Stress corrosion cracking in the context of deep geological nuclear storage

A. Didot, E. Herms, D. Feron, J. Chêne, D. Crusset

STRESS CORROSION CRACKING IN THE CONTEXT OF DEEP GEOLOGICAL NUCLEAR DISPOSAL: INVESTIGATIONS ON P235 AND P265 STEELS

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CONTENT

Background & experimental procedure

Susceptibility to SCC

Slow strain rate tests
Corrosion Potential & Temperature
Base metal and welded zone

Crack Initiation

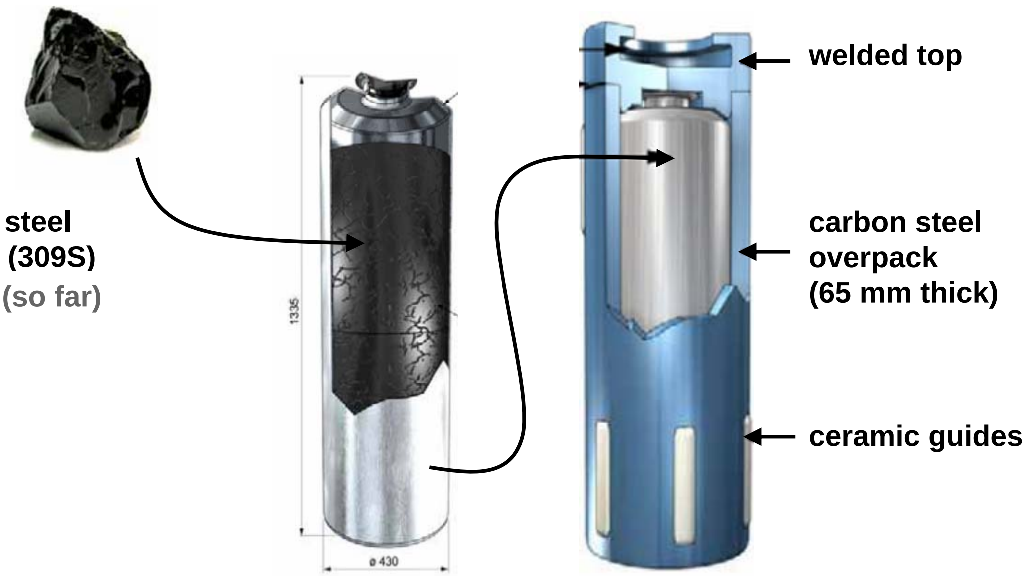
Constant deformation tests
Welded zone
Hardness, Perlite

THE « MULTI-BARRIER » CONTAINERS

1 **Vitrified nuclear waste**
Limitation of radionuclides' release
(10^5 years)

2 **Stainless steel container (309S)**
No function (so far)

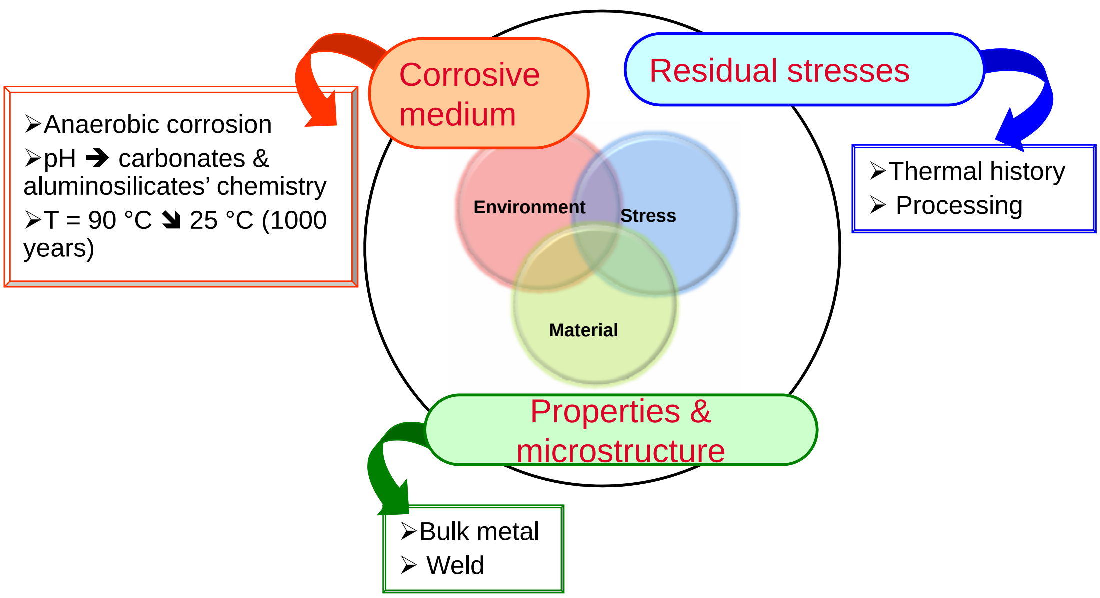
3 **Carbon steel overpack**
Isolation of the vitrified nuclear waste from interstitial water
(10^3 years)



Source : ANDRA

OBJECTIVE

Sensitivity to stress corrosion cracking of the carbon steel used for the overpack container in the conditions of the storage



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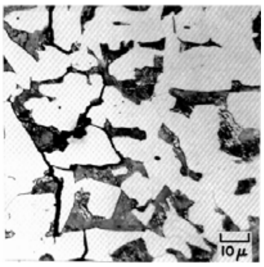
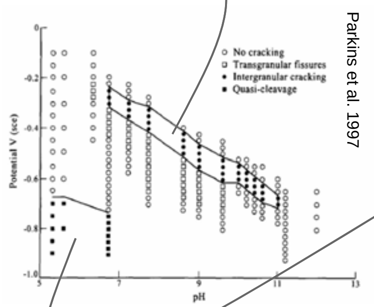
2 cracking mechanisms have been identified in buried pipes, characterized by specific potential-pH domain

Intergranular

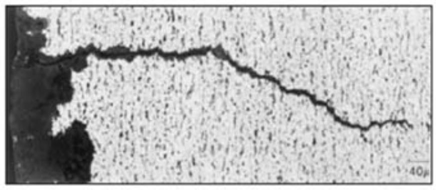


« passive » Steel
alcaline pH



Parkins et al. 1997

Transgranular

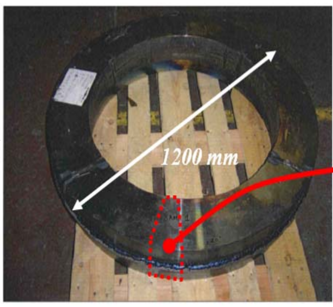


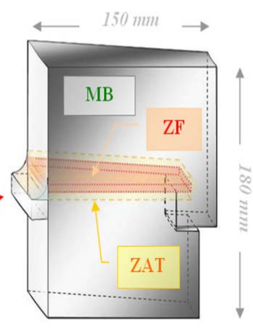
Parkins et al. 1994

« active » steel
quasi-neutral pH
Dynamic loading

Coupons have been taken from two mock-ups.

2 grades
- P265 ➔ weld
- P235 ➔ bulk





Composition Massique (%)	C	Mn	Si	P	S	Al	N	Cr	Cu	Mo	Nb	Ni	Ti	V
P235 GH	0,152	1,08	0,21	0,008	0,006	0,040	-	0,19	0,21	0,05	0,004	0,13	-	0,003
P265 GH	0,116	1,19	0,286	0,012	0,0011	0,040	0,0044	0,032	0,015	0,007	0,000	0,024	0,009	0,001

Caractéristiques mécaniques	Rp0,2% (MPa)	Rm (MPa)	At (%)
P235 GH	270	460	32
P265 GH	280	453	40

MICROSTRUCTRURE & HARDNESS

P265 (weld)

Base Metal

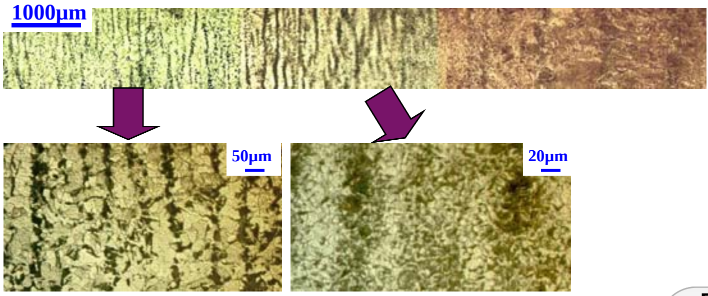
Heat Affected Zone 2-3mm

Melted Zone 6mm

190-250 HV

230-**310** HV

220-260 HV



Ferrite / Pearlite
Bands of Pearlite

Coalescent bands
of pearlite

P235 (base metal)
Bands of Pearlite

Microstructure in bands:
risk of SCC

Hardness>250Hv
risk of Hydrogen Embrittlement

SLOW STRAIN RATE TESTS

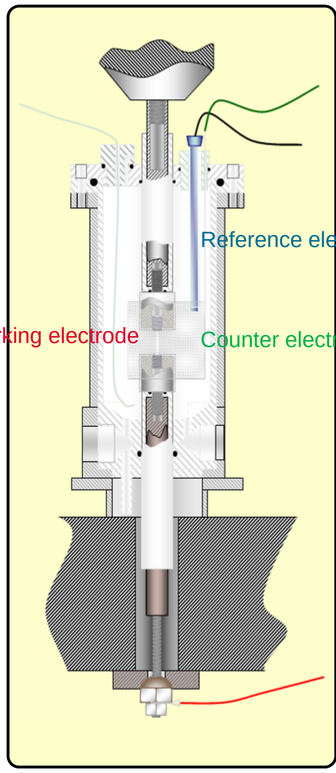
Sensitivity to stress corrosion cracking of the steel in storage environment

Mechanical dynamic solicitations
(10^{-7} à 10^{-4} s^{-1} ➔ 1 - 800 hours).

- Influence of parameters: corrosion potential, temperature, microstructure…

Environment

- synthetic representative Bure water (Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, SO_4^{2-},Cl^{-},HCO_3^{-})
- pH ~ 7 (p_{CO2})
- without oxygen
- 25 et 90 °C.



CONSTANT DEFORMATION TESTS

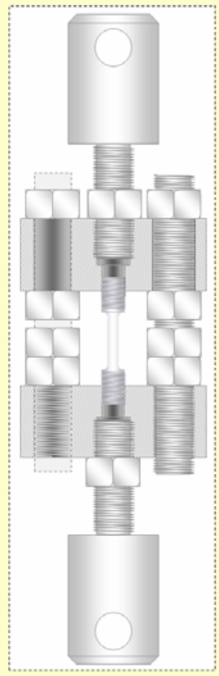
Initiation of stress corrosion cracking under representative conditions (mechanical & chemical)

Static mechanical solicitations

- 2 degrees of initial stresses as function of the yield strength (0,8 et 1,2 $Rp_{0,2\%}$) relaxation (creep, cracks)
- **1 year test** ➔ initiation of the phenomena (not initiation time).

Environment

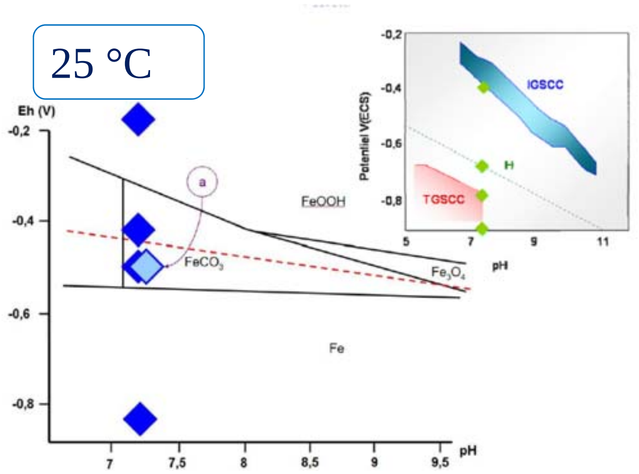
- Bure clay and bure synthetic water
- pH ~ 7 (*pCO2*)
- no oxygen
- 90 °C



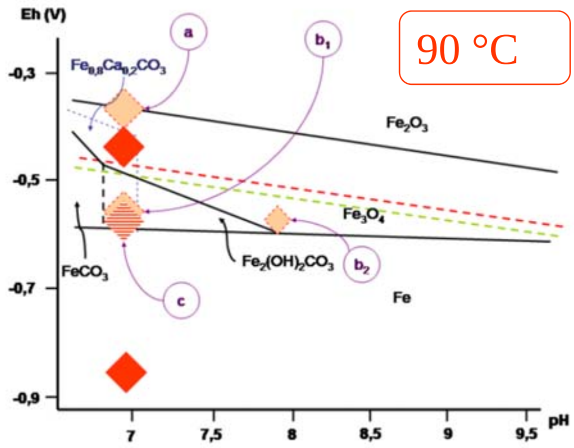
SENSITIVITY TO STRESS CORROSION CRACKING

SLOW STRAIN RATE TESTS

25 °C



90 °C



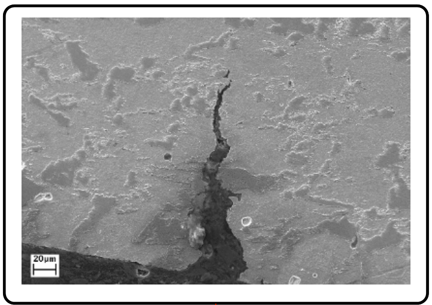
Polarisation potentials used during the slow strain rate tests plotted in the Pourbaix diagram

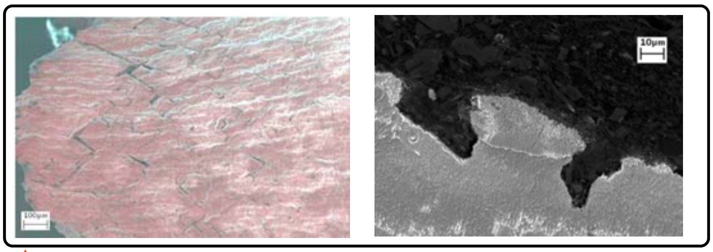
- a and b_1 are related to measured or calculated corrosion potentials
- b_2 is related to a measured pH

P265 BASE METAL

Transgranular cracking

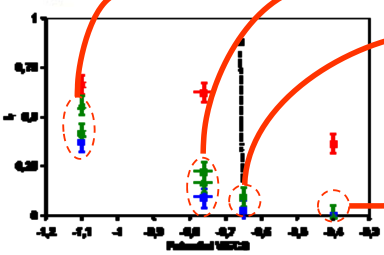
25 °C

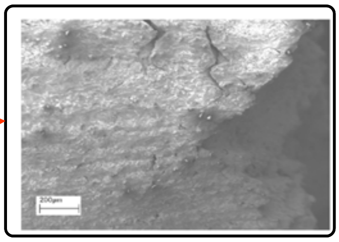


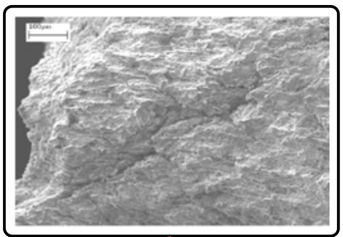


plastic deformation → localised corrosion ?

$$I_f = 1 - \frac{RA_{Solution}}{RA_{Air}}$$





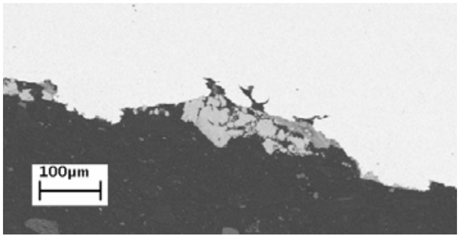


no intergranular cracking in the range of applied potentials

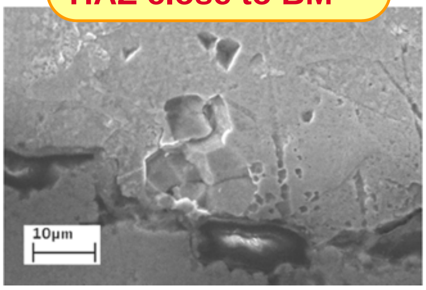
P265 BASE METAL

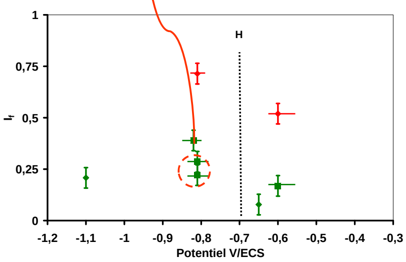
90 °C

Intergranular degradation

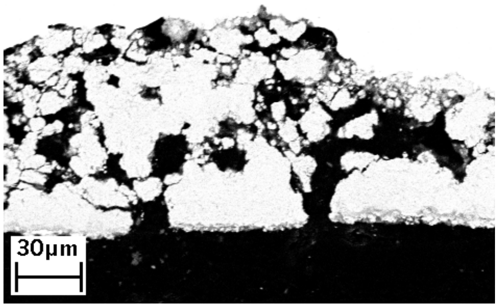


HAZ close to BM





Large deformations

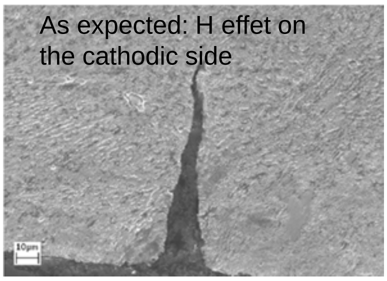


P265 WELDED ZONE

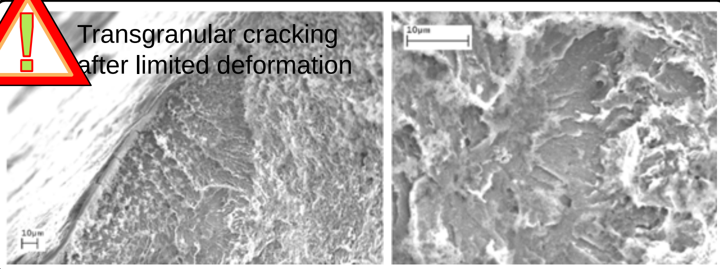
Hydrogen embrittlement at the tested corrosion potentials

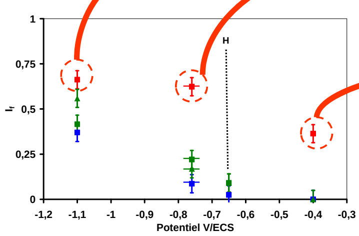
25 °C

As expected: H effet on the cathodic side

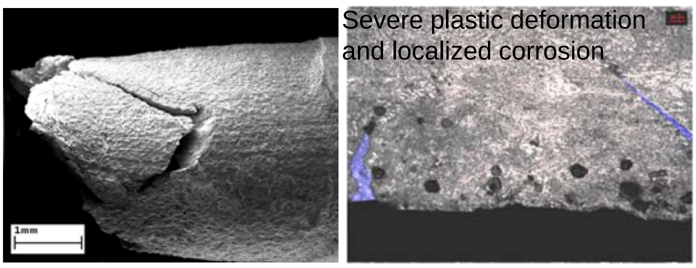


Transgranular cracking after limited deformation





Severe plastic deformation and localized corrosion

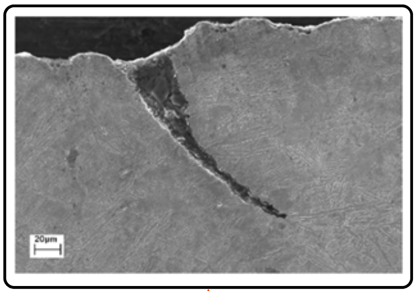


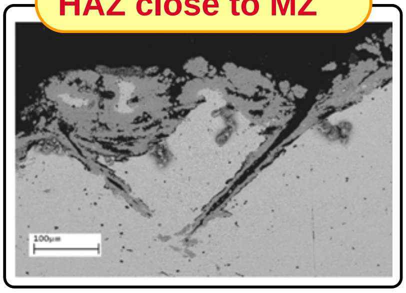
P265 WELDED ZONE

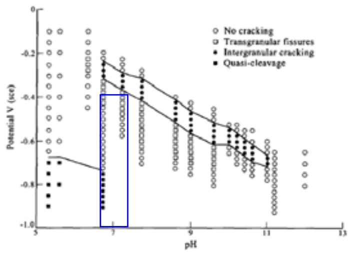
Hydrogen embrittlement ?
➔ plastic deformation & localized corrosion.

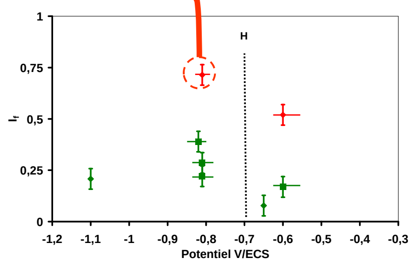
90 °C

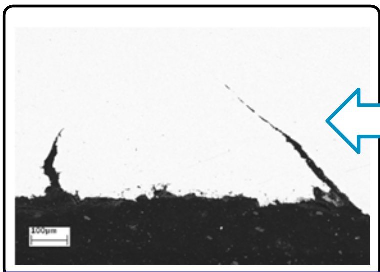
HAZ close to MZ

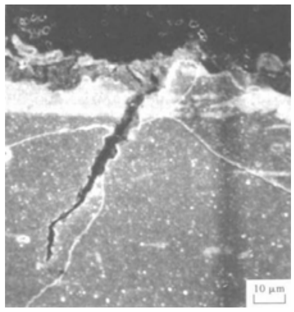












MZ / -400 $mV_{/ECS}$
10^{-6} s^{-1} / 25 °C

Non alloyed steel
-350 $mV_{/ECS}$ / 22 °C

SUMMARY & DISCUSSION OF SLOW STRAIN RATE TESTS

Welded Zone → Hydrogen embrittlement at the corrosion potential at 25 °C.

Base Metal
→ no domain of sensitivity to intergranular cracking in the range of applied potentials at 25 °C
→ The mechanism of passive film cracking is possible at 90 °C.

With rapid generalized corrosion
→ brittleness ➚ → SCC or too severe test ?
→ Intergranular attacks → Competition generalized corrosion/SCC?

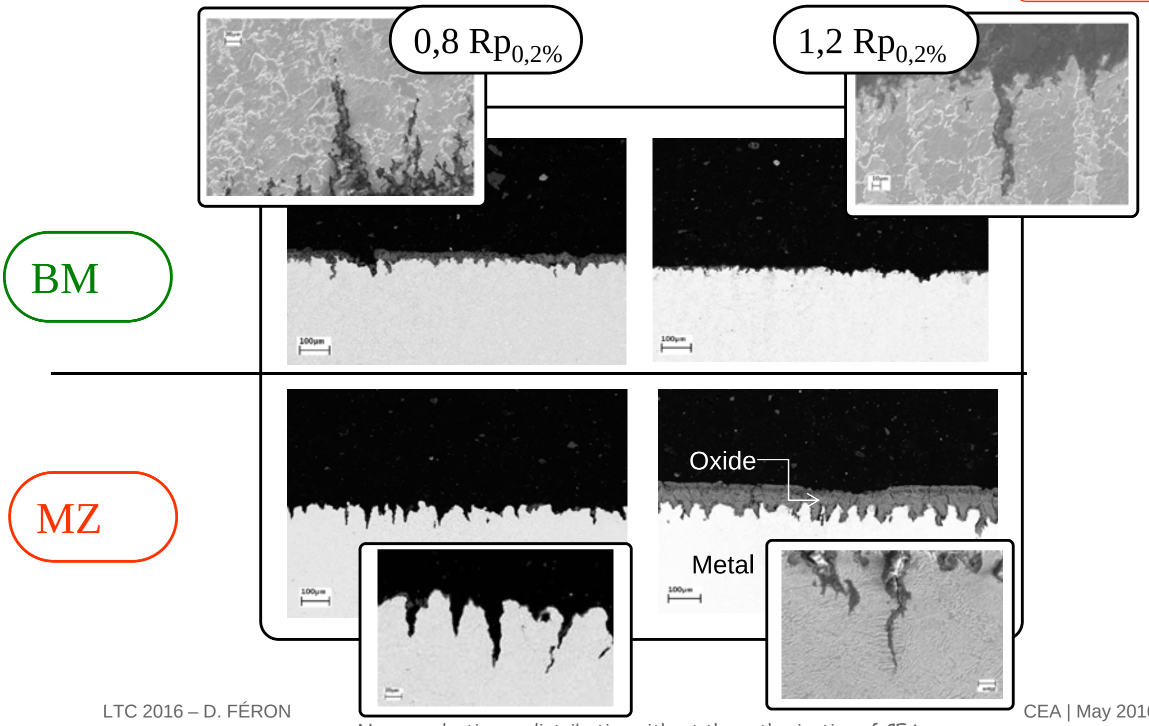
INITIATION OF STRESS CORROSION CRACKING

CONSTANT DEFORMATION TESTS

P265

After 1 year ➔ Multi cracking in BM and WZ

90 °C



P235 & P265 RESULTS ON BASE METAL

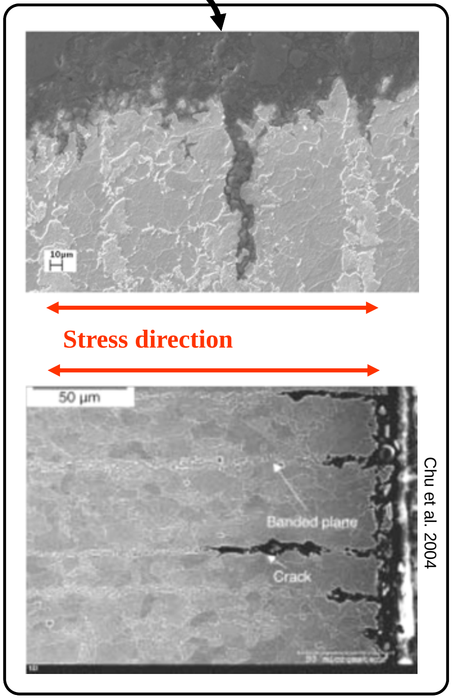
Cracks localized on the pearlite bands.

Cracks resulting from stress?
From chemical attack?

Literature➔ same results reported,
But not necessarily correlated to the stress direction.

Galvanic coupling between ferrite and pearlite.

Deleterious effect of band structures.



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P265 WELDED ZONE

Transgranular cracking

Not localized corrosion (no branching in secondary dendrites)

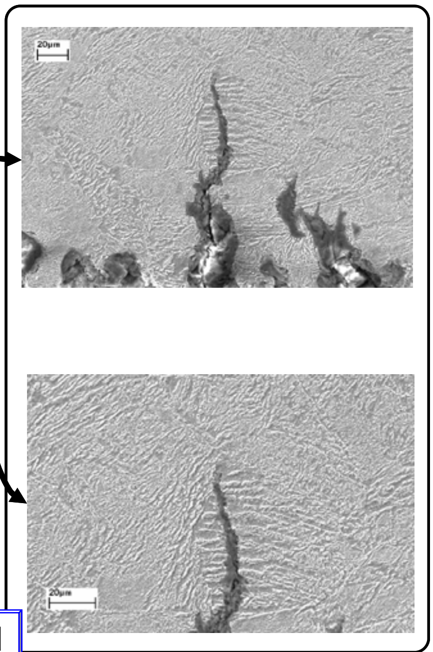
+

Mechanical loading

Hydrogen embrittlement-like phenomenon with a delayed cracking.

Caused by the excessive hardness of the welded zone (up to ~ 300Hv)…

… in the case of buried pipes, recommended hardness shouldn't exceed 250 Hv



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CONCLUSIVE COMMENTS

Tested welded joint. → Transgranular Stress Corrosion Cracking.

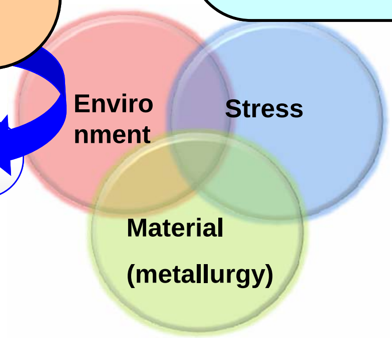
Galvanic coupling
ferrite / pearlite.

Base Metal

More extended pH range ➔
6 à 10 (90 °C)

Crack nucleation even under static loading.
Propagation ?

Intergranular Stress
Corrosion Cracking?



Welded zone hardness
Pearlite bands in the base metal

TOWARDS NEW MATERIALS LESS SENSITIVE TO SCC

MB → Avoid bands of pearlite / limit pearlite amount

Role of the processing.

Alloy P265 : sheets ⇌ overpack

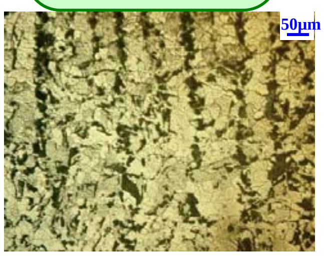
WZ → Hardness < 250 Hv

Control of the solidification rate.

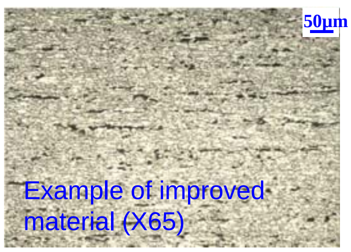
Solidification rate for massive parts ➔ overpack ?

Overpack prototype with welded joint

Acier P265



Our sample (first trial)



Details in S. Necib (Andra) présentation

Thank you for your attention

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