P2G, Zwijnaarde, 18 September 2019

Hydrogen in an existing natural gas pipeline, which aspects to deal with?

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Key facts hydrogen pipeline X-804

- Owned by Gasunie Waterstof Service,
  a subsidiary of N.V. Nederlandse Gasunie (Dutch TSO)

- Steel pipeline:
  - existing 11,7 km 16"
  - new 700 m 12"

- New begin and end valve stations

- No compression or metering

- Adjusted maintenance, repair and emergency procedures

The hydrogen pipeline X-804

Similarities Hydrogen (H_2) and Methane (CH_4)

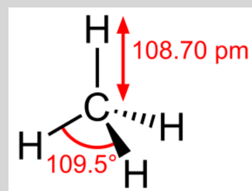
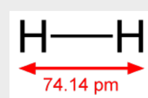
	Colourles	Odourless	Flammable	Explosive	Corrosive
Methane CH_4	yes	yes	yes	yes	no
Hydrogen H_2	yes	yes	yes	yes	no

methane: main component of natural gas

Differences Hydrogen and Methane (1/2)

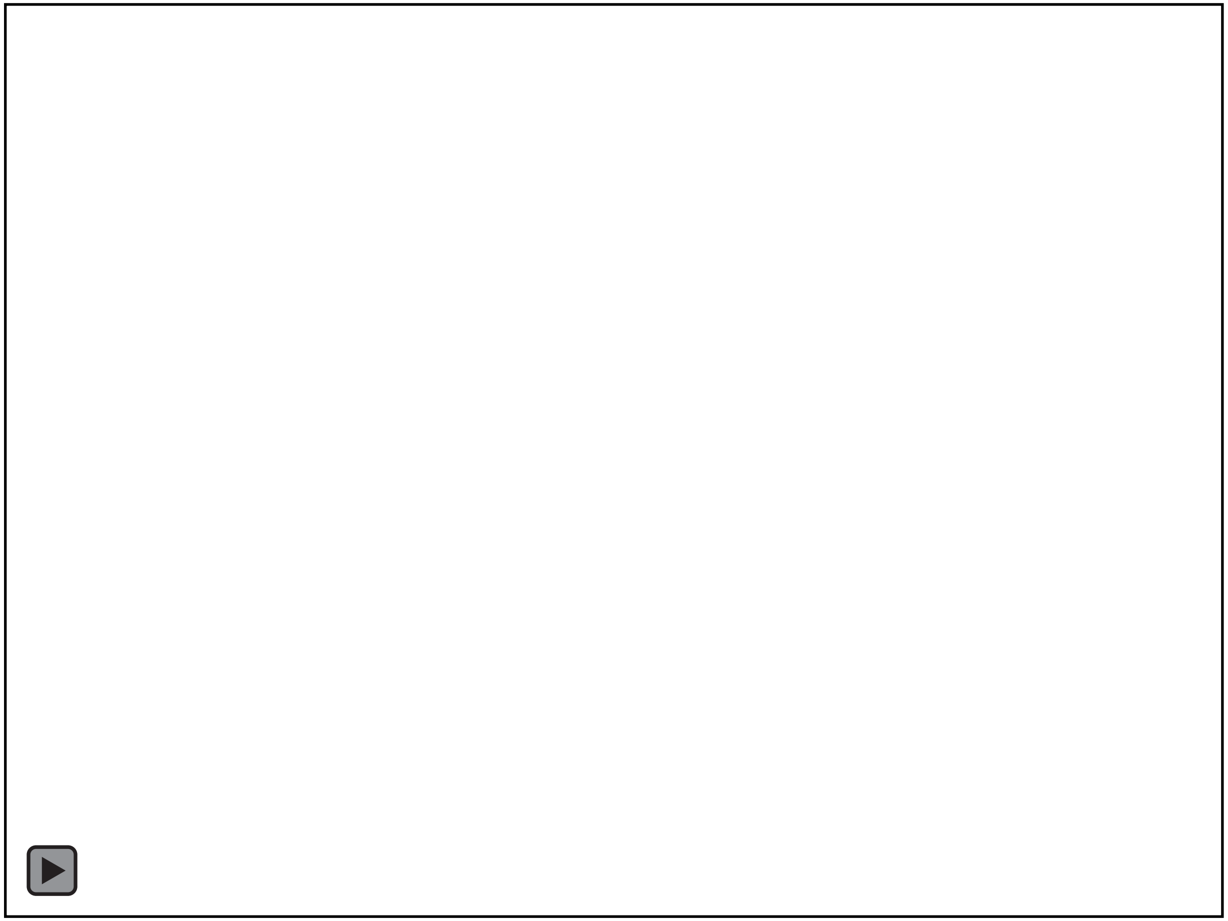
	Relative density (air = 1)	Explosion limits (lower & upper) [%])		Ignition energy [mJ]	Combustion energy [MJ/m³]
Methane CH_4	**0,55**	**4,4**	**17**	**0,26**	**32**
Hydrogen H_2	**0,07** *diffuses more rapidly*	**4,0**	**77**	**0,02** *ignites easily*	**11** *less energy*

Differences Hydrogen and Methane (2/2)

	Flame	Molecule size [pm]	Decompression Joule-Thomson [°C/bar]	Embrittlement
Methane CH_4	**blue** *visible*		**0,4** *colder if decompressed*	**no**
Hydrogen H_2	**colourless** *hardly visible*	 *possibly more emission*	**-0,03** *warmer if decompressed*	**possible**

The interaction of hydrogen atoms and steel may have a negative effect on the mechanical behaviour of steel. The general term for this degrading effect is *hydrogen embrittlement (HE).*

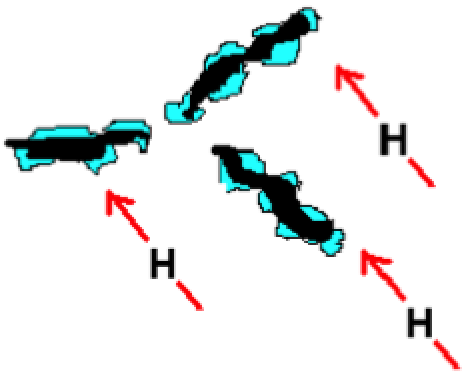
HE: Hydride forming



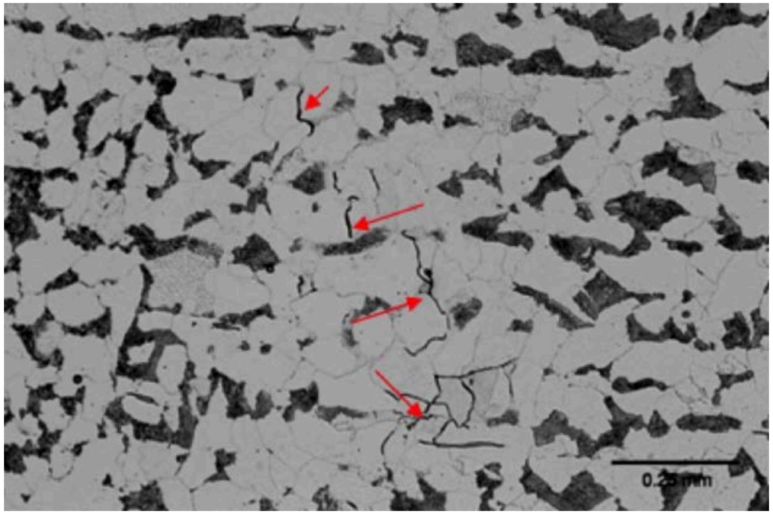
H_2 pipeline: no chemical reaction between hydrogen and iron

HE: Hydrogen attack

CH4 gas pockets (blue)

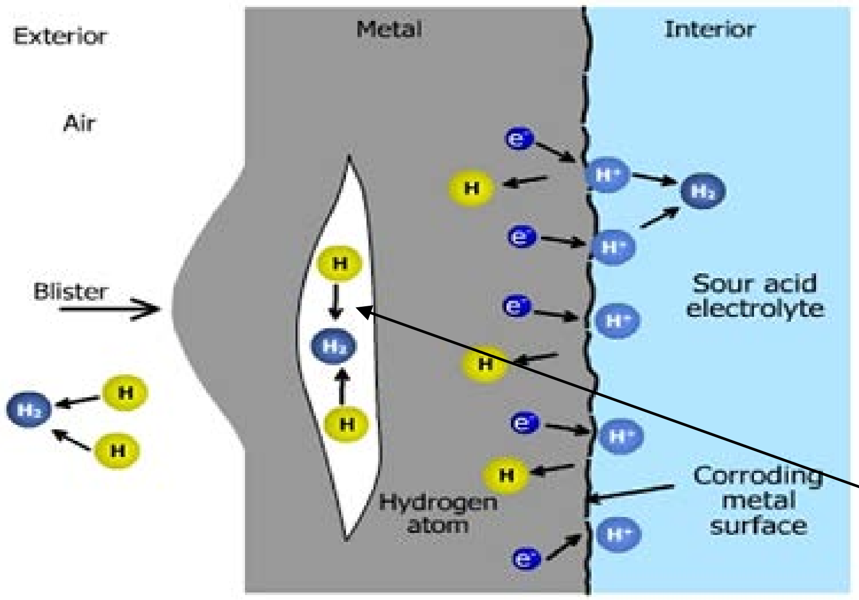


H is driven into the steel by heat & pressure, and reacts with the Fe3C to form CH4 gas



H_2 pipeline: no HA, hydrogen pressure and temperature is too low

HE: Hydrogen-induced cracking recombination of H-atoms in existing defects

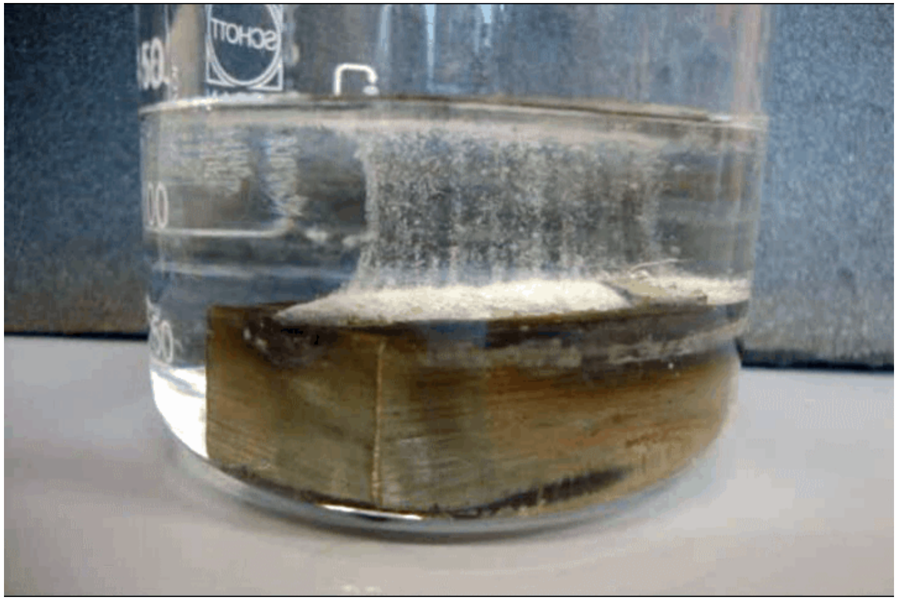


pipe wall

blister

H_2 pipelines: hydrogen pressure is too low

Hydrogen from the weld electrode may cause cold cracking



H_2 pipelines: no cold cracking because hydrogen concentration is too low

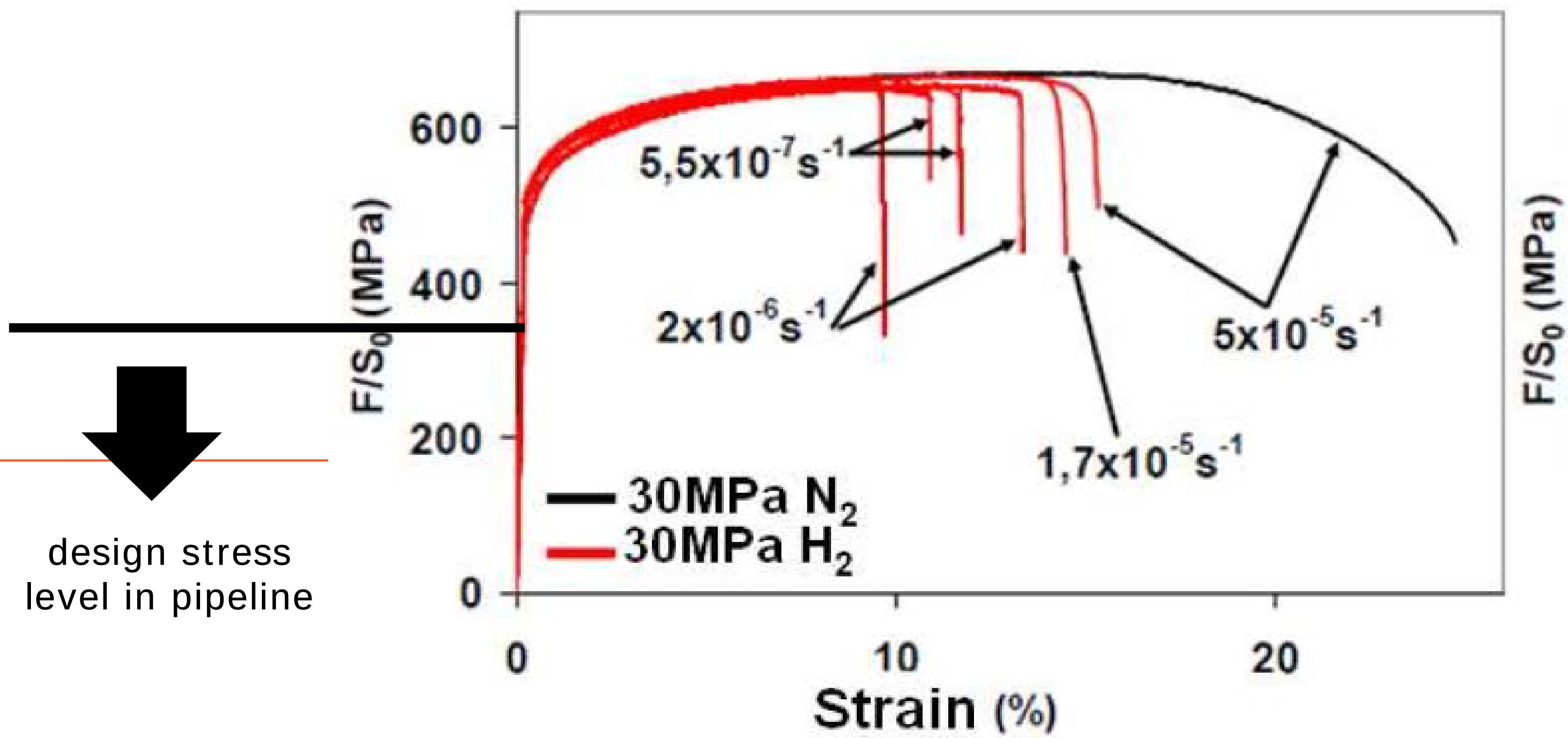
Hydrogen concentration in steel source of H:

source	hydrogen concentration [at. ppm]	equivalent pressure [bar (a)]
81 bar H_2	**0,25**	**81**
3 ml H_2/100 g weld consumable	150	15000
1 bar H_2S [c]	185	16000
cathodic charging (overprotection cathodic protection)	650	21000

0,25 atomic ppm H = 1 hydrogen atom on 4 million iron atoms

a) K. van Gelder et al., Hydrogen-induced cracking: determination of maximum allowed H_2S partial pressures, Corrosion, vol 42, no 1, 36-43 1986
b) D.X. He et l., Effect of cathodic potential on hydrogen content in a pipeline steel exposed to NS4 near-neutral pH soil solution, Corrosion, 778-786 2004
c) M. Tröger et al., Investigations on hydrogen assisted cracking of welded high-strength pipes in gaseous hydrogen, Steely Hydrogen Conference proceedings 2014

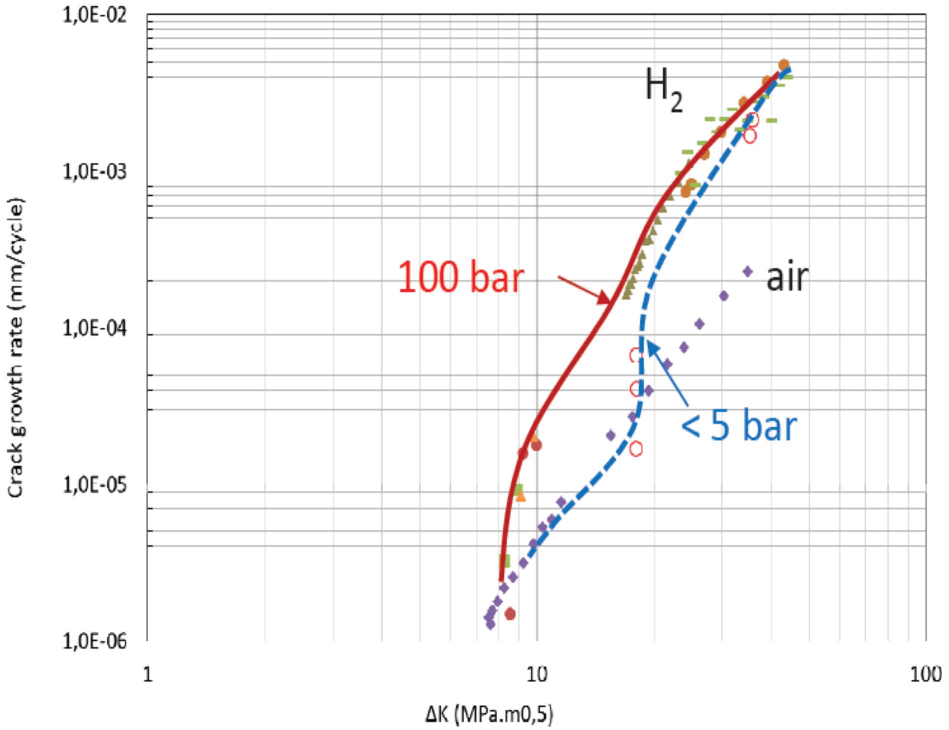
HE: decrease in ductility in H_2



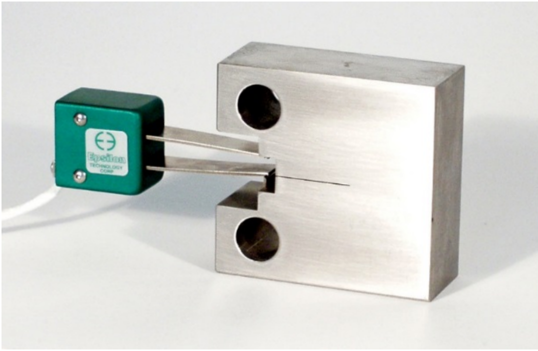
L. Briottet, I. Moro, P. Lemoine, Quantifying the hydrogen embrittlement of pipe steels for safety considerations, International Conference on Hydrogen Safety, 4th, San Francisco, 2011

HE: enhanced fatigue crack growth in H_2

0,01 μm/cycle



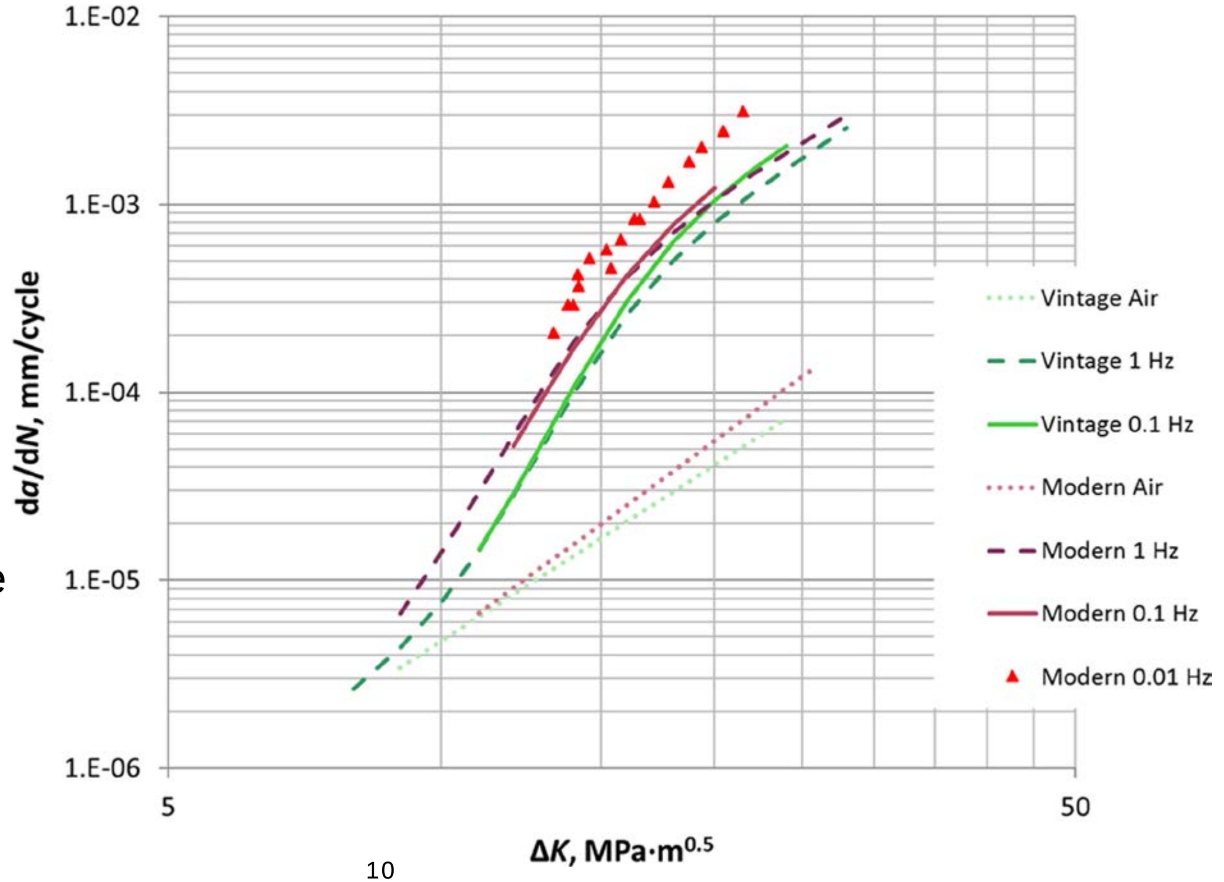
- R=0,1
- f=0,5Hz
- Air or 100bar H_2
- Constant load amplitude test
- CT and SENT specimen



J. Solin, N. de Miguel, Labscale – Full scale experimental comparison - Mechanisms, Modeling, Experiments and Pressure Vessel Design, Mathryce dissemination workshop, Paris, September 18, 2015

Fatigue crack/defect growth in H_2
effect of frequency and old and new steel

0,01 μm/cycle

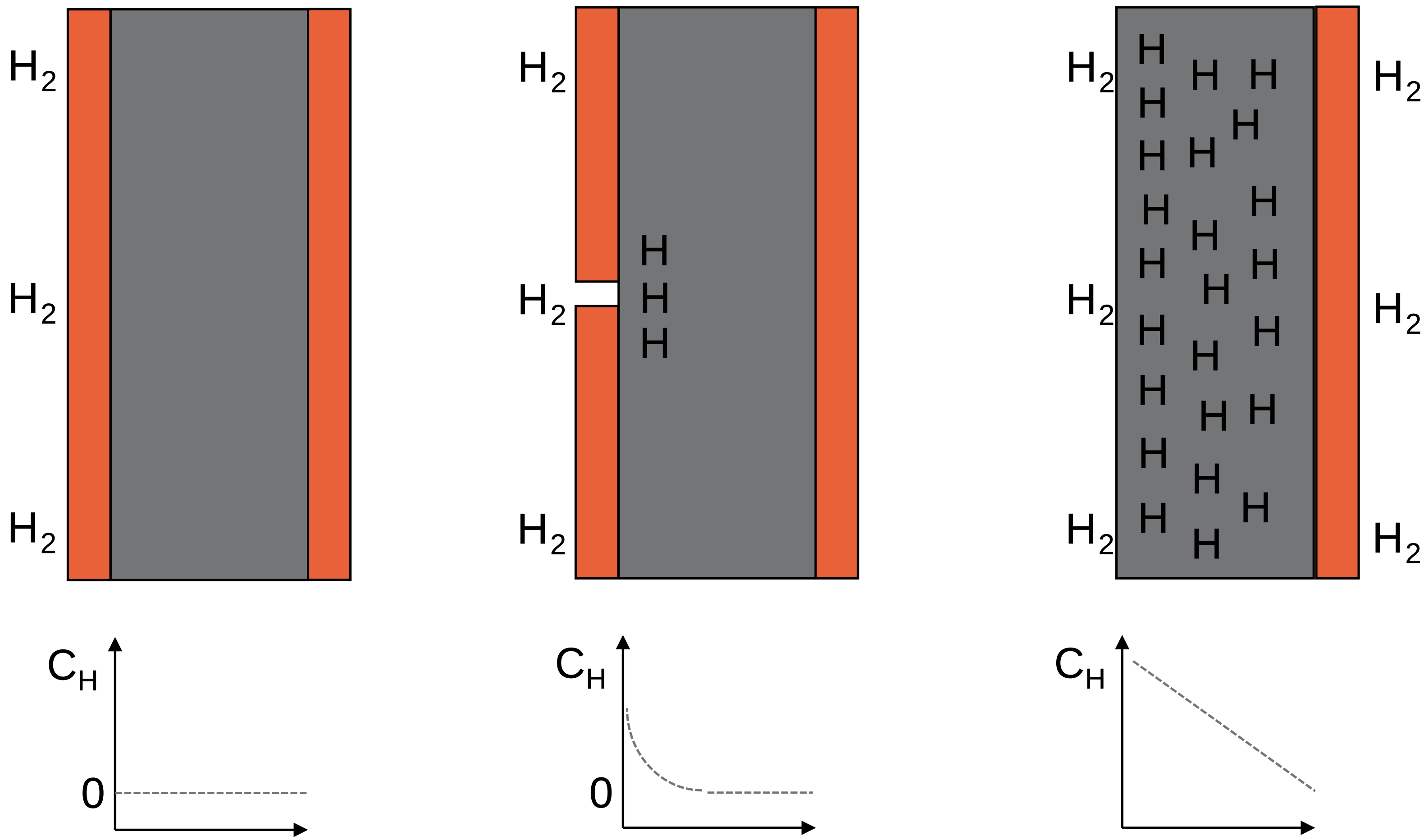


0,01 μm/cycle, 100 year 1 cycle per day = 0,37 mm crack growth

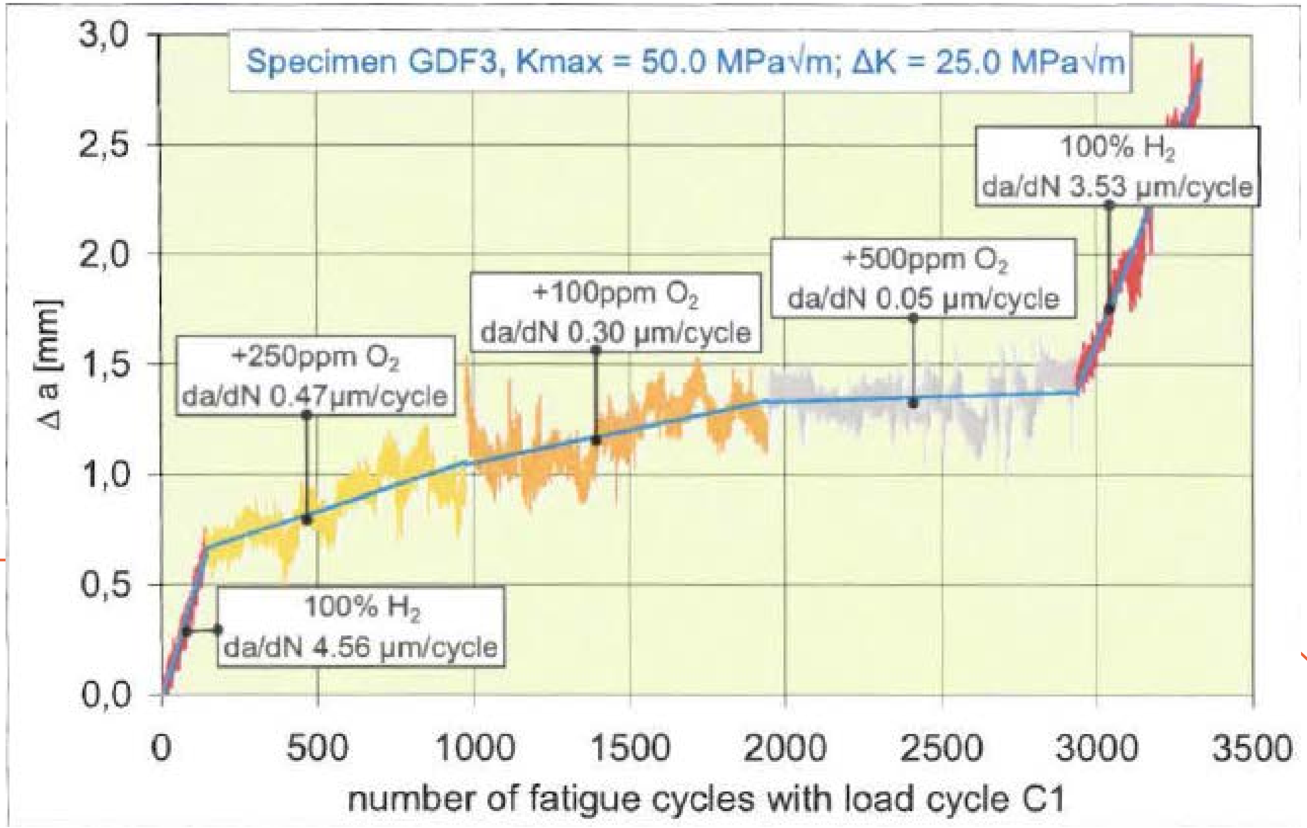
A.J. Slifka, Fatigue Measurement of Pipeline Steels for the Application of Transporting Gaseous Hydrogen, Journal of Pressure Vessel Technology (2018)

Absorption of hydrogen atoms in a steel wall

effect of oxide layer

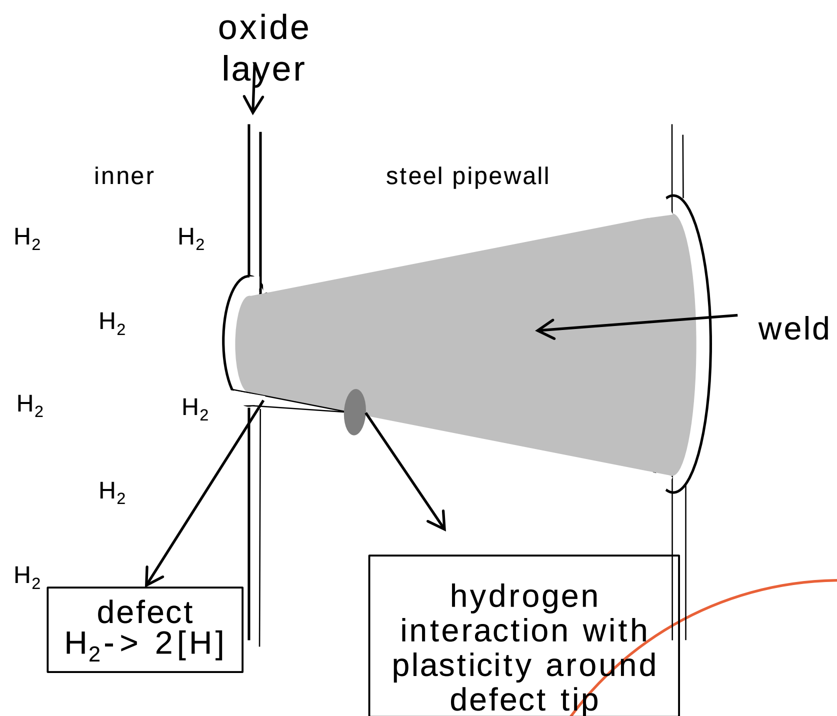


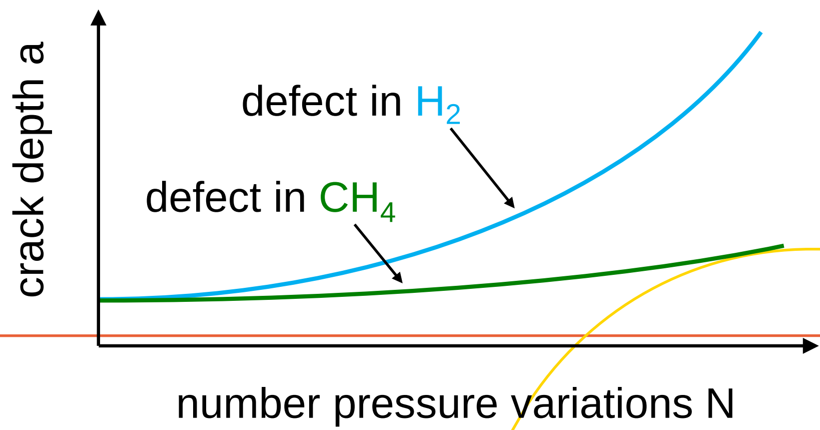
HE: enhanced fatigue crack growth in H_2
effect of oxygen



frequency 0,00164 s^{-1}, 66 bar H_2, steel X52=L360

Scenario for hydrogen-enhanced fatigue crack growth





Nothing new

"*The major technical problem with transmission of hydrogen gas at high pressure is the possibility of slow fatigue crack growth from existing cracks or crack-like defects in the pipe body or weld*."

E. Anderson et al. Geneva Research Centre in "Analysis of the potential transmission of hydrogen by pipeline in Switzerland"

Proceedings of the 2nd World Hydrogen Energy Conference, Zurich, Switzerland, 21-24 August **1978**

Conclusion (1/4)

Where hydrogen gas is being transported in pipelines at ambient temperatures and moderate pressures, the relevant hydrogen degradation mechanism is hydrogen-enhanced fatigue crack growth. When taking this degradation mechanism into account, 100% hydrogen gas up to the design pressure can be transported in existing natural gas pipelines without affecting the integrity of the pipeline during its lifetime.

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Conclusion (2/4)

Though the integrity may not be affected by the hydrogen, it does not mean that hydrogen can actually be transported in the existing pipeline. Hydrogen is a smaller molecule than the methane molecule and the ignition energy is much lower.

Conclusion (3/4)

So before hydrogen can be transported in an existing pipeline the following has to be considered:

- cleanliness of the pipeline
- explosive safety of equipment (ATEX)
- is the leak tightness of existing valves (internal and external) sufficient?
- is the leak tightness of existing flanges sufficient?
- do the risk contours of the pipeline become larger because the risk assessment for hydrogen is different?
- can operational and maintenance activities be performed in a safe manner?

Conclusion (4/4)

- no in-line inspection (pigging) (embrittlement of magnets)
- no live welding possible
- venting to air or flaring?
- measuring equipment may not measure H_2
- oxygen is a gas that can mitigate the effect of hydrogen-enhanced fatigue.