HENRI PROJECT FIRST MEETING

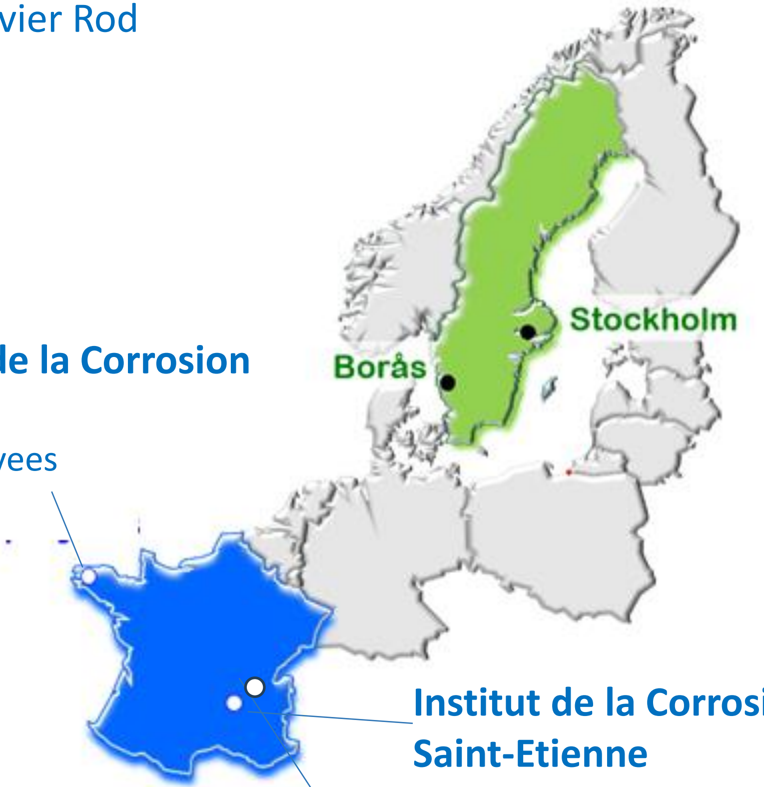
SEPTEMBER 21, 2023

HENRI
HYDROGEN ENERGY RESERVOIR

Institut de la Corrosion
French Corrosion Institute

CORROSION AT IC – RISE AT A GLANCE

RISE Corrosion department
Resp : Olivier Rod



RISE Corrosion Sweden
58 employees

Institut de la Corrosion Brest
35 employees

Institut de la Corrosion Saint-Etienne
16 employees

MECM Lyon
6 employees

CORROSION TEAM

A private research laboratory for Corrosion study in all industrial sectors

39 (100) collaborators

2 (4) Sites
(Brest & Saint-Etienne)
(Stockholm & Boras)

Subsidiary of RISE
3000 collaborators

€ 7 M (€ 13 M)

Different type of activities

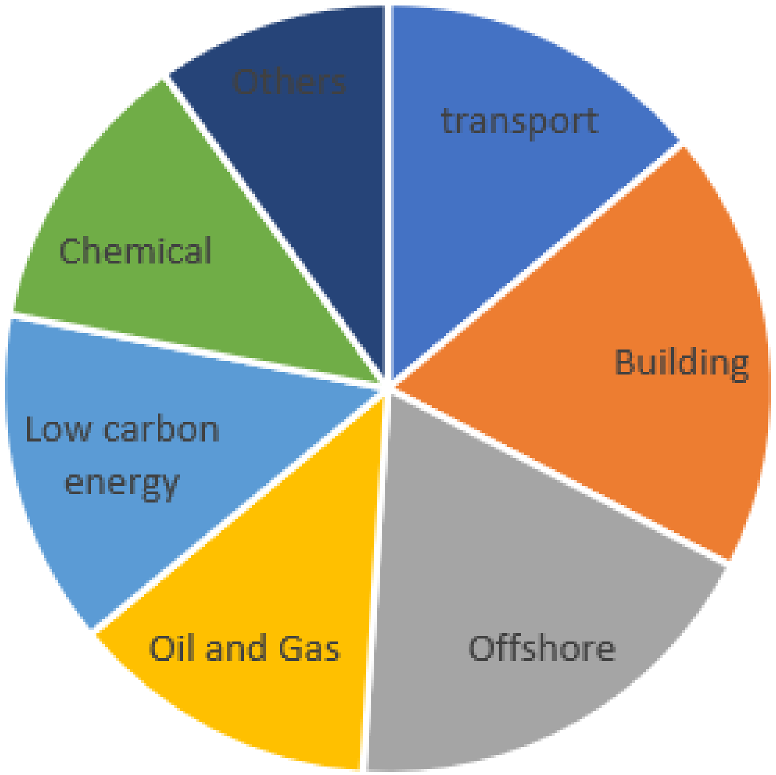
40 Joint Industrial Programs in progress

Over **80** industrial partners in R&D

Training and Failure analysis

2000 m² of laboratories in France

IC ACTIVITY



Industrial sectors

- All represented
- Strong background in fit-for-purpose test bench development
- ATEX test room for explosive gases
- Long term partnerships : IFPEN, CETIM, ANDRA, CORRTEX

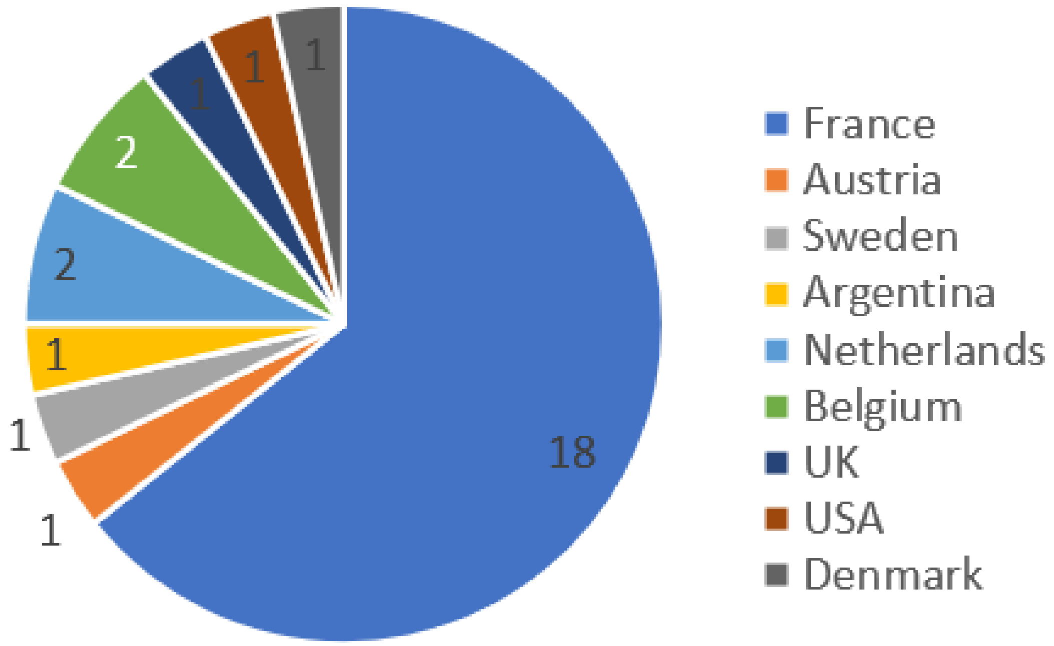
Funding

- Joint Industrial projects
- ARCOR / MRC
- Consultancies
- Bi-lateral agreement for R&D

MRC 13 – Hydrogen

28 members from 9 countries

Airbus	Aperam	Akzo Nobel	Böhler Edel
GE Power	Geostock	GRT Gaz	Industeel
Alleima	Shell	Storengy	Technip Energies
Technip FMC	Tenaris	Terega	Total Energies
Ugitech	Vallourec	DGA	Tata Steel
Bekaert	Edf	OCAS	Ascometal
Trapil	NOV	BakerHugues	Subsea7



Project in progress

- ❑ Test method for fracture toughness evaluation under H2 pressure
- ❑ Properties of CRA under H2 pressure and cryogenic temperatures
- ❑ Test method for permeability evaluation under H2 pressure

ON THE H2 ENERGY…. The development in progress

2018 | 2019 | 2020 | 2021 | 2022

First tests coming from customers inquiries

Review of the need of the market:
- Literature reviews
- Customers interviews

Turn the existing capacities for H2 handling

Build Partnerships
- IFPEN
- Universities
- Other institutions

First european project participation (literature)

Participate / build industrial projects
- JIPs
- MRC
- Direct inquiries
- Horizon

Develop the turnover through customer consultencies

Invest new equipments

Investment 2022

- ✓ Fatigue machine equipped with hydrogen module (700 bar/ -25 to +150°C)
- ✓ Module for cryogenic testing down to - 150°C
- ✓ Equipment for permeation under pressure to increase our capacity
- ✓ TDS analyzer with mass spectrometry detection

Possible investments 2023-25

- ✓ Autoclave 1000 bar for very high pressure testing
- ✓ Machine SSRT (700 bar – 25 - 200°C)
- ✓ Increase our fatigue testing capacity with a H_2 module on an additional fatigue machine
- ✓ Mass spectrometer for permeation detection
- ✓ Gas humidifier for test H2 test under controlled %RH

Development of activities 2022-2025

- ✓ International collaborations and projects
- ✓ Develop testing capacities and project portfolio

Testing capacities today

- ✓ Tensile tests under pressure (up to 250°C , up to 150 bar) for different type of loads (static or dynamic, toughness,…)
- ✓ Autoclave exposures (350 bar / 350°C)
- ✓ Polymer / metal permeation under pressure (400 bar max)

Activities today

- ✓ MRC Hydrogen – 28 members
- ✓ +/- 25% of the turnover around H2 at Saint-Etienne (inquiries and projects)
- ✓ Material and component testing in St-Etienne (France)
- ✓ Hydrogen embrittlement – projects in Brest & Stockholm

WORK SCOPE

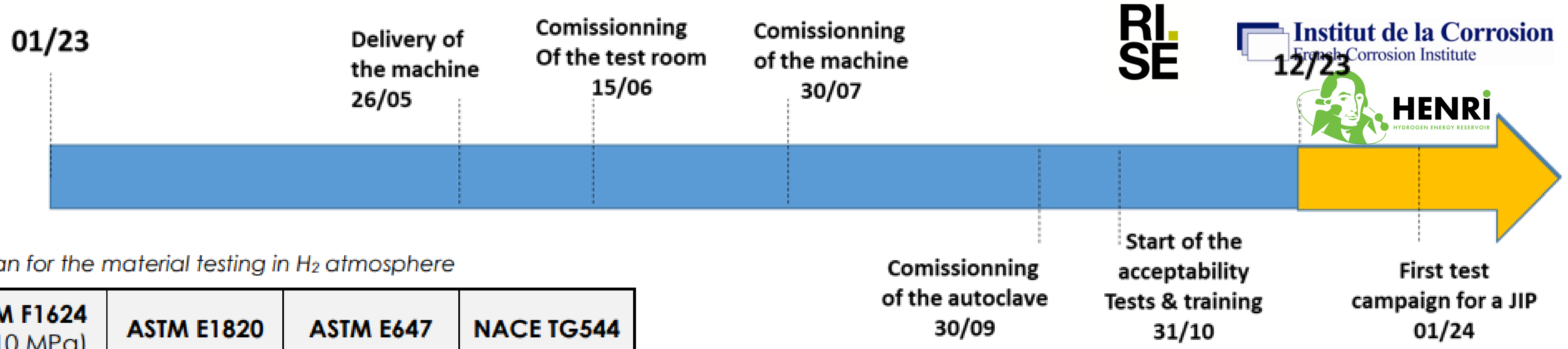


Table 5: Experimental plan for the material testing in H_2 atmosphere

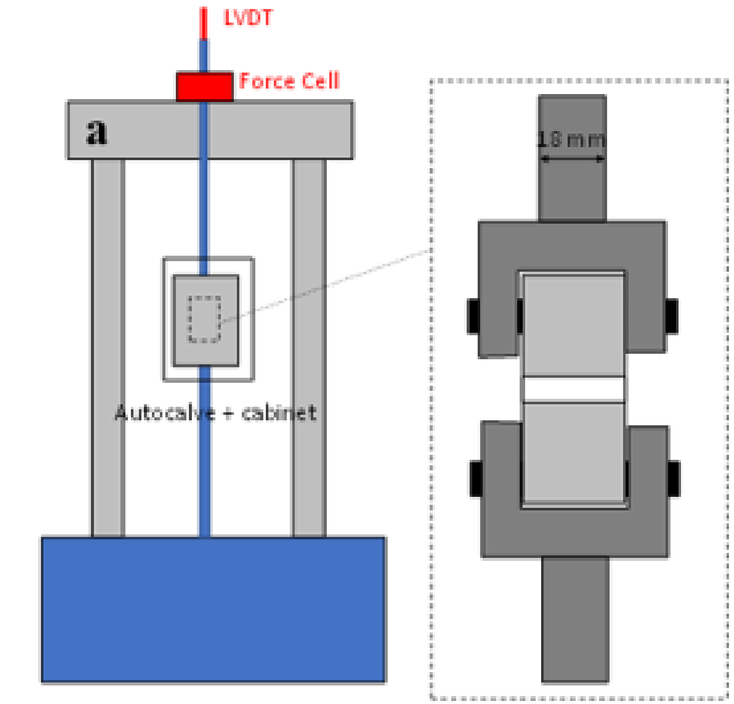
Material	ASTM F1624 (P<10 MPa)	ASTM F1624 (P>10 MPa)	ASTM E1820	ASTM E647	NACE TG544
12022.1 – BM	-	-	1	1	-
11416.1 – BM	2	-	2	2	2
13030 – BM	-	-	1	1	2
13030 – WM	-	-	1	1	-
12022.1 – BM	2	-	2	2	2
12022.1 – WM	-	-	1	1	-
11503.1 – BM	2	-	2	2	2
11503.1 – WM	-	-	1	1	-
L290NM – BM	-	-	1	1	-
13126.1 – BM	2	-	1	1	-
L415NE – BM	-	-	1	1	-
11523.1 – BM	-	-	1	1	-
Total tests	**8**	**-**	**15**	**15**	**8**

Without an additional experimental development :

- ❑ Only 7 fatigue tests completed in June 2025
- ❑Only 12 fatigue tests completed in December 2025

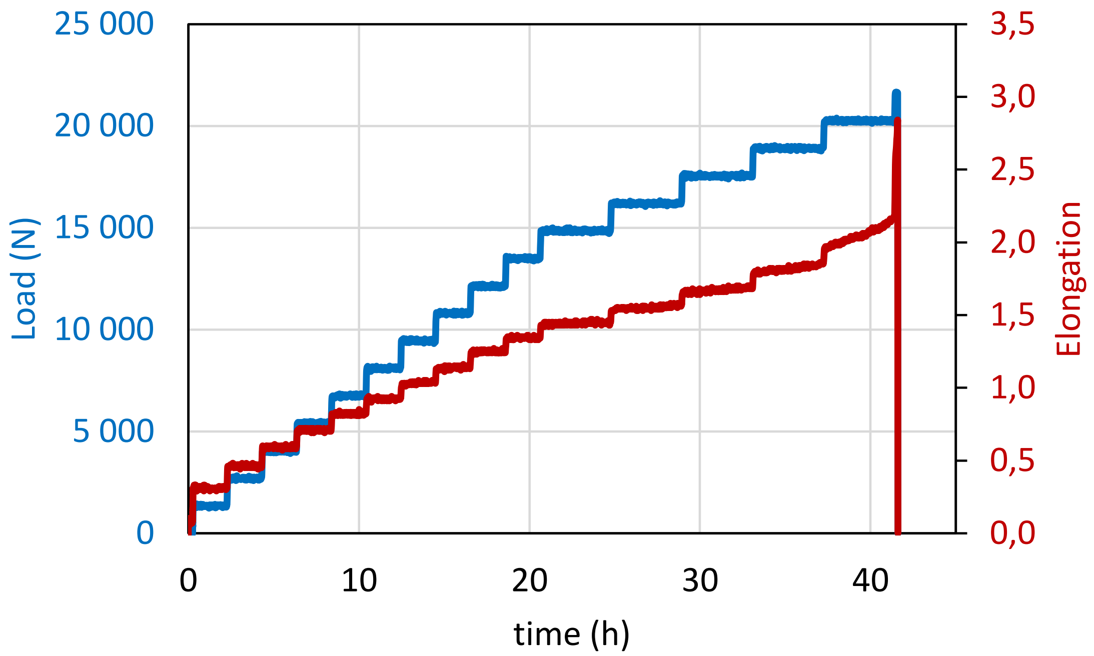
ASTM E1820/ASTM E647 will be conducted on a test bench under commissioning

ASTM F1624 - *MODIFIED*



Schematic of the tensile machine set-up

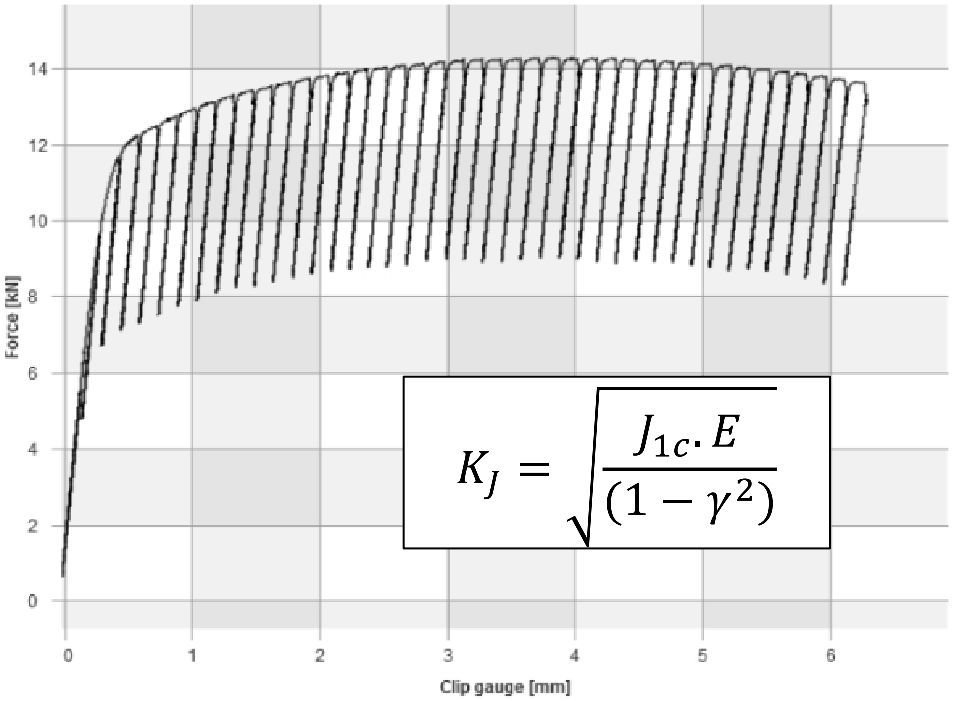
Set-up in the autoclave



- ❑ **Incremental step loading – Inspired from ASTM F1624**
  - The force is applied and the displacement measured
  - No extensometer yet – further development

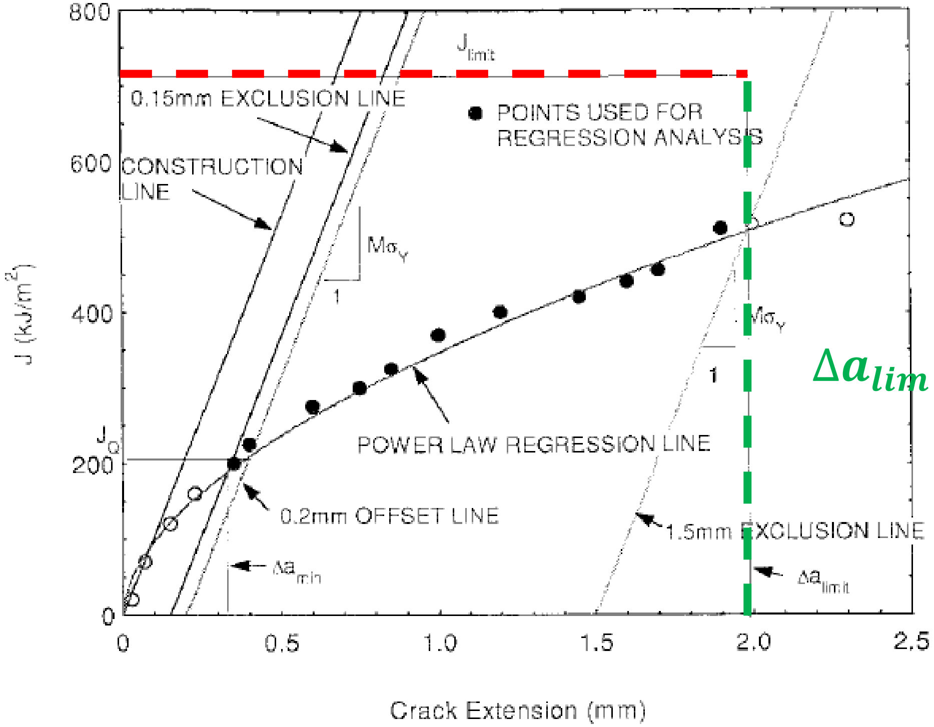
- ❑ **Test applicable for fast screening / same limitation as other fracture mechanics tests**

ASTM E1820



$$K_J = \sqrt{\frac{J_{1c}.E}{(1-\gamma^2)}}$$

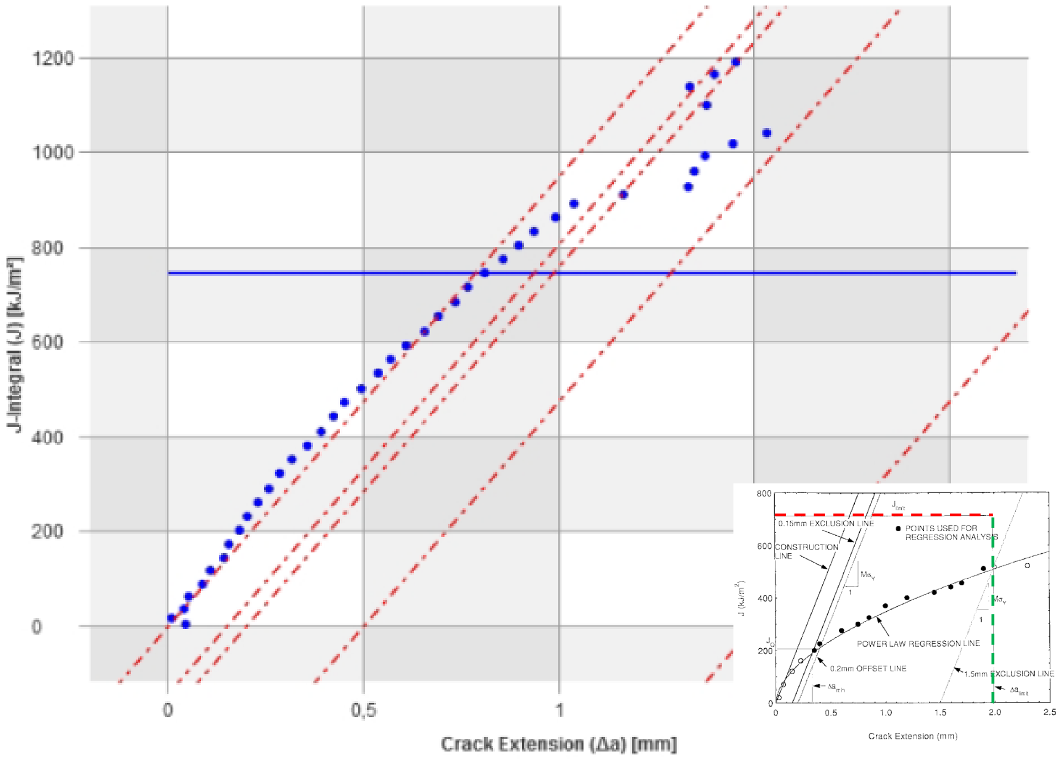
$$J_{lim} = \frac{b_0 \sigma_y}{7.5}$$

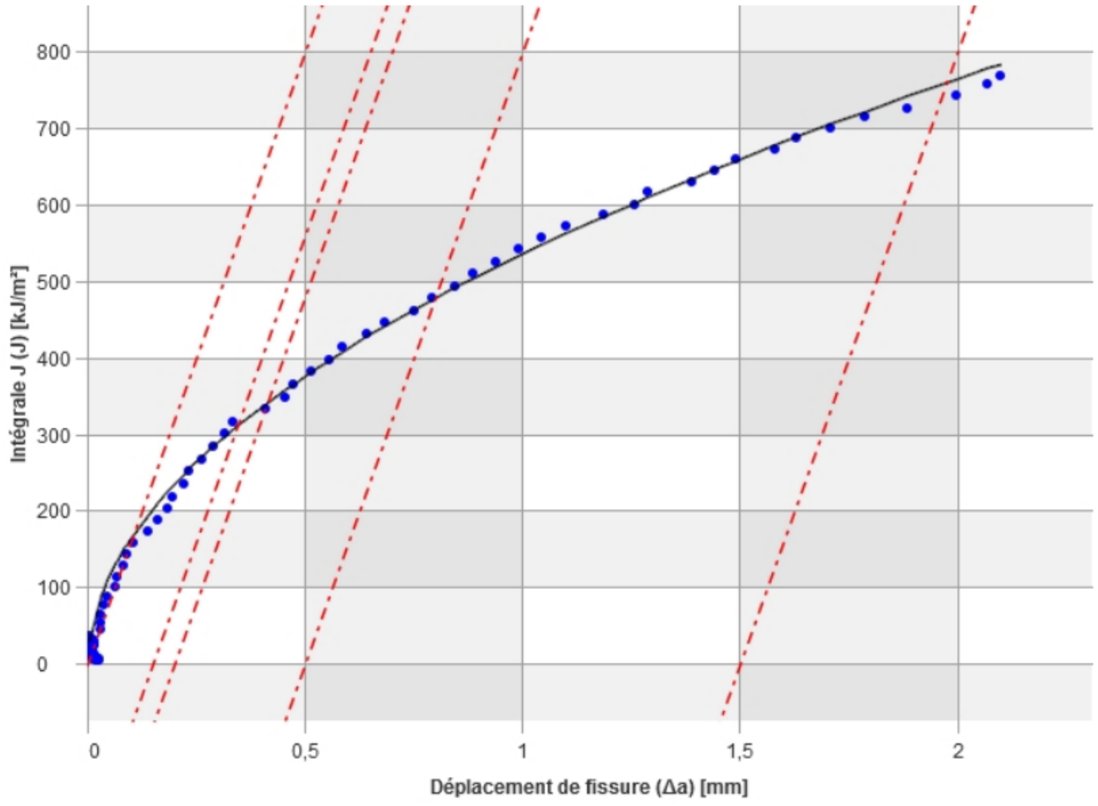


$$\Delta a_{lim} = 0.25 b_0$$

- ❑ **Particularly applicable for ductile material but suffers from the some the limitation if the mechanical properties of the material are too low**

ASTM E1820





X65 : invalid / Too small specimen – generalized plasticity is reached before JQ

JQ ≈ 900 kJ/m²

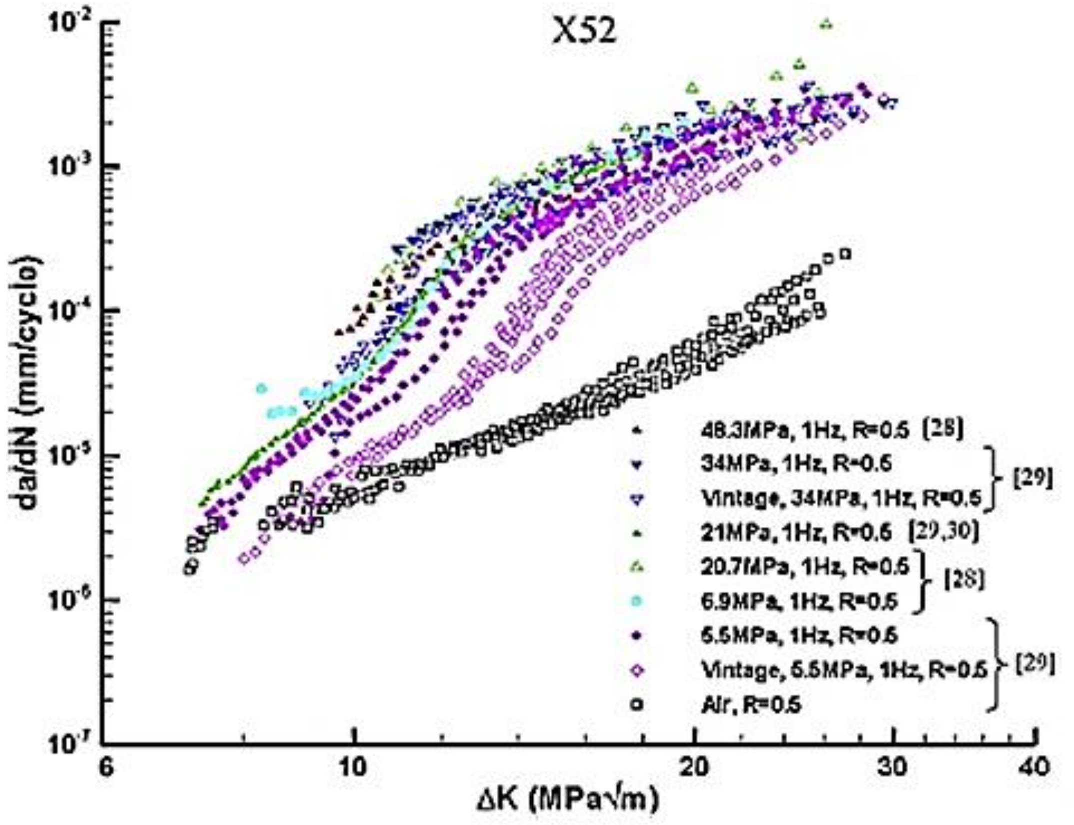
KJ ≈ 455 MPa√m

X100 : valid

JQ ≈ 341 kJ/m²

KJ ≈ 280 MPa √ m

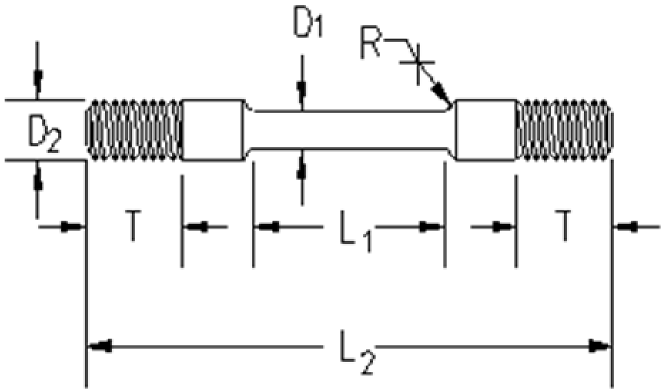
ASTM E647 – FATIGUE CRACK GROWTH RATE



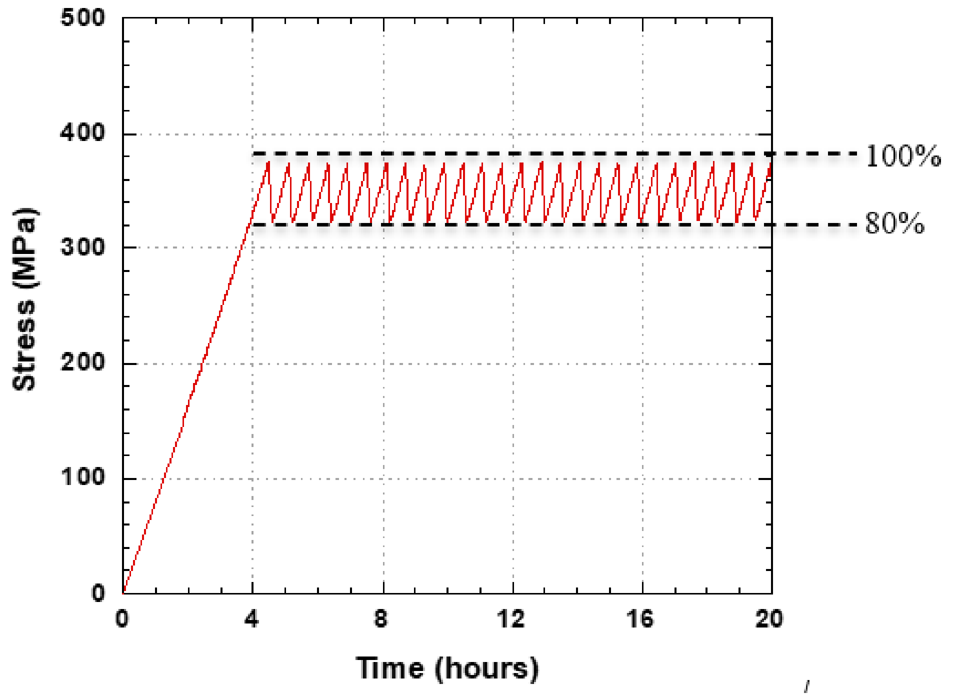
NACE TG544 – RIPPLE LOAD TEST

- Dynamic load test, in which a cyclic uniaxial tensile load is applied on a specimen by a slow strain rate machine.
- The specimen is subjected to a percentage of the SMYS. After reaching the upper loading boundary, the loading is decreased to a lower loading level. Then, repetitive loading cycles between the upper and lower loading boundary are applied.
- Inspired from draft standard from NACE – TG544

- **The limitations are the same as those of SSRT**



	mm
L_1	25.4 ± 0.1 mm
L_2	NS(A)
D_1	3.81 ± 0.05 mm
D_2	6.35 ± 0.05 mm
R	6.35 min.
T	NS
Thread	NS



Applied to material qualification to underground H2

RIPPLE LOAD TESTING

Material	Partial pressures (bars)			Results	Number of cycles
	H_2	H_2S	CO_2		
P110	120	0	0	No failure	114
	120	1	0	No failure	114
	120	1	15	No failure	129
	120	1	0	Failure	1*
L80	120	0	0	No failure	198
	120	1	0	No failure	192
K55	120	0	0	No failure	271
	120	1	0	No failure	279
J55 Weld	120	0	0	No failure	280
	120	1	0	No failure	295
13%Cr	120	0	0	No failure	158
	120	1	0	No failure	179

* Test performed between 80% and 100% of AYS

- **In the conditions selected in the project, all tested materials seem to be resistant to cracking.**
- **The complementary test on the P110 (tested at loading boundaries given by ASYS) lead to failure after few hours of test.**
- **P110 is susceptible in presence of H2S when loaded at the standard stress level (100%AYS). The fracture is attributed to SSC not hydrogen charging from the gas phase.**