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

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D. Crusset, Andra, Châtenay-Malabry, France

LTC 2016, 6TH INTERNATIONAL WORKSHOP ON LONG -TERM PREDICTION OF CORROSION DAMAGE IN NUCLEAR WASTE SYSTEMS, TORONTO, CANADA, MAY 9-12, 2016

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

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THE « MULTI-BARRIER » CONTAINERS

① **Vitrified nuclear waste**

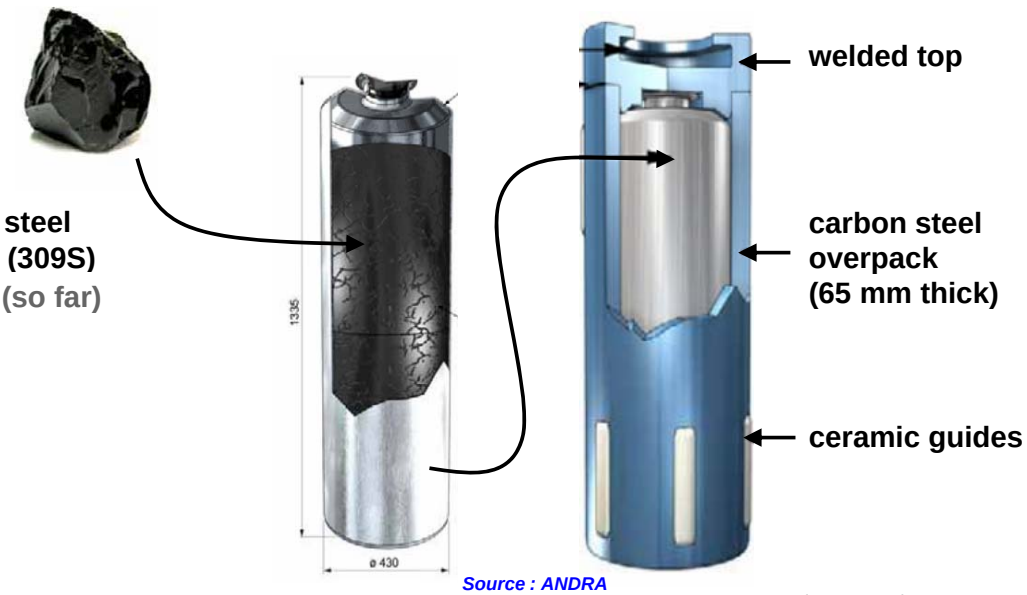
Limitation of radionuclides' release
(10^5 years)

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

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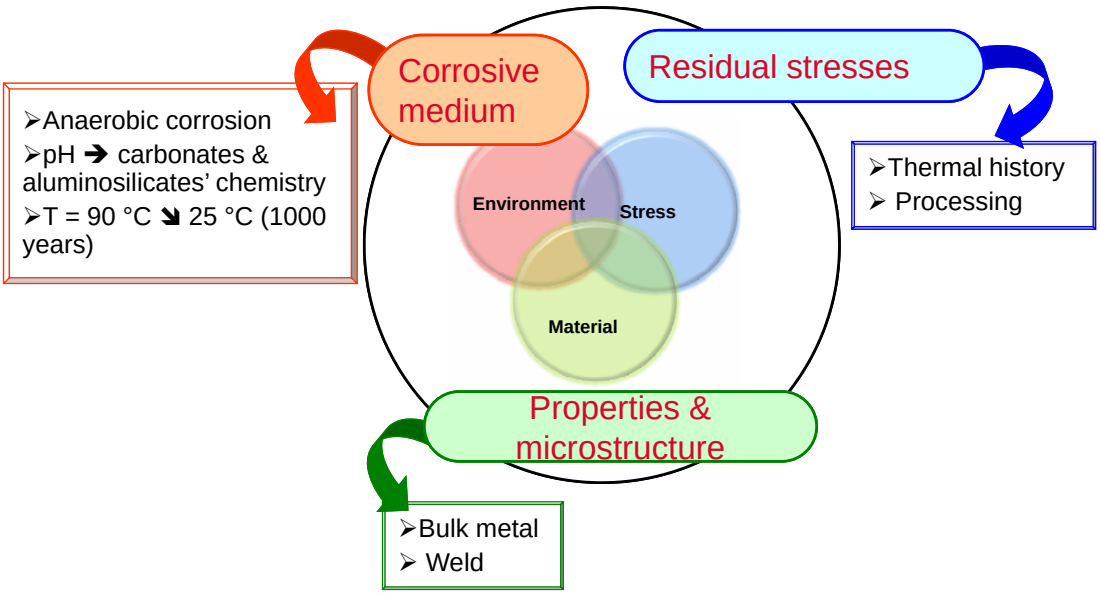
OBJECTIVE

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



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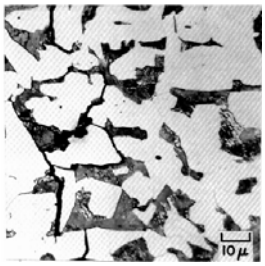
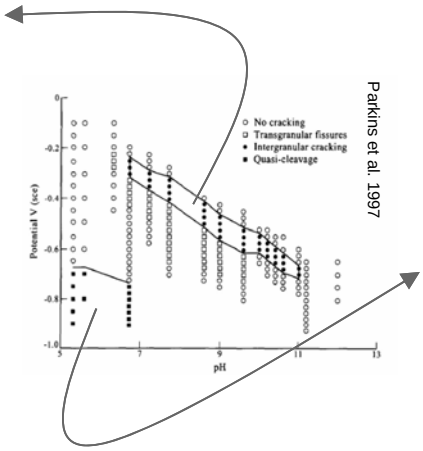
2 cracking mechanisms have been identified in buried pipes, characterized by specific potential-pH domain

Intergranular

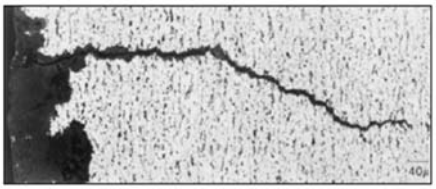


« passive » Steel
alcaline pH



Parkins et al. 1997

Transgranular



Parkins et al. 1994

« active » steel
quasi-neutral pH
Dynamic loading

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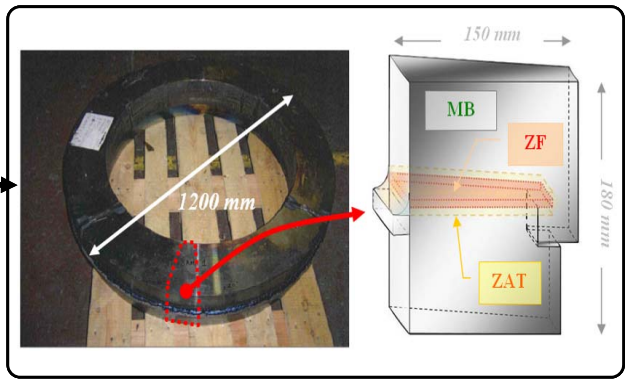
Coupons have been taken from two mock-ups.

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

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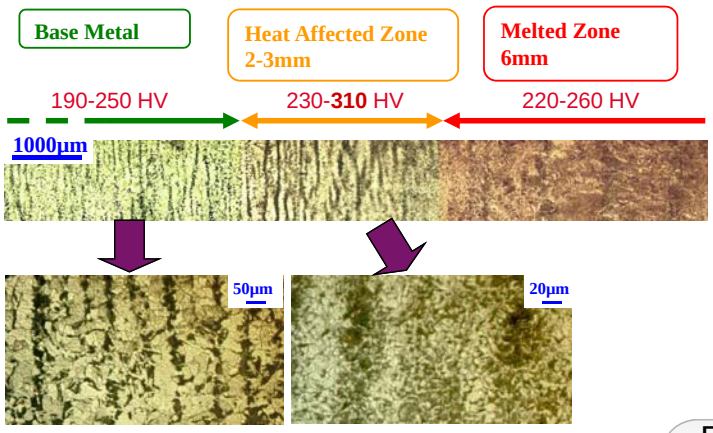
MICROSTRUCTRURE & HARDNESS

P265 (weld)



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

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SLOW STRAIN RATE TESTS

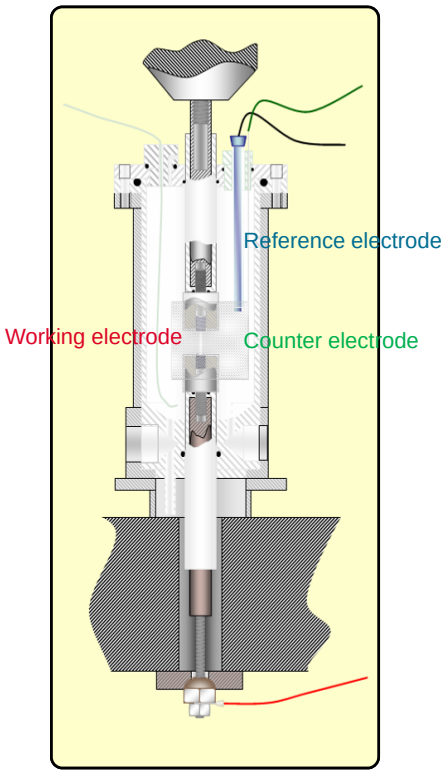
Sensitivity to stress corrosion cracking of the steel in storage environment

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.



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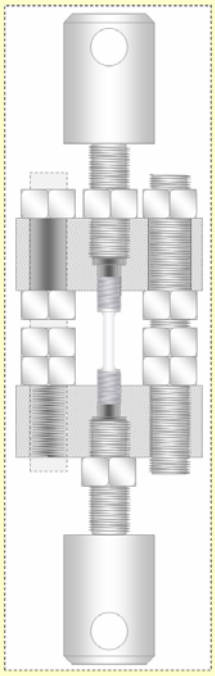
CONSTANT DEFORMATION TESTS

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

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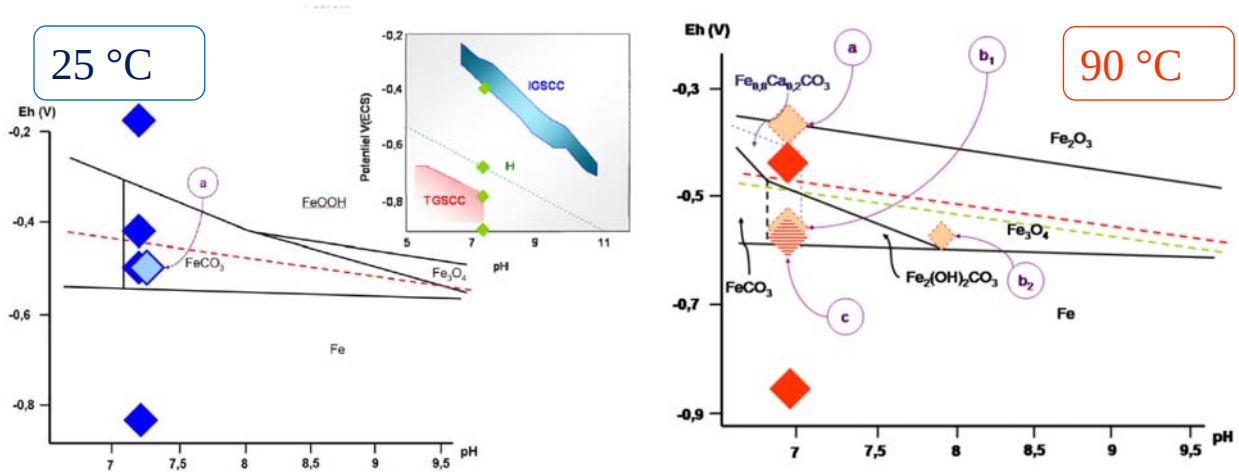
SENSITIVITY TO STRESS CORROSION CRACKING

SLOW STRAIN RATE TESTS



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

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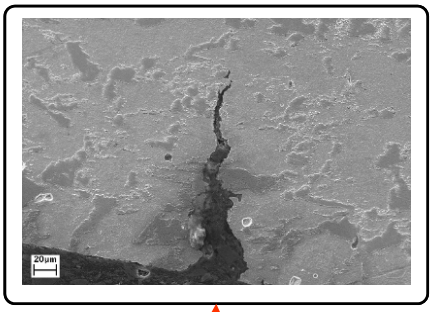
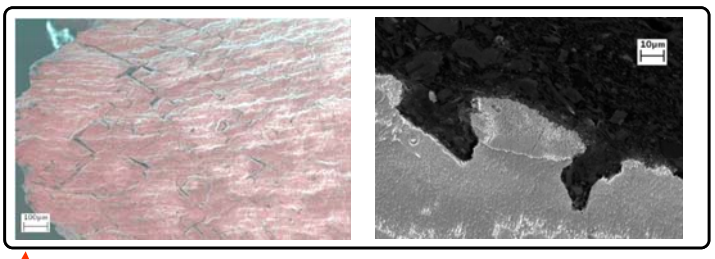
P265 BASE METAL

Transgranular cracking

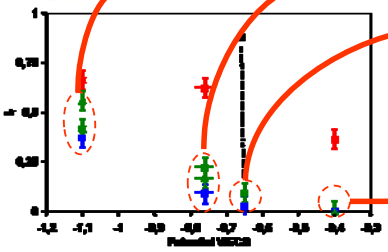
25 °C

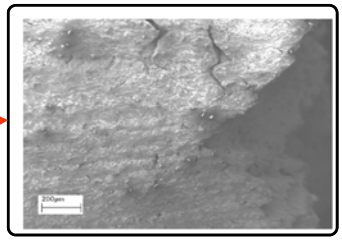


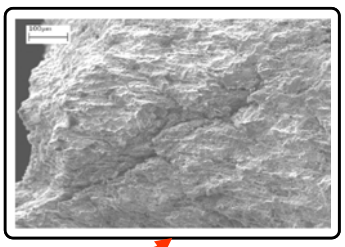


plastic deformation → localised corrosion ?

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







no intergranular cracking in the range of applied potentials

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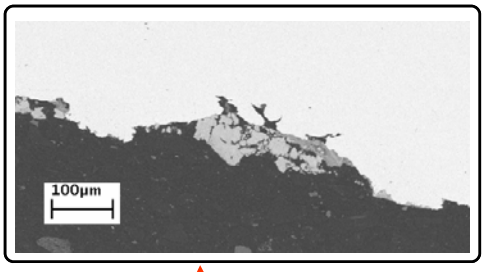
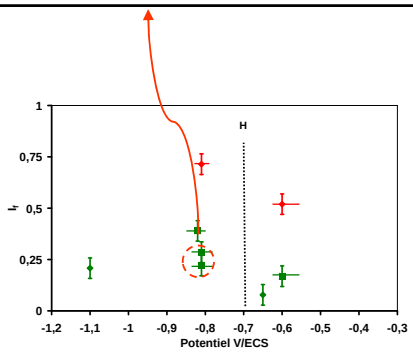
P265 BASE METAL

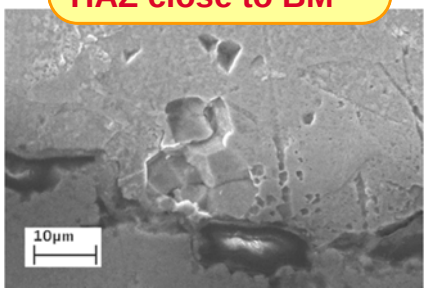
90 °C

Intergranular degradation

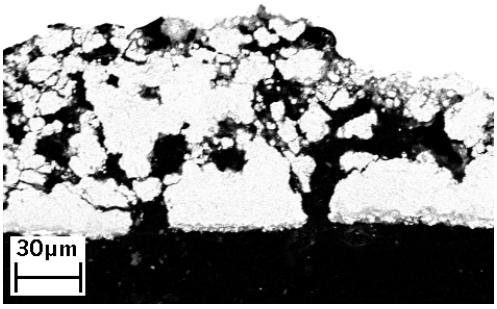




HAZ close to BM



Large deformations



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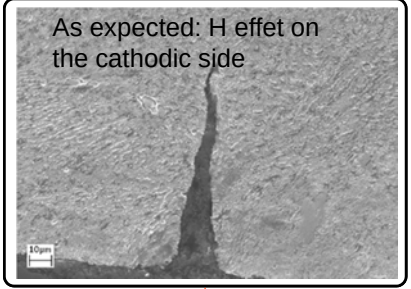
P265 WELDED ZONE

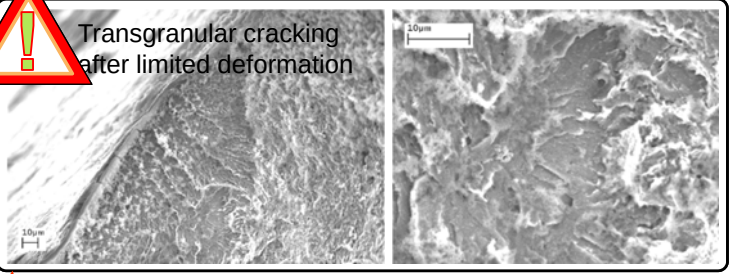
Hydrogen embrittlement at the tested corrosion potentials

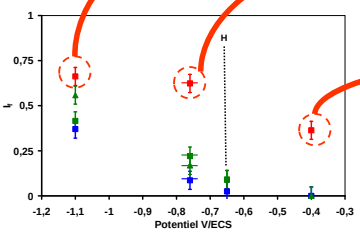
25 °C

As expected: H effet on the cathodic side

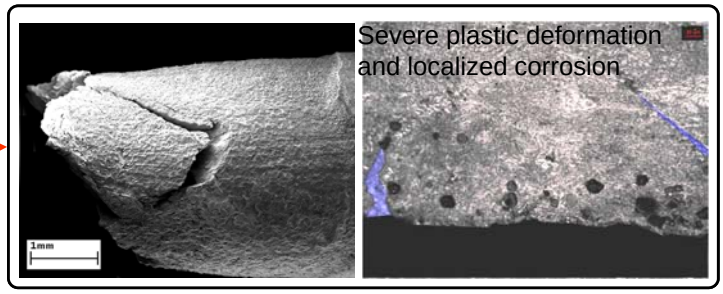


Transgranular cracking after limited deformation





Severe plastic deformation and localized corrosion



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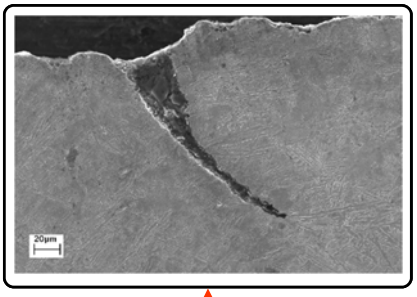
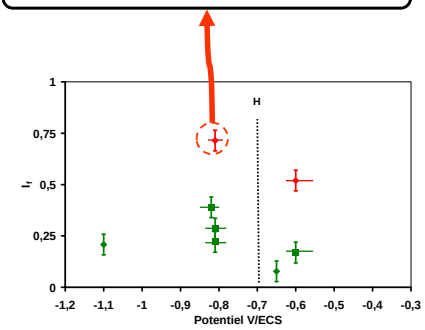
P265 WELDED ZONE

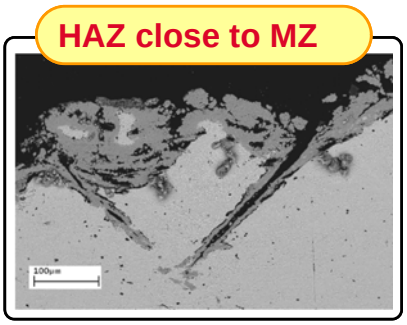
Hydrogen embrittlement ?
➔ plastic deformation & localized corrosion.

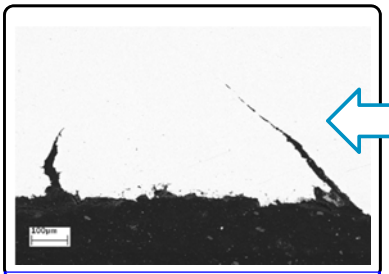
90 °C



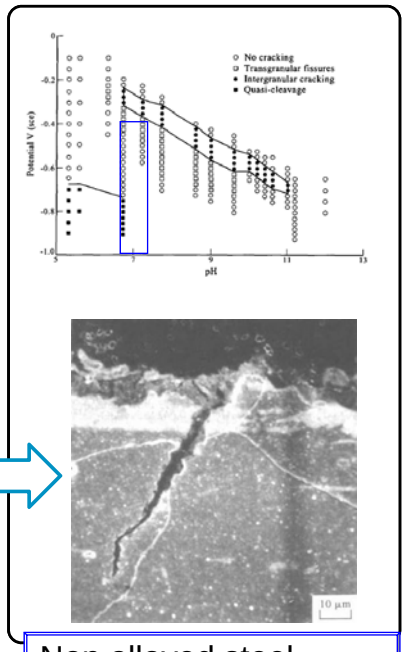


HAZ close to MZ





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



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

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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?

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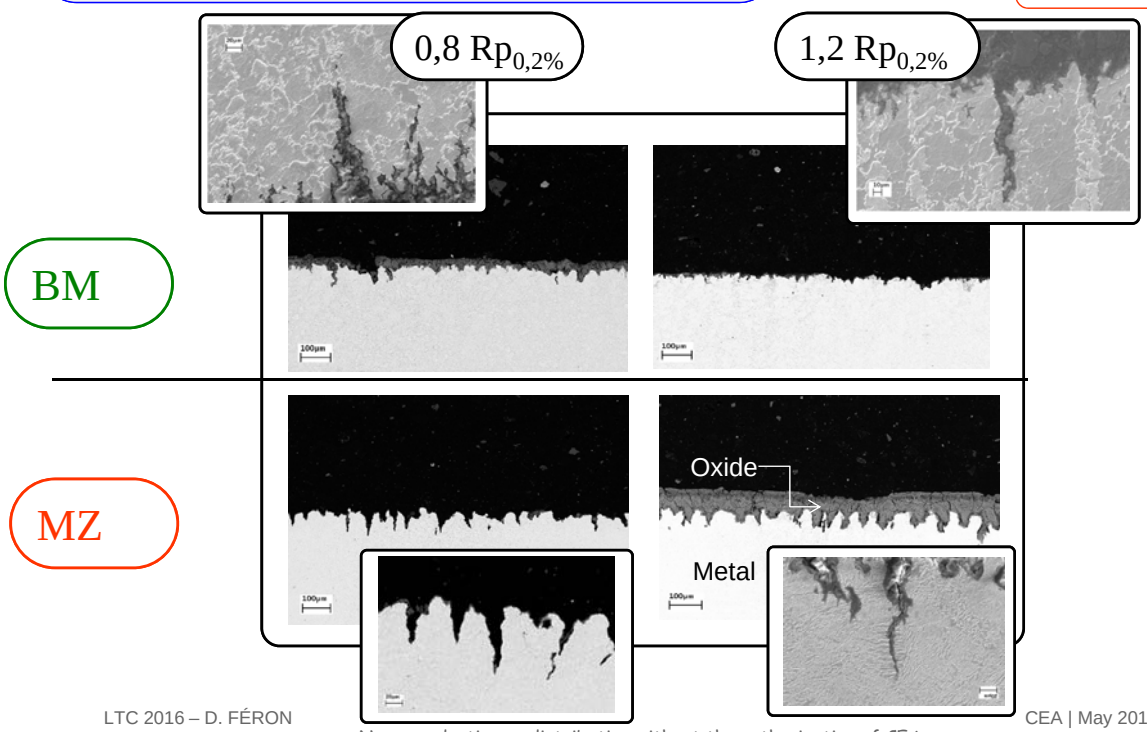
INITIATION OF STRESS CORROSION CRACKING

CONSTANT DEFORMATION TESTS

After 1 year ➔ Multi cracking in BM and WZ

90 °C



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P235 & P265 RESULTS ON BASE METAL

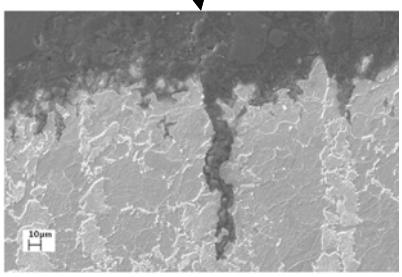
Cracks localized on the pearlite bands.

Cracks resulting from stress?
From chemical attack?

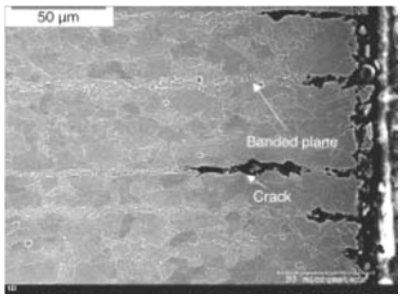
Literature➔ same results reported,
But not necessarily correlated to the stress direction.

Galvanic coupling between ferrite and pearlite.

Deleterious effect of band structures.



Stress direction



Chu et al. 2004

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P265 WELDED ZONE

Transgranular cracking

Not localized corrosion (no branching in secondary dendrites)

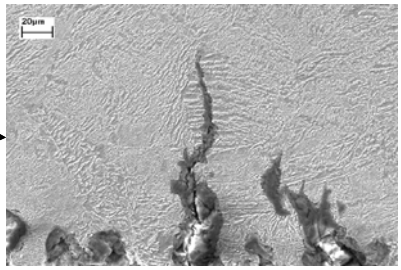
+

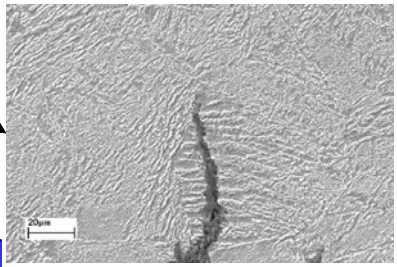
Mechanical loading

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

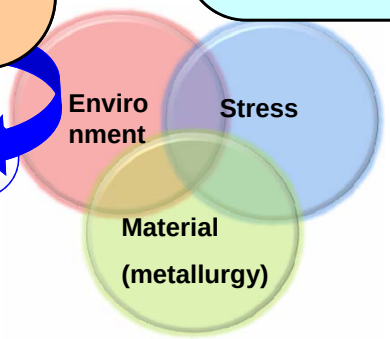
Tested welded joint. → Transgranular Stress Corrosion Cracking.

Base Metal → Galvanic coupling ferrite / pearlite.

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

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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

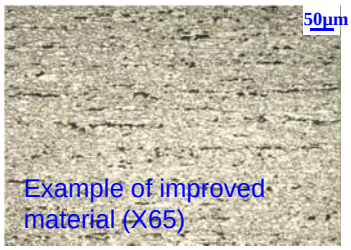
Control of the solidification rate.

Solidification rate for massive parts ➔ overpack ?

Overpack prototype with welded joint

Acier P265

Our sample (first trial)



Example of improved material (X65)

Details in S. Necib (Andra) présentation

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Thank you for your attention

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