operation of Flexible Pipes**. SINTEF Ocean, 2017. v. 1

• Corrosion in annular space





- Gases such as H_2O, CH_4 and CO_2 vapor permeate through the metallic and polymeric components reaching the annular space of the flexible ducts.
- If there is an external rupture, seawater may enter
- This generates a corrosive environment supersaturated with Fe^{2+} given the high V/A (in the order of 0.1 mL/cm²)

This facilitates supersaturation, favoring the precipitation of $FeCO_3$ and decreasing the corrosion rate

ROPITAL, F. CONDAT-TARAVEL, C. SAAS, J.N. DURET, C. **Methodology To Study the General Corrosion of Steel Armours** . Eurocorr. London: 2000

HANONGE, D.; FERRAZ, J. P.; FERRE, R. CO2-Stress Corrosion Cracking Risk Mitigation for Flexible Pipe Design. **Subsea Pipeline Technology**, p. 1–24, 2022.

anp
Agência Nacional do Petróleo

Safety Alert 001 - ANP/SSM

CO_2 Stress Corrosion Cracking (SCC-CO2)

The Superintendence of Operational Safety and Environment is issuing this safety alert to notify the petroleum and gas industry and other stakeholders about a corrosion mechanism known as **CO_2 Stress Corrosion Cracking (SCC)**.

What happened?

An accident of this nature was reported to this Superintendence in January 2017. It involved a gas injection flexible pipe failure in its second year of operation, although the manufacturer had evaluated its service life as 20 years.

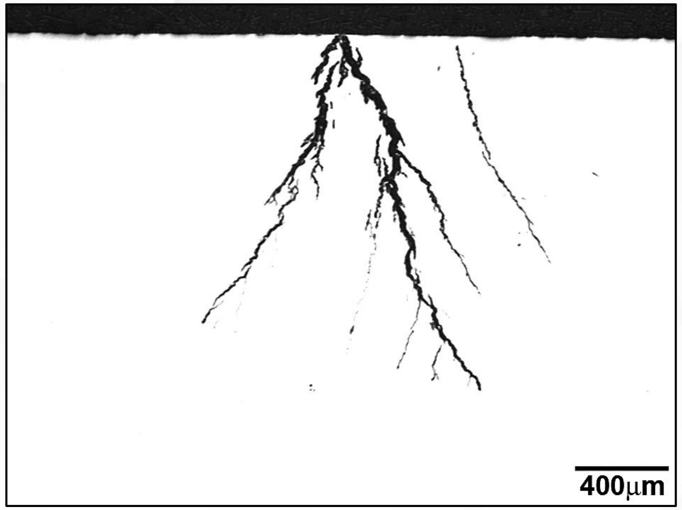
Without any previous records of such accident, classification is still on its first stages, bringing new challenges to pre-salt exploration. Researchers, however, have already identified SCC-CO_2 causes, as stated below.

Potential consequences

CO_2 Stress Corrosion Cracking may cause unexpected and catastrophic failure of a flexible pipe, leading to production losses and environmental accidents.

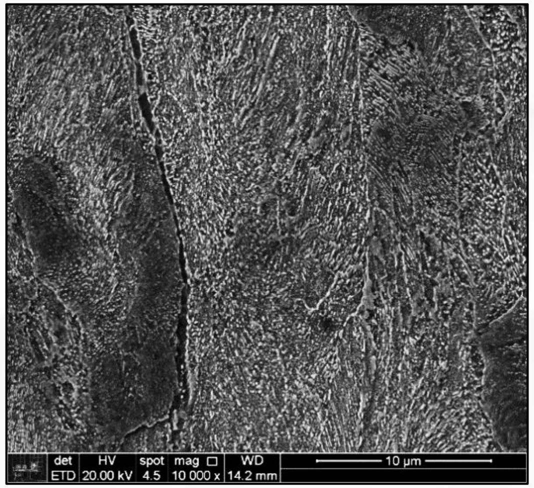
Causes

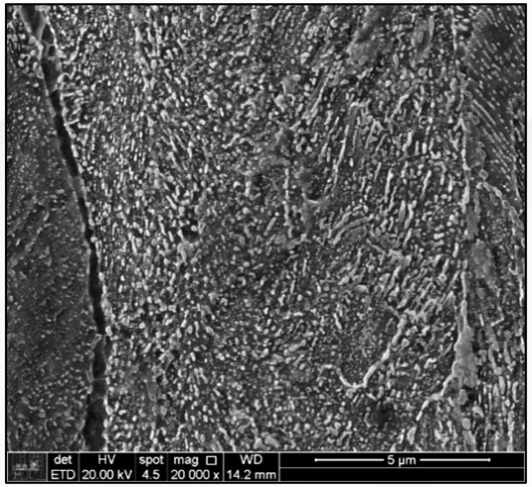
- Environment containing H_2O and CO_2;
- Static, cyclic or residual stress on pipe;
- Time;
- Susceptible material.

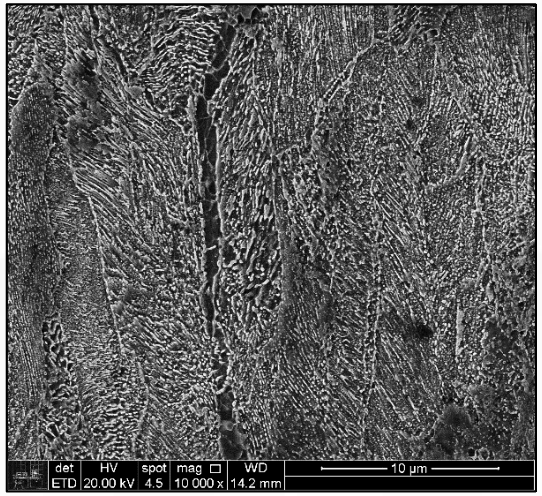


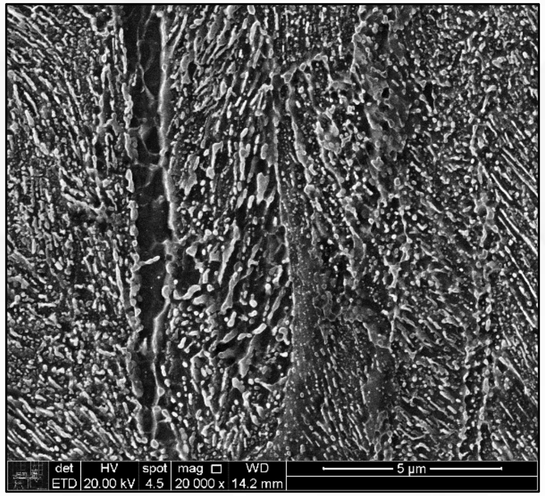
Characterization

- Tensile armour steel characterization

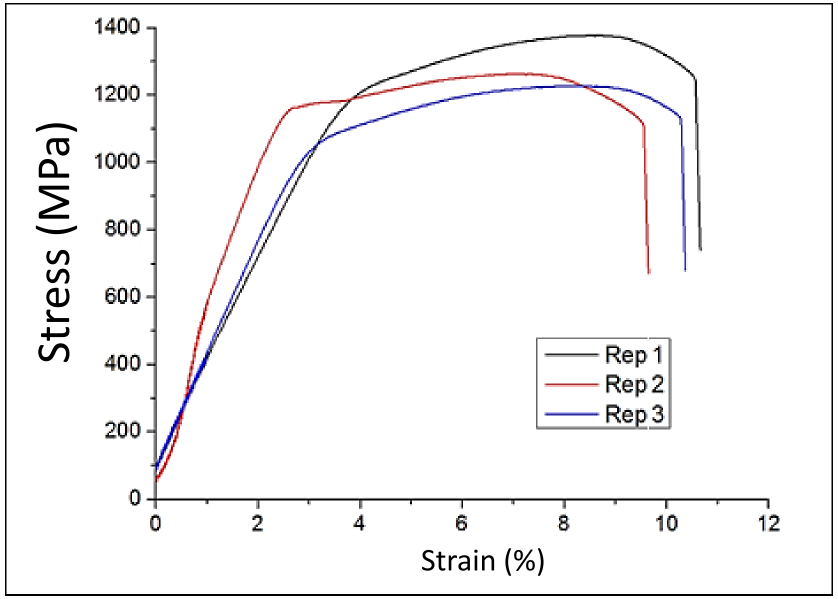






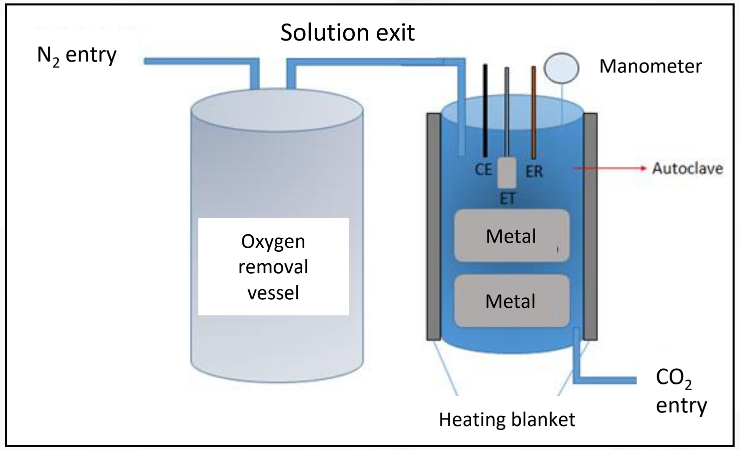


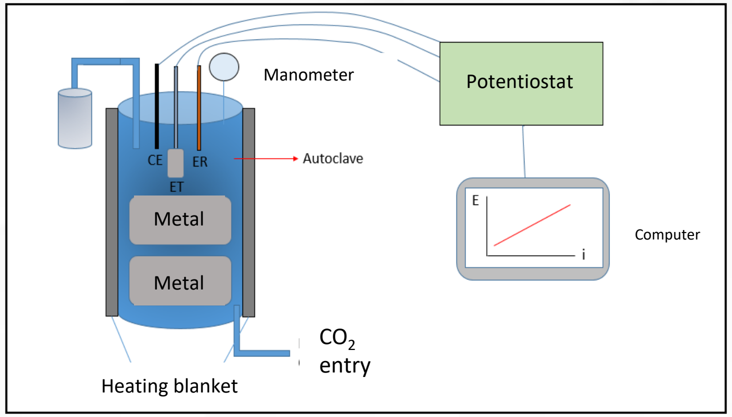
Elements	(%)
C	0.732 ± 0.001
Mn	0.811 ± 0.005
Si	0.241 ± 0.001
Al	0.029 ± 0.001
Cu	0.008 ± 0.001
P	0.008 ± 0.001
S	Lower than 0.001
Cr	Not detected
Ni	Lower than 0.001
Mo	Lower than 0.001
Ceq (%)	0.868



Electrochemical corrosion rate monitoring

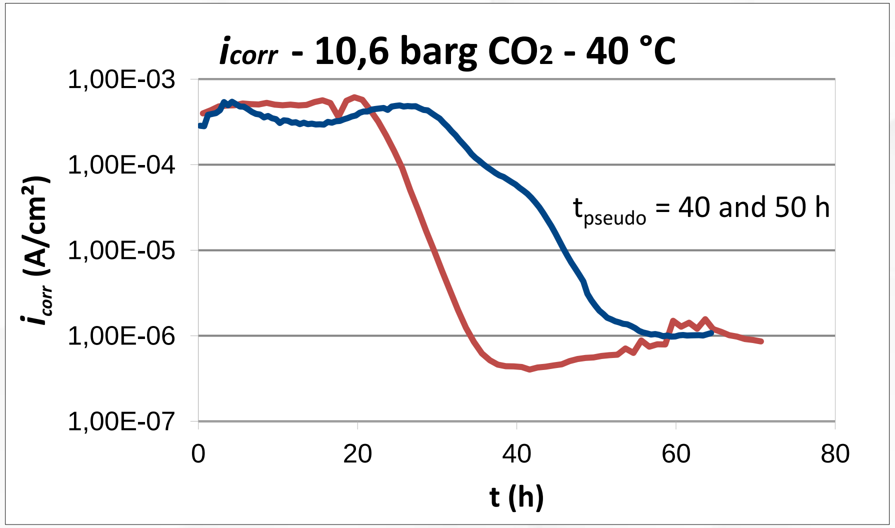
- Environment: simulated ocean water (ASTM D1141:2021) at 40 °C, 10,6 barg of CO_2 , V/A of 1 mL/cm²
- Corrosion rate was monitored by LPR until i_{corr} = 3.10^{-6} A/cm² (pseudo passivation time)

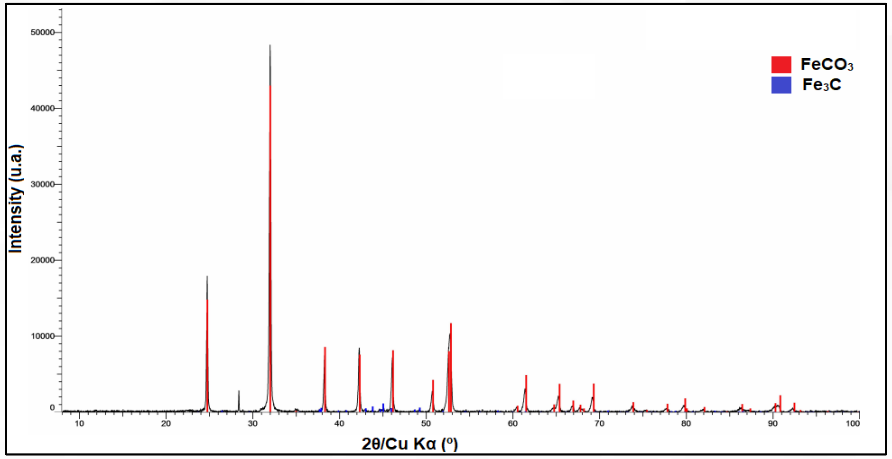


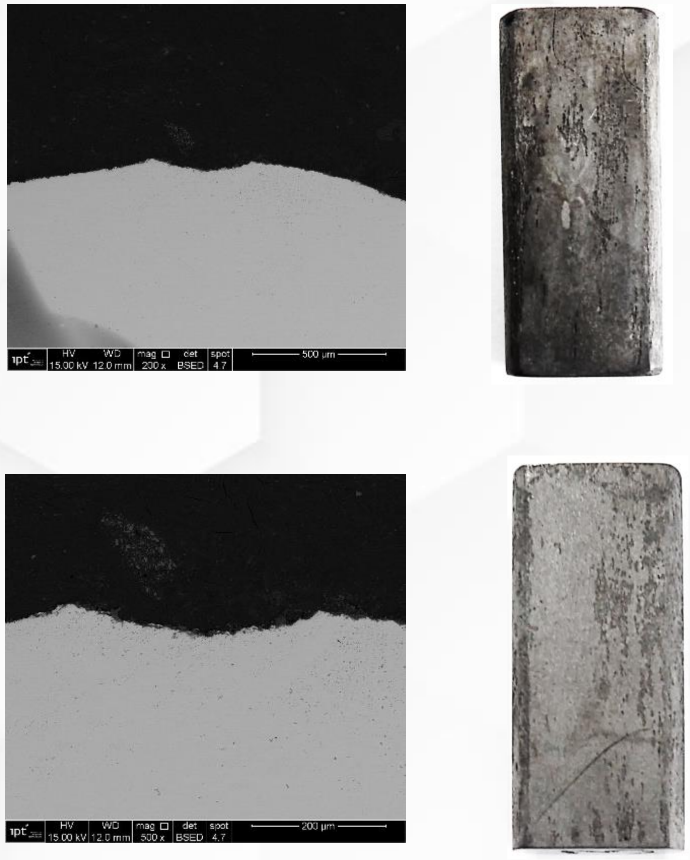


Results

Electrochemical corrosion rate monitoring







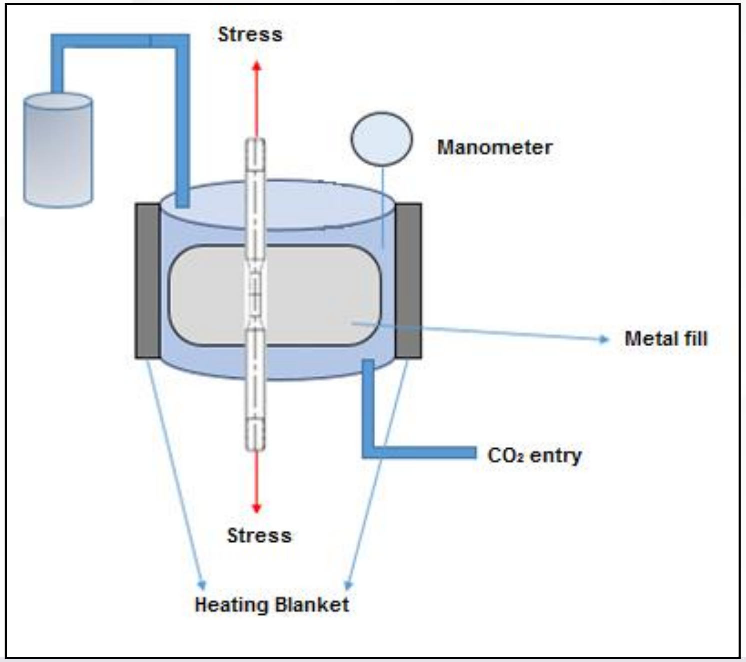
Localized corrosion

Condition for SCC tests

Slow strain rate tests

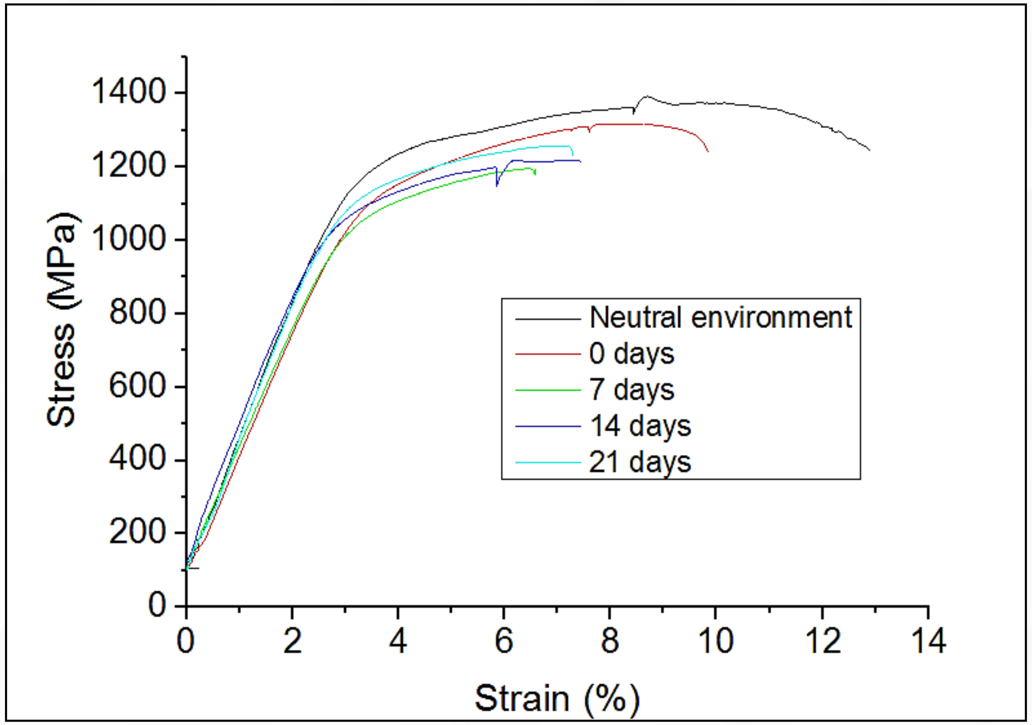
- Tests were conducted in an autoclave, with a strain rate of 1.10^{-6} s^{-1}.
- Tests in neutral environment
  - Without electrolyte, 1 barg of N_2, at 40 °C
- Tests in corrosive environments
  - Tests carried out in autoclave with substitute ocean water (ASTM D1141:2021) with a V/A ratio of 1 L/cm², at 10 barg of CO_2, with pre-corrosion before the test.
  - The periods for pre-corrosion were: (0, 7,14 and 21) days.

Test	V/S (mL/cm²)	T (ºC)	CO_2 (bar)	Pré-corrosion
0	N/A	40	0	N_2 (neutral environment)
1	1	40	10	0 days of pre-corrosion
2	1	40	10	7 days of pre-corrosion
3	1	40	10	14 days of pre-corrosion
4	1	40	10	21 days of pre-corrosion



Results

Slow strain rate tests



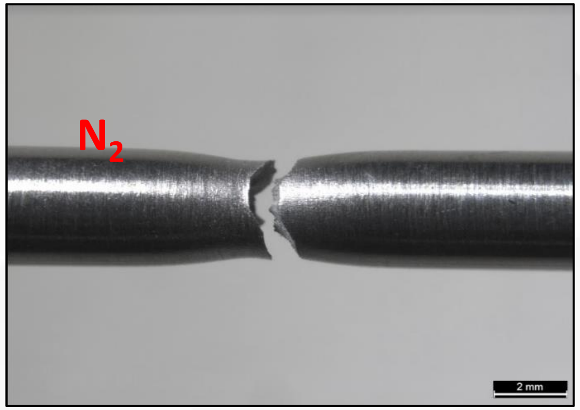
- Tests on SSRT did not indicate SCC-CO_2, given that the resistance limit is reached (it has ductile characteristics).
- Decreased yield strength and strength limit between 0 and 7 days of pre-corrosion

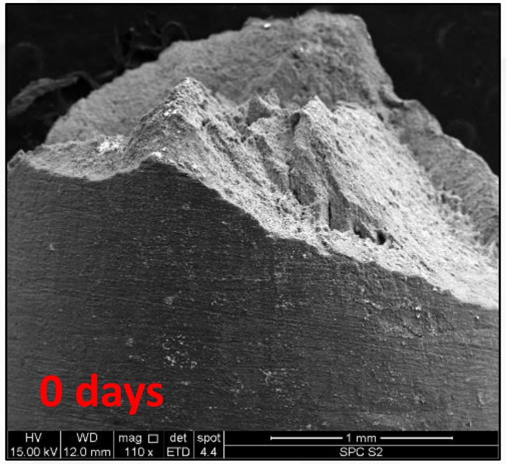
A clear influence of **pseudo passivation.**

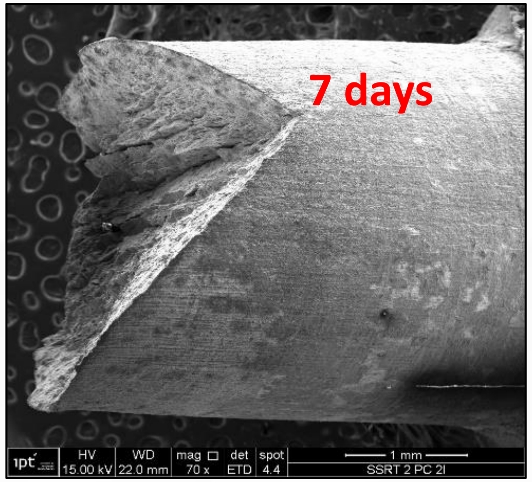
- After 7 days of exposure, the curves practically overlap.

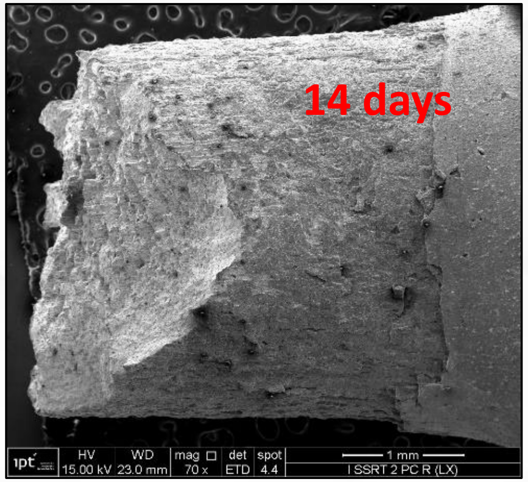
Results

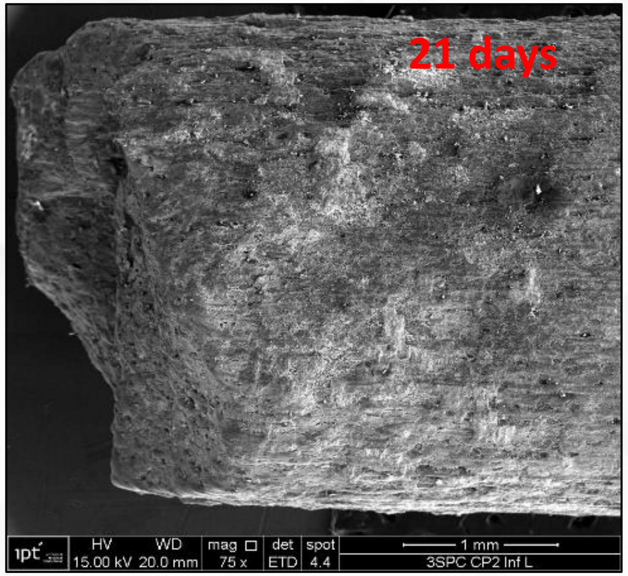
Slow strain rate tests











Fractures with an angle of approx. 45°

↓

Indication of ductile fracture

↓

no SCC CO_2

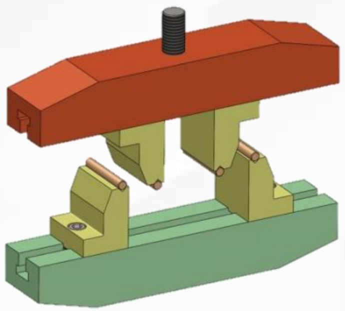
↑

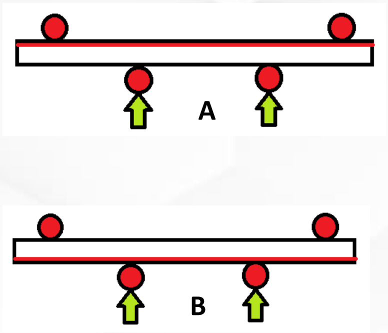
Specimens did not show SCC cracks

Methodology

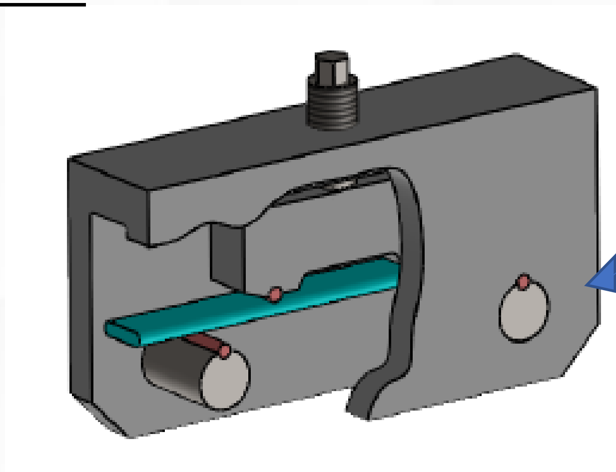
4-point bend test

- 3 specimens (dimensions of the original wire) were plastically deformed in the following sequence: 2 %, -2 %, 2 %, -2 %, and 1.7 %.
- Then, they were placed on the support and then plastically deformed by 2 % and kept that way (last pass of the cycle).
- The support with the specimen was placed in an autoclave containing substitute ocean water, with 10,6 barg of CO_2, a 40 °C with V/A ratio of 1 mL/cm² for <u>6 months</u>.





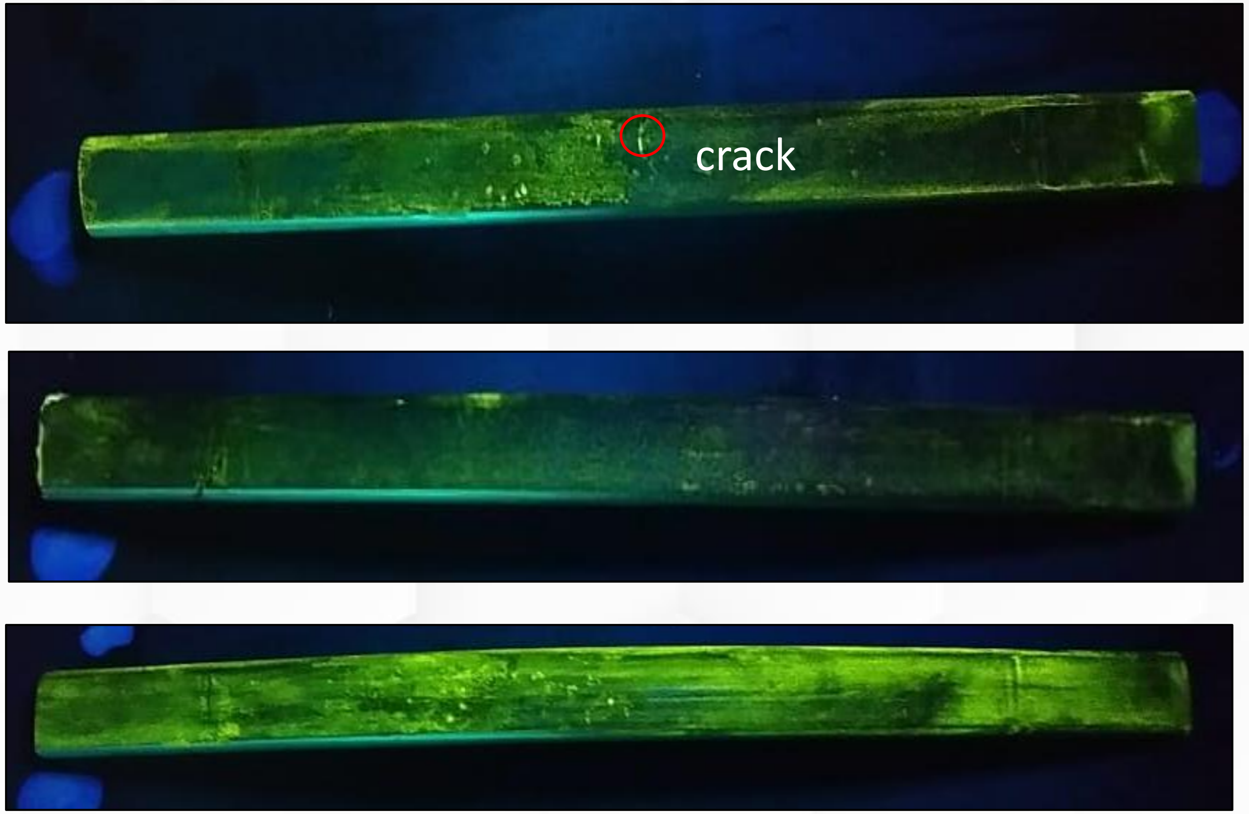
A (2 %) →B (-2 %)→ A (2 %)→ B (-2 %)→ A (1,7 %)



2 %

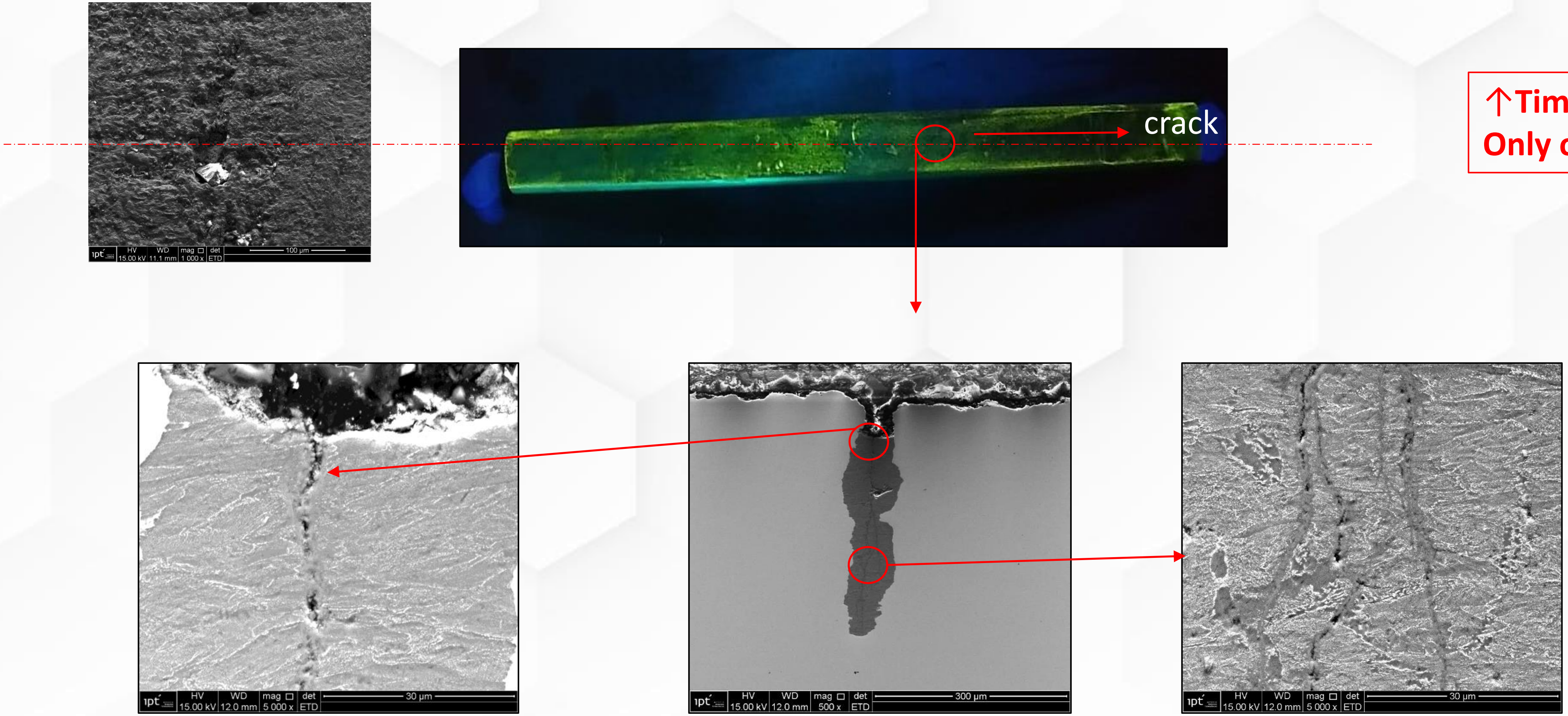
Results

4-point bend test



Results

4-point bend test



↑Time
Only one crack

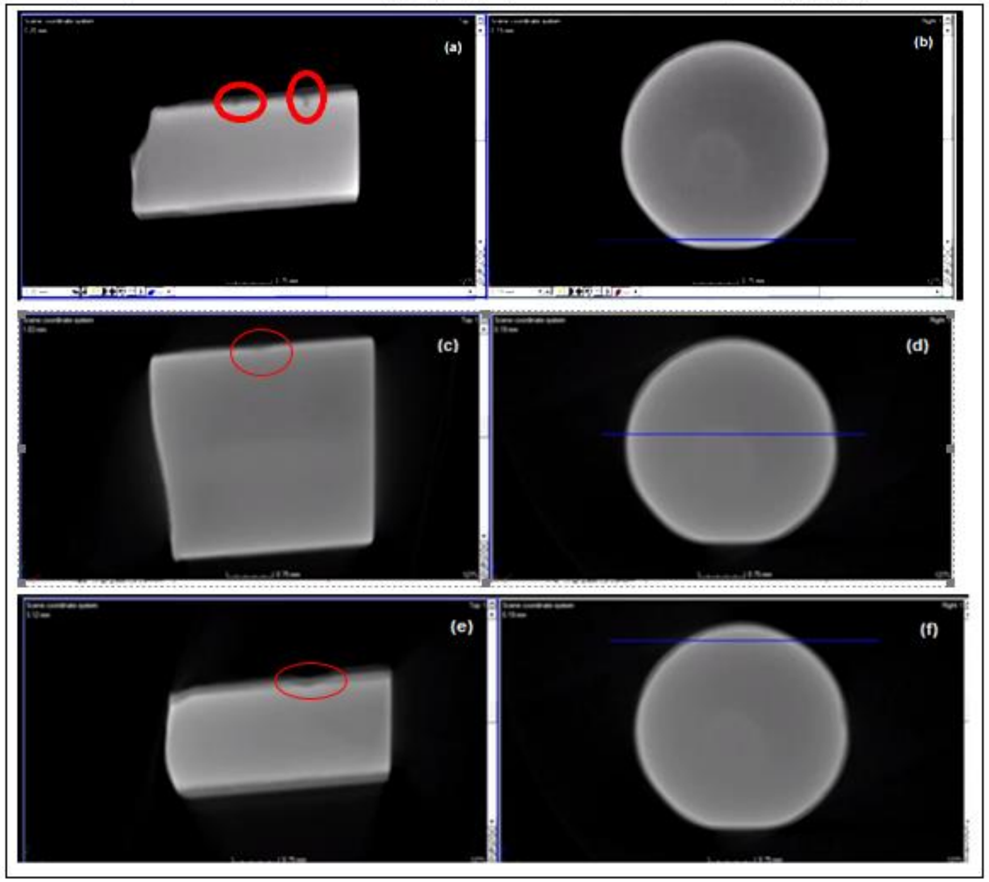
Static-load test

- Test carried out on the tensile armour steel, at 10 barg of CO_2, at 40 °C, V/S ratio of 1 mL/cm², with the electrolyte being simulated ocean water.
- The applied stress was 90 % of the yield strength, being constantly adjusted during the test according to the relief of the SSRT machine for 1000 h.
- Same configuration as the SSRT test, but with static load
- After the test, tomographic and metallographic analysis were made

Static-load test

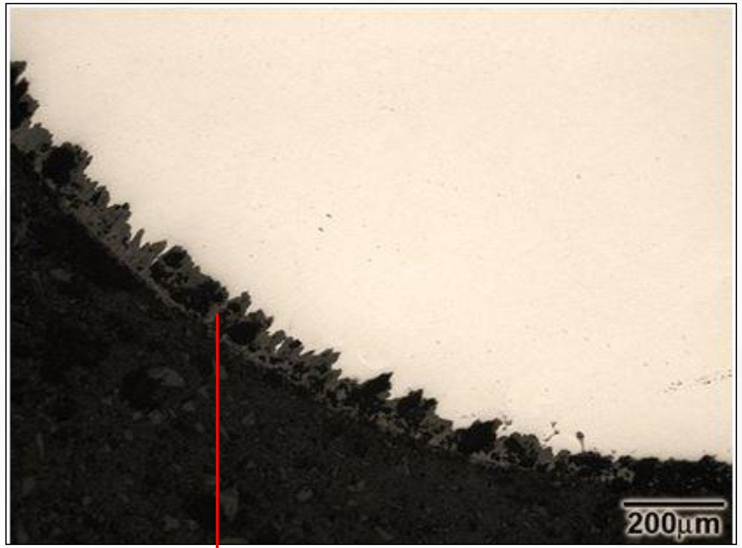
- After 1000 hours (50 days), the constant load SCC specimen test did not show rupture

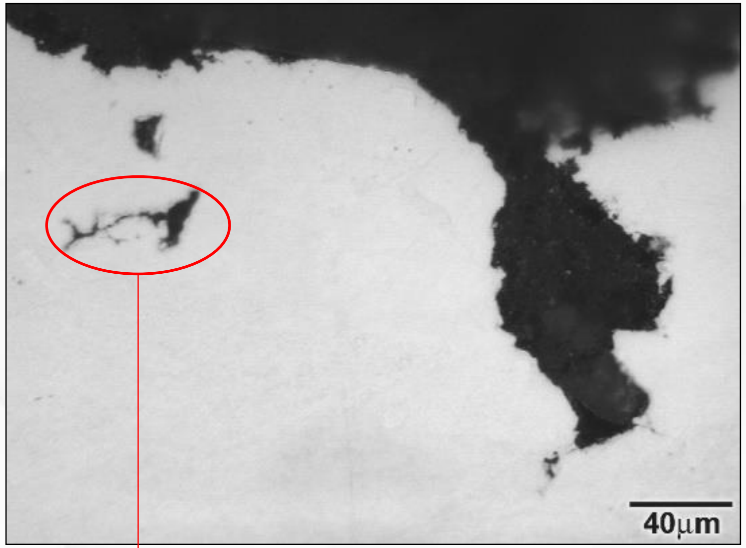
The tomography indicated that there were cracks in the specimen



Results

Static-load test





Severe corrosion (transverse)

Cracks/fissures

Discussion

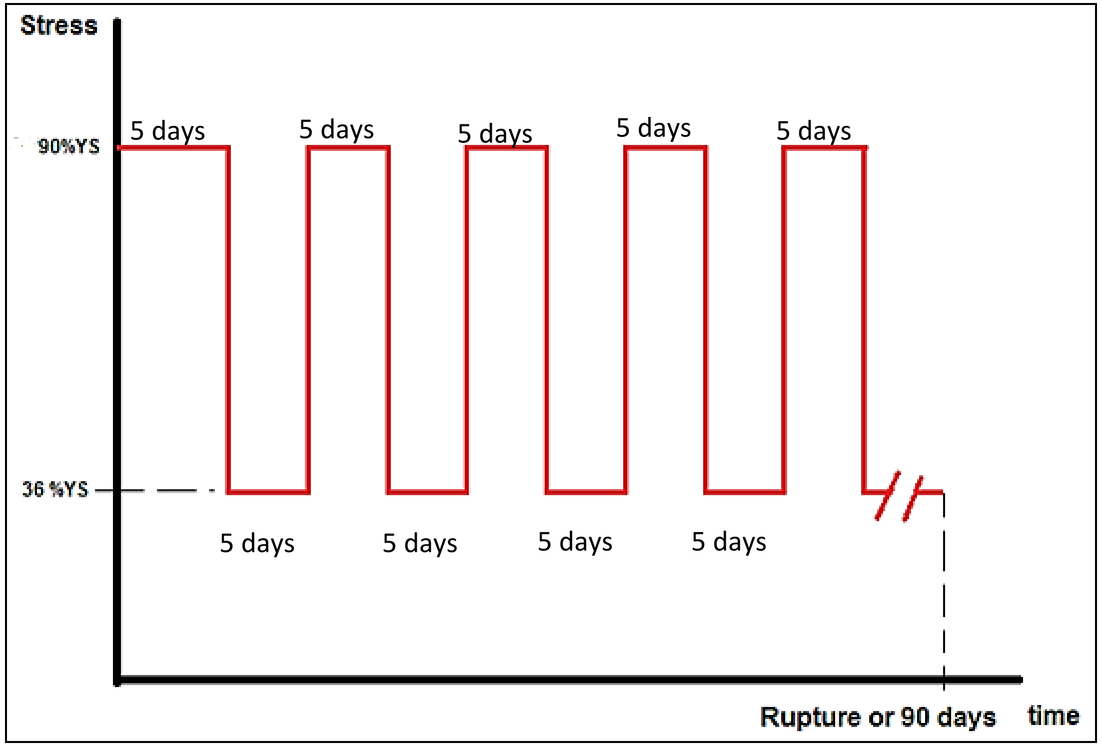
- Localized corrosion occurred when the carbon steel was immersed in simulated ocean water at10,6 barg of CO2, 40 °C.
- Successive rupture of the $FeCO_3$ layer by external stress leads SCC-CO_2

↓

Formulation of SCC-CO_2 test at low frequency alternating load

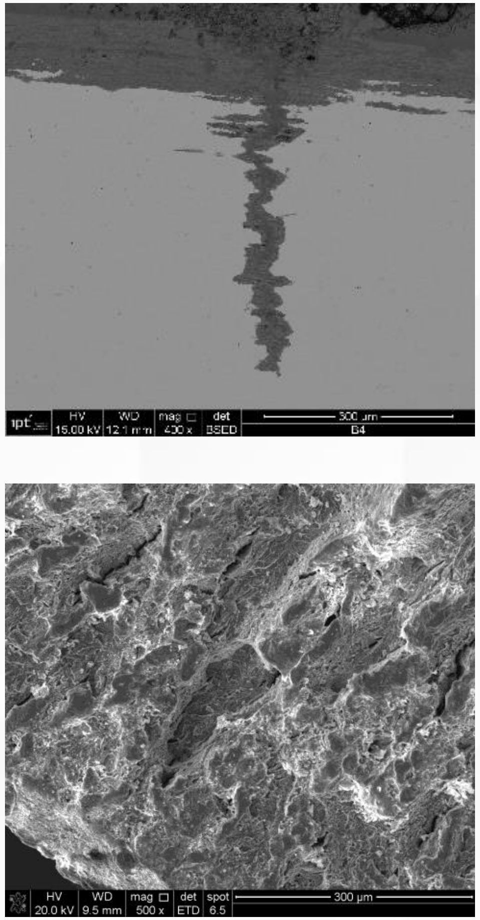
Proposed alternating load test

- In order to produce film rupture, cycles of load (90% of yield strenght) and unloading (36% of yield strenght) were applied in the tensile armour steel specimen
- The period of first cycle of specimen loading must be equal or superior than the pseudopassivation time
- Test duration: 90 days or until rupture.
- Environment: synthetic seawater at 40 °C, 10,6 barg of CO_2 , V/A of 1 mL/cm².

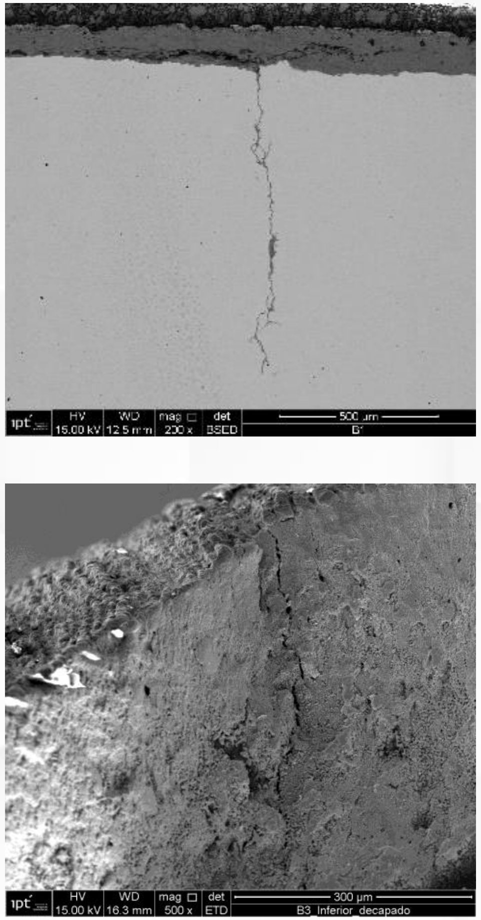


Results

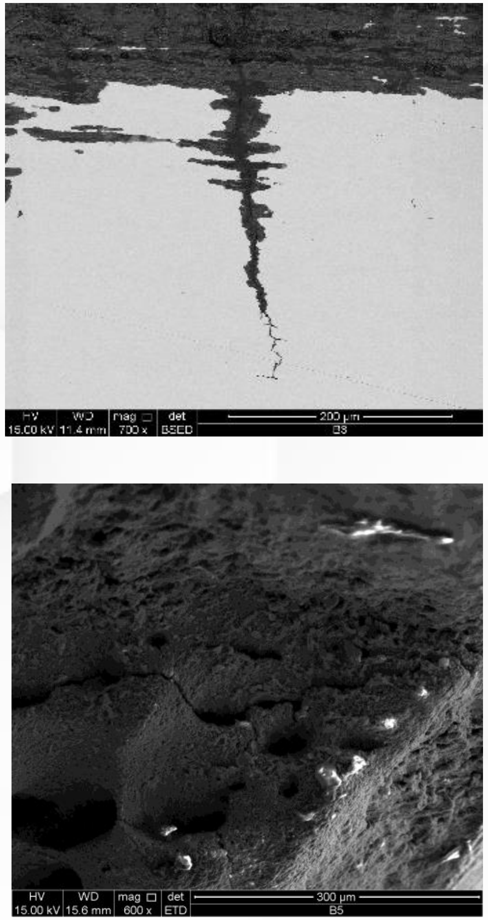
Alternating-load test



Rep 1



Rep 2



Rep 3

Alternating load test

→ The full methodology became a patent filed with PETROBRAS

Dados gerais do processo

Título

MÉTODO DINÂMICO DE ENSAIO ACELERADO DE CORROSÃO SOB TENSÃO EM MEIO CONTENDO CO2 APLICADO EM MATERIAIS METÁLICOS

Resumo

: Este novo procedimento é realizado com a aplicação de uma carga constante abaixo do limite de escoamento real do aço (Actual Yield Strength, AYS), menor que 90 % AYS. Após um determinado

Nº pedido	Data depósito
BR 10 2022 023369-1	17/11/2022

Nº patente	Categoria
	Patente de invenção

Alternating-load test

Acknowledges