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Hydrogen and Integrity of Existing Natural Gas Networks

HIPS-NET workshop

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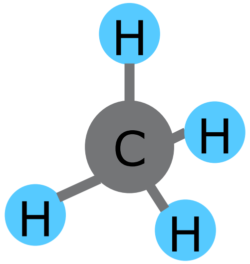
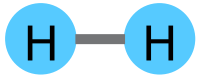




Natural gas / methane and hydrogen are similar gases.

But there are differences.

For integrity of network hydrogen molecules

can be source of hydrogen atoms.

Hydrogen atoms may cause hydrogen embrittlement of the steel pipe.

- The interaction of hydrogen atoms and steel may have a negative effect on the mechanical behaviour of the steel. The general term for this degrading effect is *hydrogen embrittlement.*
- Hydrogen embrittlement is well known in the petrochemical industry and in the welding world.
- The form of HE depends on many variables:
  one of them is the hydrogen atom concentration in the steel

Hydrogen concentration in steel
Hydrogen gas loading, no oxide layer present

- Chemical equation: $H_2 \rightleftarrows 2[H]_{Fe}$
- Sieverts' law: $C_H = k\sqrt{p_{H_2}}$
- k: solubility depends on steel and temperature
- Hydrogen pressure 81 bar / 8,1 MPa (a)

→ 0,25 atomic parts per million = 1 H-atom per 4 million Fe-atoms

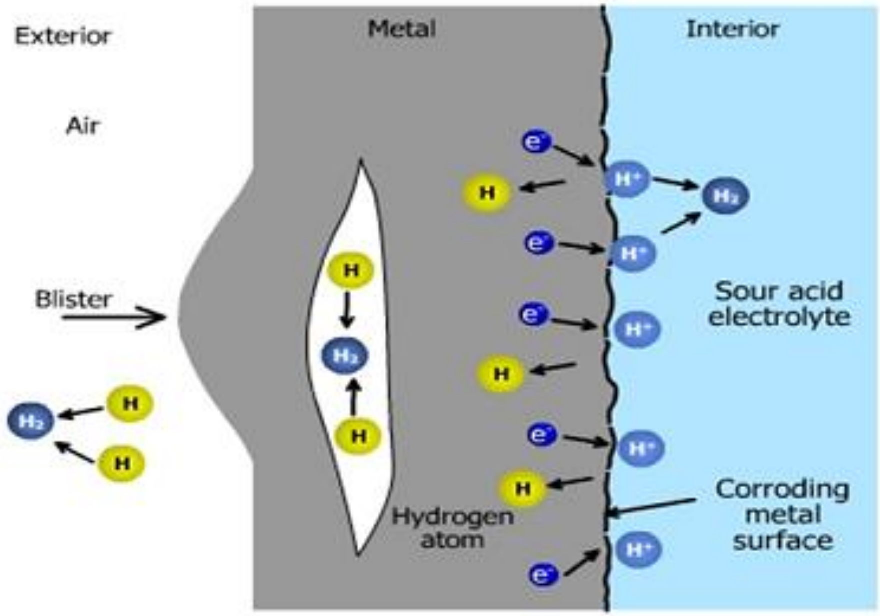
Comparison with other hydrogen sources
wet *H_2S gas, welding, active cathodic protection*

H source	H concentration [atomic ppm]	equivalent pressure [bar (a)]
81 bar H_2	**0,25**	**81**
wet 0,01 bar H_2S [a]	14	7062
active cathodic protection [b]	56	11438
3 ml H_2/100 g weld electrode	150	14519

no oxide layer present (applies to: wet 0,01 bar H_2S, active cathodic protection, 3 ml H_2/100 g weld electrode)

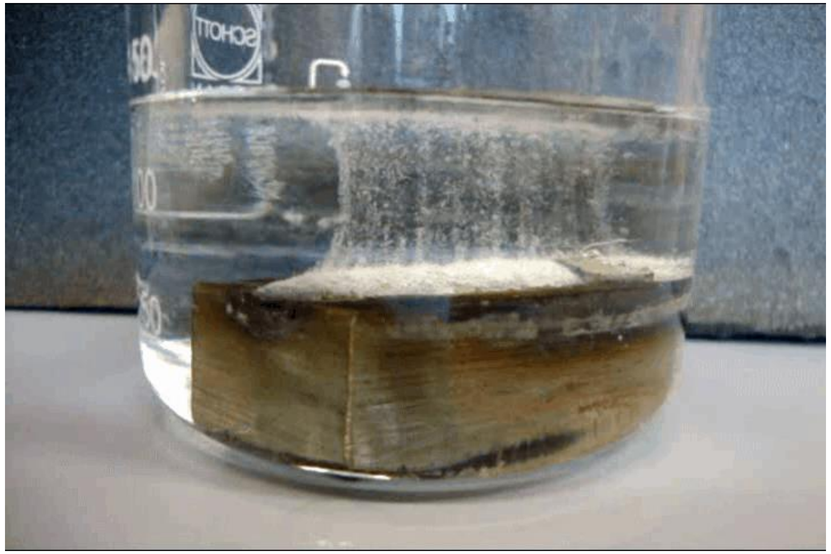
a) K. van Gelder et al., Hydrogen-induced cracking: determination of maximum allowed H_2S partial pressures, Corrosion, vol 42, no 1, 36-43 1986
b) D.X. He et l., Effect of cathodic potential on hydrogen content in a pipeline steel exposed to NS4 near-neutral pH soil solution, Corrosion, 778-786 2004

wet H_2S gas -> Hydrogen-induced cracking recombination of H-atoms in defects in the steel wall



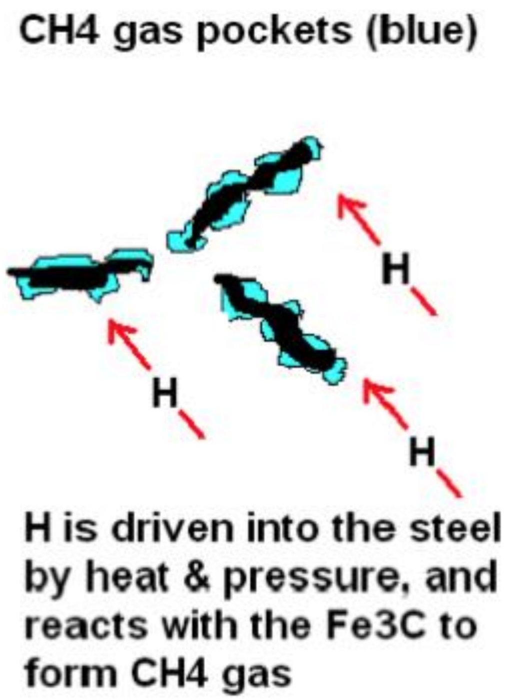
Pipelines: no HIC because hydrogen gas pressure is significantly lower.

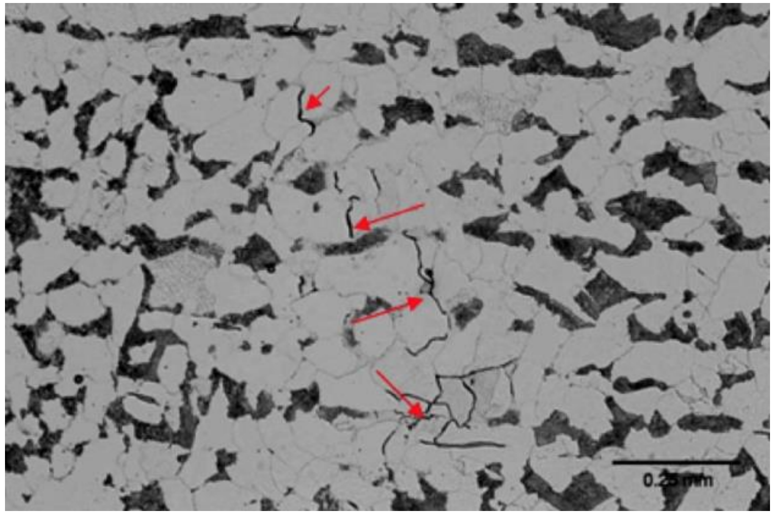
Hydrogen from the weld electrode -> cold cracking



Pipelines: no cold cracking because hydrogen concentration is too low.

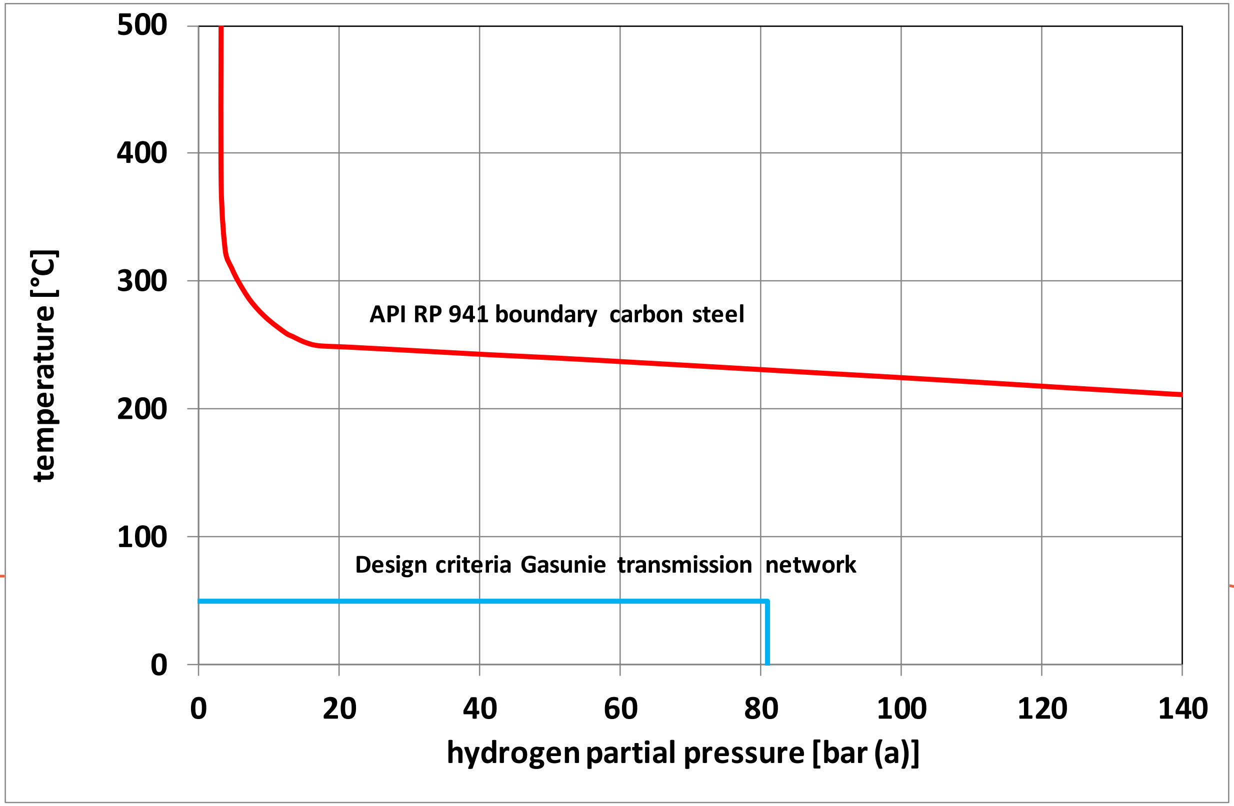
Hydrogen reacts with carbon -> Hydrogen attack



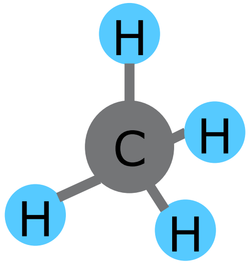


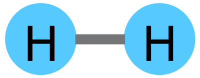
https://www.csb.gov/csb-releases-new-computer-animation-of-2010-explosion-and-fire-that-killed-seven-workers-at-the-tesoro-refinery-in-anacortes-washington/

Hydrogen attack depends on temperature and pressure



Pipelines: no hydrogen attack because pressure and temperature is significanty lower.

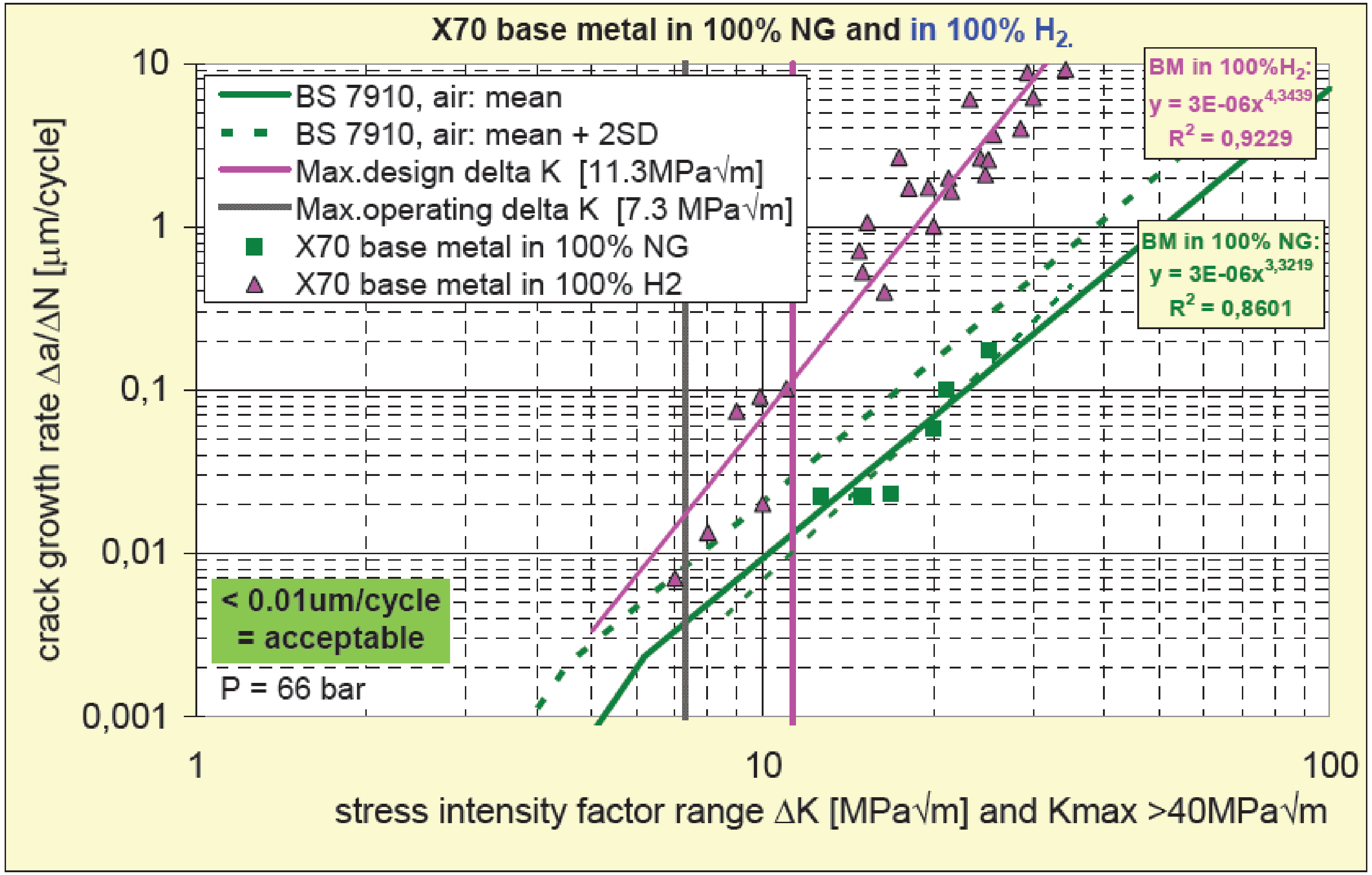


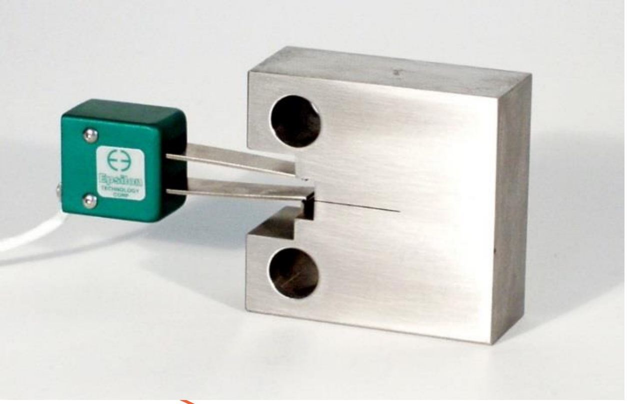


When does hydrogen gas have a negative effect

on steel behaviour?

Fatigue crack growth in H_2 (purple) and in CH_4/air (green)



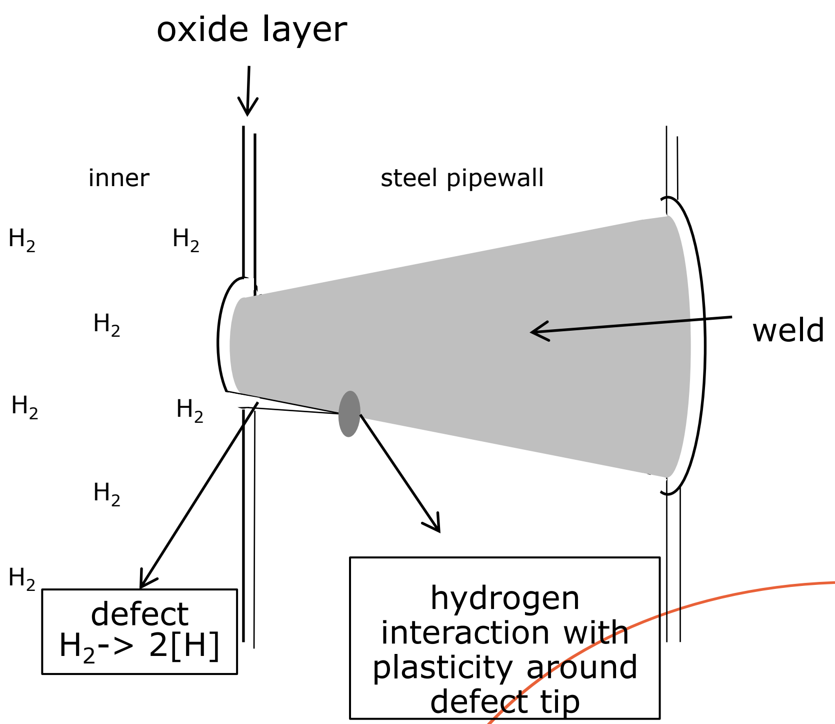


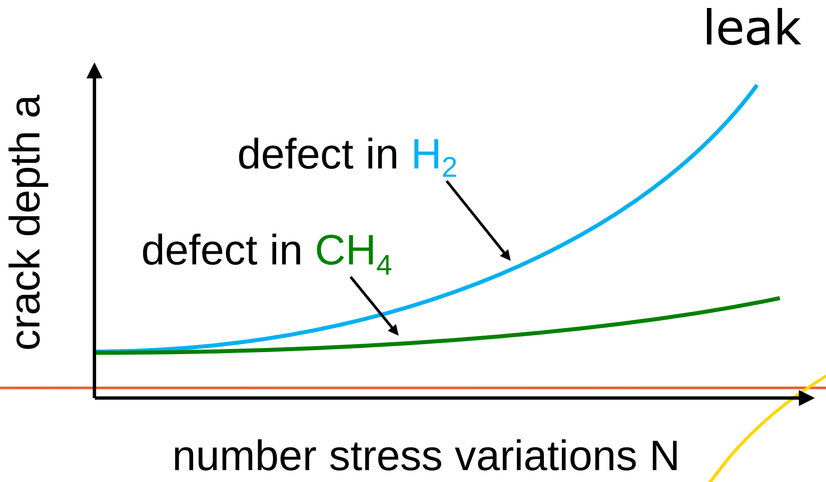
compact tension specimen

crack driving force $\Delta K = \Delta\sigma\sqrt{\pi a}$

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

Scenario for hydrogen-enhanced fatigue crack growth





girth weld of pipeline with inner weld defect

The approach for dealing with hydrogen-enhanced fatigue of existing natural gas pipelines

	description	example
1	choice of a assumed crack-like defect in the pipeline	weld defect typically: 3 mm high and 50 mm long
2	the stress intensity factor ΔK of the assumed defect (“crack force”)	see next slide
3	the fatigue load (stress range and number of cycles)	daily pressure variation of 10% of internal pressure
4	the required lifetime of the pipeline	100 year
5	the fatigue crack growth rate at ΔK of the assumed defect in H_2 gas	see next slide
6	the lifetime of the assumed defect	see next slide

Step 2 & 3 crack force ΔK and stress range Δσ assumed defect is 3 by 50 mm in longitudinal pipe weld or girth weld in 14,1 mm, 48”, 66 bar

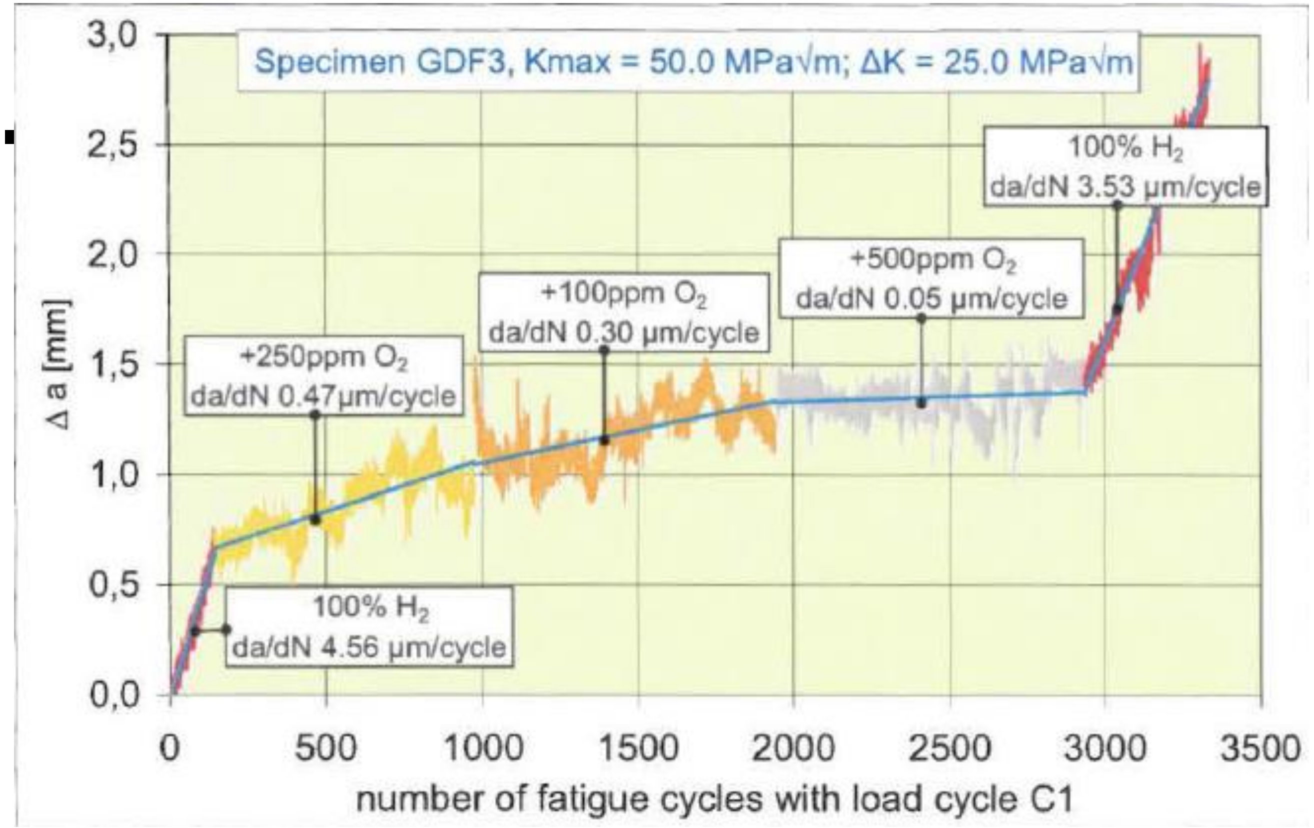
pressure cycle		crack orientation in weld	stress [MPa]	stress range Δσ [MPa]	crack force variation ΔK [MPa√m]
[%]	[bar]				
10	6,6	longitudinal	292	29	**3,4**
		girth	150	15	**1,7**

Step 5 & 6 ΔK of the assumed defect in H_2 gas and the crack growth over 100 year

pressure cycle [bar]	crack orientation in weld	crack force variation ΔK [MPa√m]	crack growth rate [mm/cycle]	crack growth 100 year [mm]
6,6	longitudinal	3,4	$6{,}1.10^{-7}$	0,022
6,6	girth	1,7	$3{,}0.10^{-8}$	0,001

Crack growth is so small over a period of 100 year,
100% H_2 at 66 bar does not impose an integrity risk.

Fatigue crack growth in the presence with O_2



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

Conclusion (1/3)

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.

But ....

Conclusion (2/3)

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 (3/3)

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

- 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?
- is welding on a live pipeline possible?

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**