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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

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)

**OBJECTIVE**

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

- Anaerobic corrosion
- pH → carbonates & aluminosilicates' chemistry
- T = 90 °C ☐ 25 °C (1000 years)

- Corrosive medium
- Residual stresses
- Properties & microstructure
- Bulk metal
- Weld
- Thermal history
- Processing
2 cracking mechanisms have been identified in buried pipes, characterized by specific potential-pH domain.

- **Intergranular**

- **Transgranular**

« passive » Steel

alcaline pH

« active » steel

quasi-neutral pH

Dynamic loading

Coupons have been taken from two mock-ups.

2 grades

- P265 ➔ weld
- P235 ➔ bulk

### Coupon Composition

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<th></th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>N</th>
<th>Cr</th>
<th>Cu</th>
<th>Mo</th>
<th>Nb</th>
<th>Ni</th>
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<td>0.152</td>
<td>1.08</td>
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<td>0.040</td>
<td>-</td>
<td>0.19</td>
<td>0.21</td>
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<td>0.13</td>
<td>-</td>
<td>0.003</td>
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<tr>
<td>P265 GH</td>
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<td>1.19</td>
<td>0.286</td>
<td>0.012</td>
<td>0.011</td>
<td>0.040</td>
<td>0.0044</td>
<td>0.032</td>
<td>0.015</td>
<td>0.007</td>
<td>0.004</td>
<td>0.024</td>
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</table>

### Mechanical Characteristics

<table>
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<tr>
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<th>Rp0.2% (MPa)</th>
<th>Rm (MPa)</th>
<th>At (%)</th>
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<tr>
<td>P235 GH</td>
<td>270</td>
<td>460</td>
<td>32</td>
</tr>
<tr>
<td>P265 GH</td>
<td>280</td>
<td>453</td>
<td>40</td>
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</tbody>
</table>
**MICROSTRUCTURE & HARDNESS**

**P265 (weld)**

- Base Metal: 190-250 HV
- Heat Affected Zone: 230-310 HV
- Melted Zone: 220-260 HV

- Microstructure in bands: risk of SCC
- Hardness > 250 Hv
  - 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 (pCO_{2})
  - 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 Rp0.2\%) relaxation (creep, cracks)
- 1 year test \( \Rightarrow \) 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
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

Transgranular cracking

$T = 1 - \frac{R_{450^\circ C}}{R_{450^\circ C}}$

- no intergranular cracking in the range of applied potentials
P265 BASE METAL

90 °C

Intergranular degradation

HAZ close to BM

Large deformations

Potentiel V/ECS

If

H

P265 WELDED ZONE

25 °C

Hydrogen embrittlement at the tested corrosion potentials

As expected: H effet on the cathodic side

Transgranular cracking after limited deformation

Severe plastic deformation and localized corrosion

Potentiel V/ECS
**SUMMARY & DISCUSSION OF SLOW STRAIN RATE TESTS**

- **Welded Zone**: Hydrogen embrittlement at the corrosion potential at 25 °C.
  - 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.

- **Base Metal**: With rapid generalized corrosion
  - Britleness ➔ SCC or too severe test?
  - Intergranular attacks ➔ Competition generalized corrosion/SCC?
INITIATION OF STRESS CORROSION CRACKING

CONSTANT DEFORMATION TESTS

After 1 year → Multi cracking in BM and WZ

90 °C

BM

0,8 Rp₀.₂%

1,2 Rp₀.₂%

MZ

Metal

Oxide
Deleterious effect of band structures.

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.

Stress direction

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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
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

Environment
Stress
Material (metallurgy)

TOWARDS NEW MATERIALS LESS SENSITIVE TO SCC

Alloy P265 : sheets ⇌ overpack

Avoid bands of pearlite / limit pearlite amount

Role of the processing.

Acier P265

Our sample (first trial)

Example of improved material (X65)

Avoid bands of pearlite / limit pearlite amount

Hardness < 250 Hv

Control of the solidification rate.

Solidification rate for massive parts overpack?

Overpack prototype with welded joint

Role of the processing.

Details in S. Necib (Andra) présentation

Control of the solidification rate.

Our sample (first trial)

Example of improved material (X65)

Avoid bands of pearlite / limit pearlite amount

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Thank you for your attention