Hydrogen Effects on Materials for CNG / H_2 Blends

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Issue: Can existing CNG on-board storage tanks be used for HCNG?

- **What are considerations for**
  - Type 1, 2, 3, 4 tanks?
  - 20% H_2 and less?
  - higher than 20% H_2?
- **Type 3 and Type 4 are likely fine**
  - Comments from manufacturers
- **Concern is primarily for steel Type 1 and Type 2 tanks**
  - Commonly designed and manufactured according to NGV-2 and ISO 9809-1

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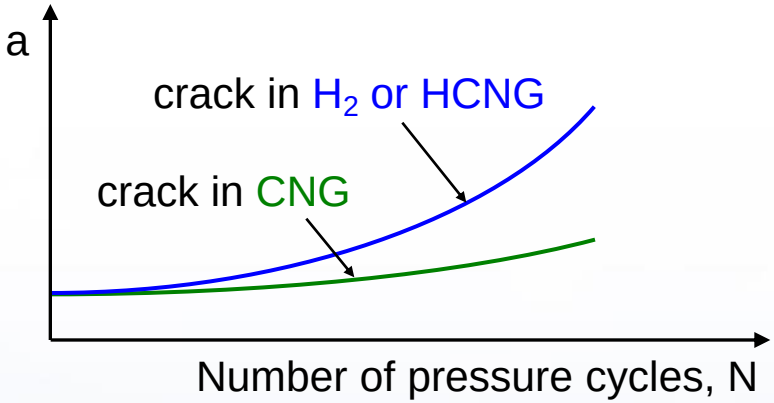
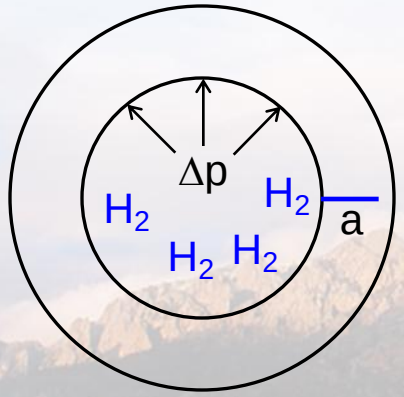
What is the concern for steel HCNG storage tanks?

H_2-assisted fatigue cracking





H_2 cylinder

Barthélémy, 1st ESSHS, 2006

No concerns for HCNG in steel storage tanks if material strength is limited

- **H_2 compatibility of Cr-Mo steel cylinders designed to ISO 9809-1 demonstrated through service experience**
  - Example: typical duty cycle for steel H_2 trailer tubes in USA
    - H_2 pressure ~20 MPa
    - pressure cycles ~2/week (50 year life)
  - Such service conditions bound the H_2 partial pressure and number of pressure cycles for steel HCNG storage tanks
  - H_2 transport cylinders must have tensile strength < 950 MPa
- **All HCNG blends expected to be compatible with steel CNG tanks provided tensile strength < 950 MPa**
- **But CNG tanks designed to ISO 9809-1 allow tensile strength up to 1100 MPa**

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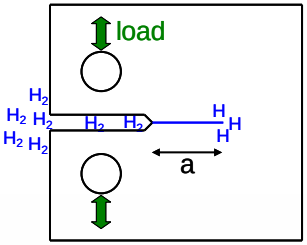
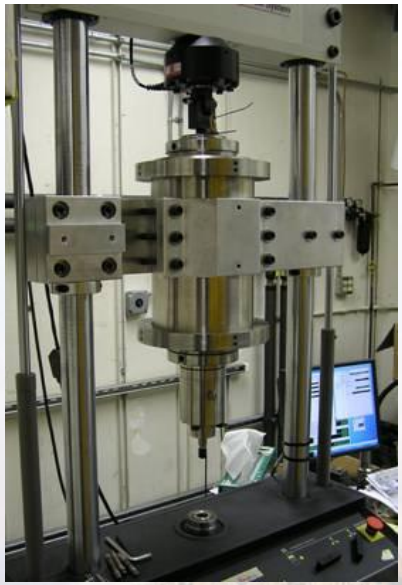
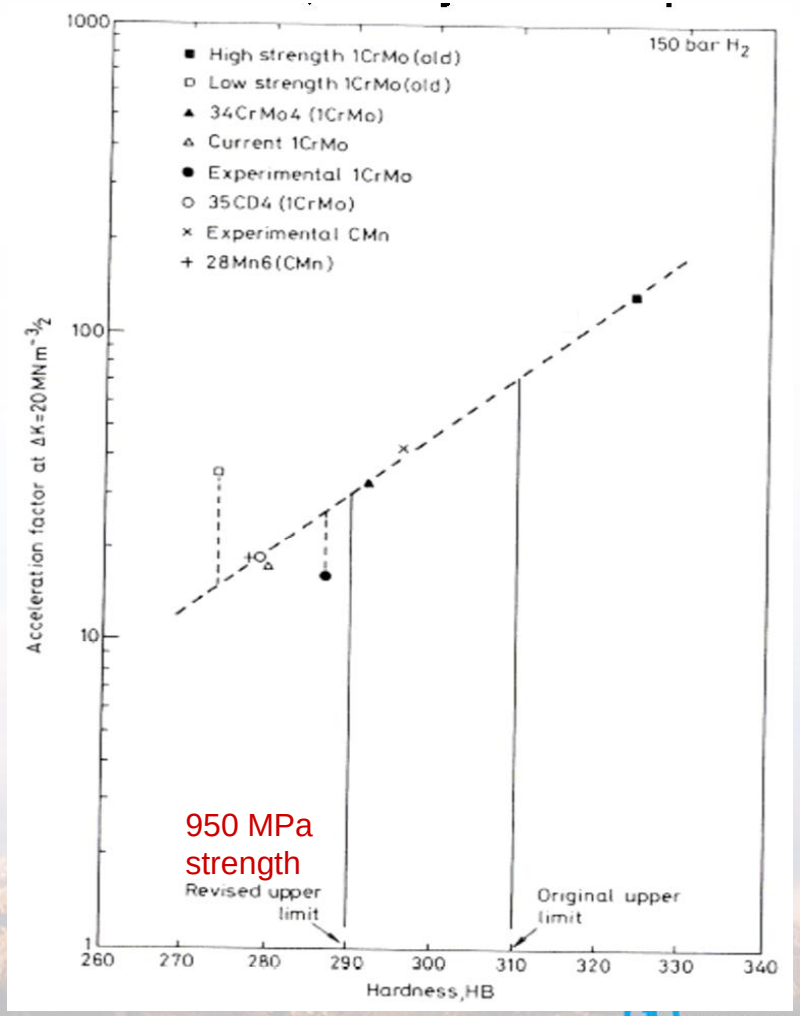
Issue: H_2-assisted fatigue cracking enhanced in higher strength steel







R. Irani, ISO/TC 58/WG 7 workshop, 2008

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ISO 11114-4 addresses H_2 compatibility of steel cylinders with strength > 950 MPa in two ways

1) Lower H_2 partial pressures

- **According to ISO 11114-4, cylinders may be designed to ISO 9809-1 (i.e., with strength up to 1100 MPa) "if at least one of the following conditions for intended gas service is fulfilled:**
  - the working pressure of the filled embrittling gas is less than 20% of the test pressure of the cylinder
  - the partial pressure of the filled embrittling gas of a gas mixture is less than 5 MPa (50 bar) in the case of hydrogen…"
- **Based on ISO 11114-4, CNG tanks are suitable for HCNG blends with <20% H_2**
- **However, guidance apparently not developed from fatigue cracking data nor service experience**

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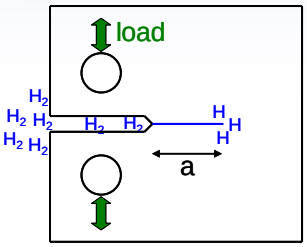
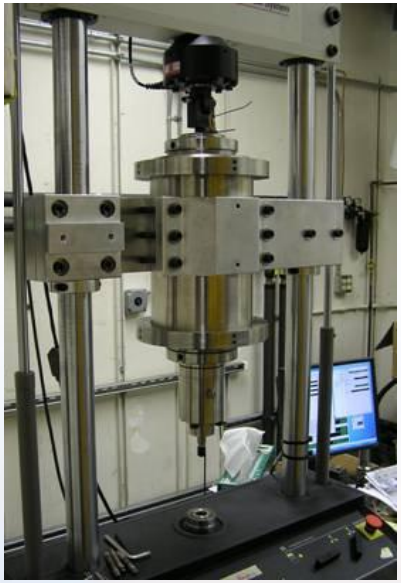
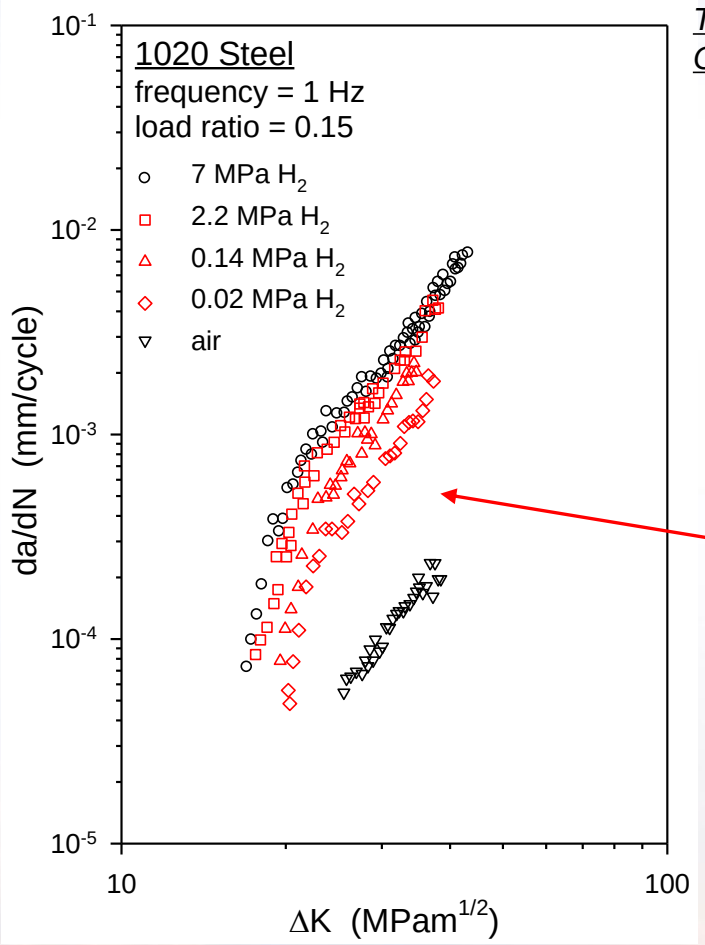
Issue: steels are susceptible to H_2-assisted fatigue cracking at low H_2 pressures







Technical Reference on Hydrogen Compatibility of Materials, Sandia, 2008

Fatigue cracking rates in H_2 pressure < 5 MPa can be notably higher than rates in air

- **Recommend evaluating H_2-assisted fatigue cracking in higher strength steels at low H_2 pressure**

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ISO 11114-4 addresses H_2 compatibility of steel cylinders with strength > 950 MPa in two ways

2) Higher H_2 partial pressures

- **ISO 11114-4 specifies that steels with strength >950 MPa can be qualified based on materials testing in H_2 gas**
- **Evolving ISO 11114-4 currently specifies 3 tests:**
  - Method A (disc rupture test)
  - Method B (crack propagation threshold test under step loading)
  - Method C (crack propagation threshold test under static load)
- **Based on ISO 11114-4, CNG tanks suitable for HCNG blends with >20% H_2 if steel passes qualification test**
- **However, qualification tests do not directly evaluate H_2-assisted fatigue cracking**
- **Recommend evaluating H_2-assisted fatigue cracking in higher strength steels at H_2 partial pressure in blend**

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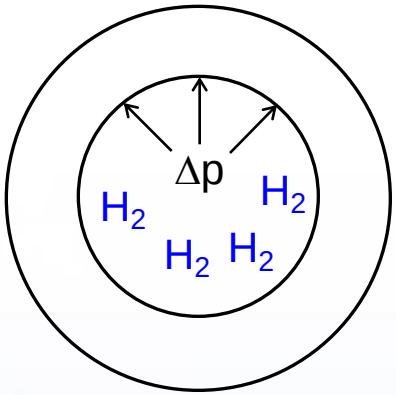
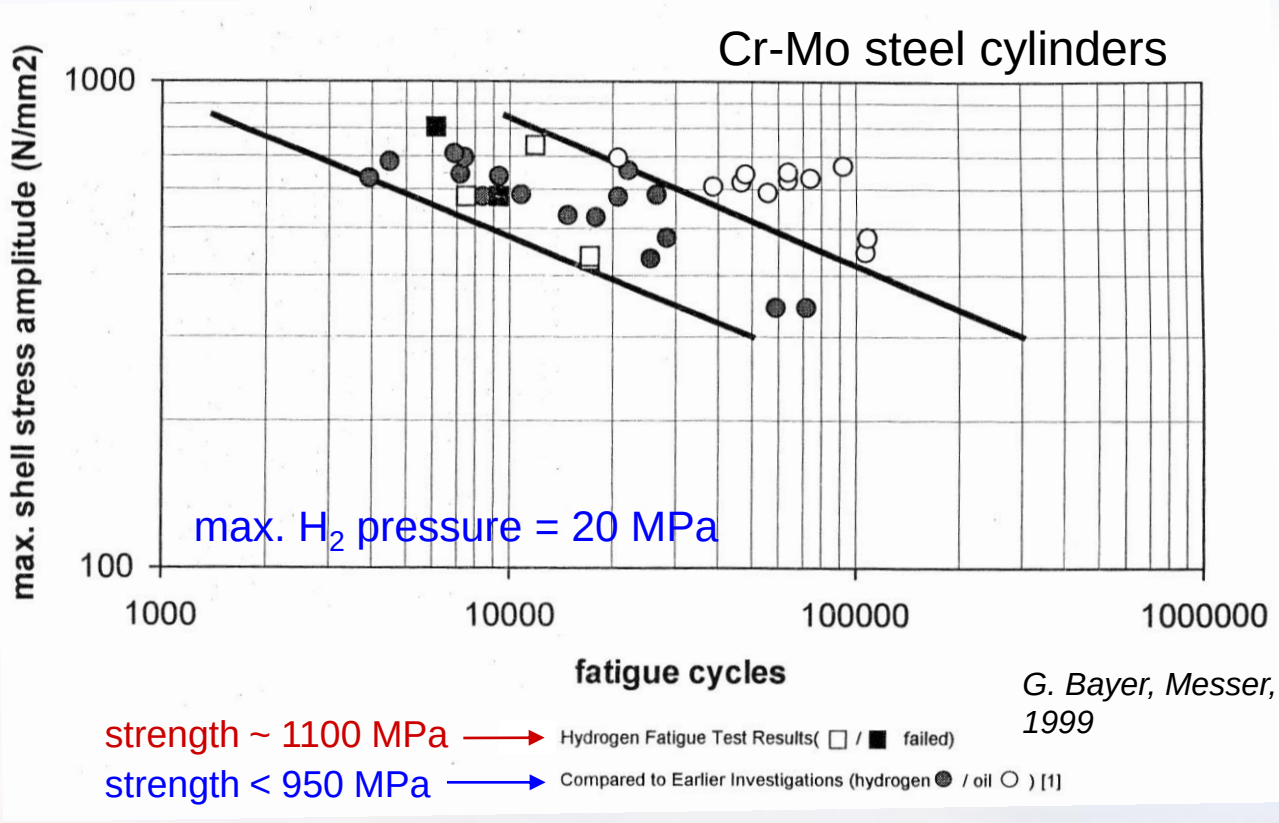
Limited H_2-assisted fatigue cracking data for higher strength steel cylinders are promising



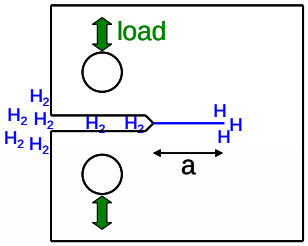


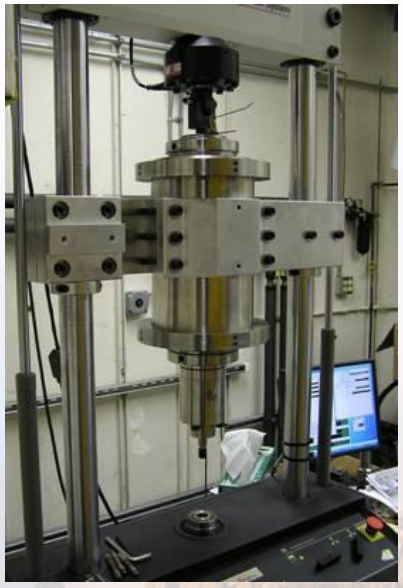
G. Bayer, Messer, 1999

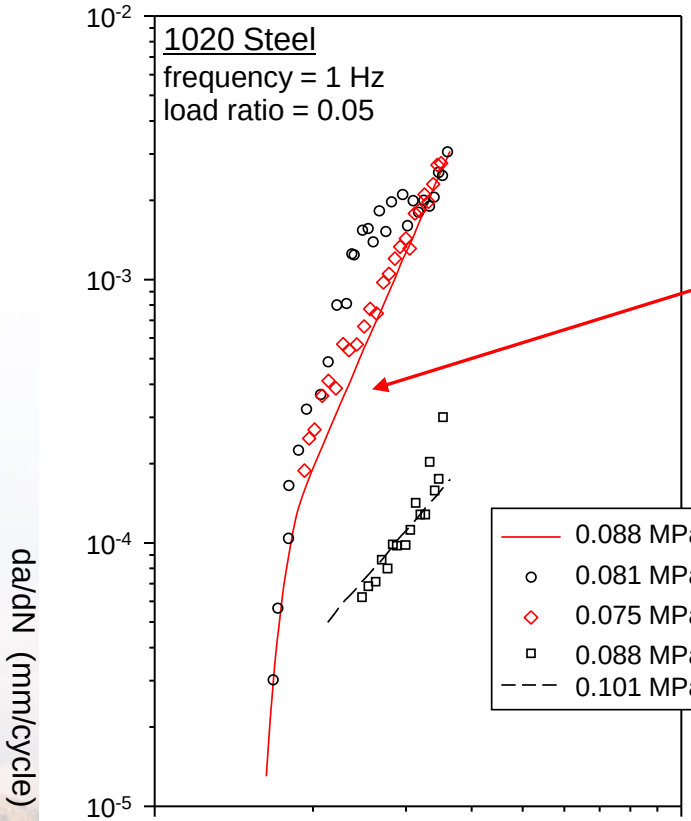
- **Higher strength cylinders with 400 MPa wall stress did not exhibit cracking in H_2 after 17,000 cycles**

Issue: Does CNG modify H_2-assisted fatigue cracking of steels in gas blends?

Some data show H_2-assisted fatigue cracking same in HCNG and H_2 …





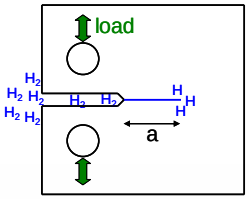


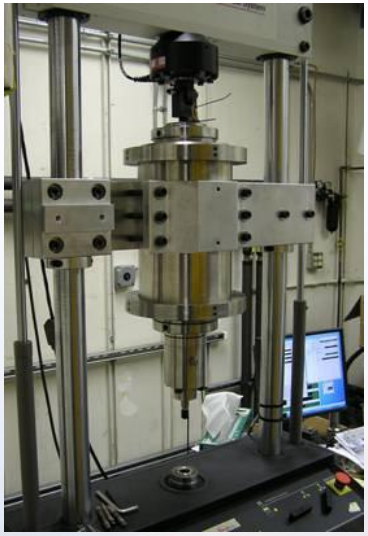
H_2-assisted fatigue cracking rates in HCNG blend same as rates in pure H_2

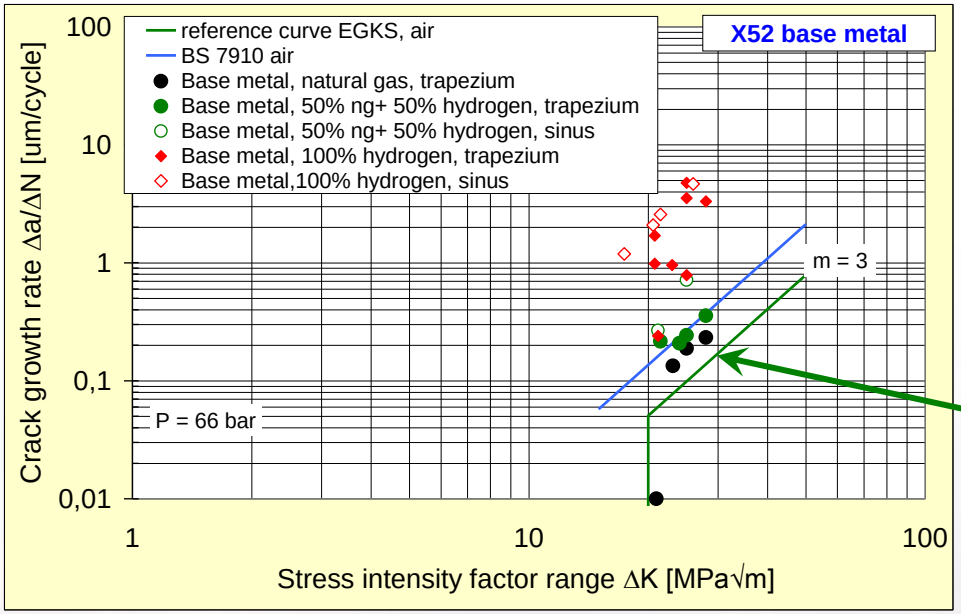
Technical Reference on Hydrogen Compatibility of Materials, Sandia, 2008

Issue: Does CNG modify H_2-assisted fatigue cracking of steels in gas blends?

… but other data show lower cracking rates in HCNG compared to H_2







Fatigue cracking rates in HCNG notably less than rates in pure H_2

I. Alliat, NATURALHY EC project, 2007

- **Why are fatigue cracking data for HCNG blends not consistent?**

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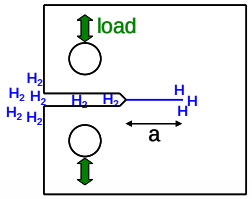
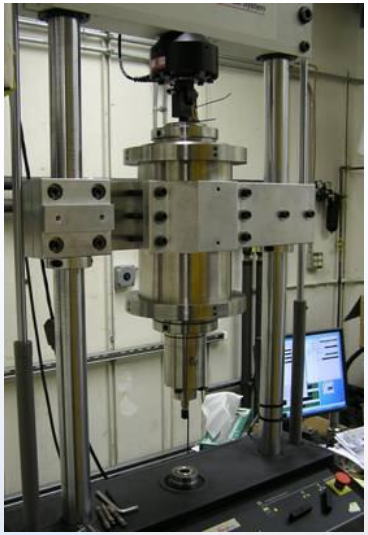
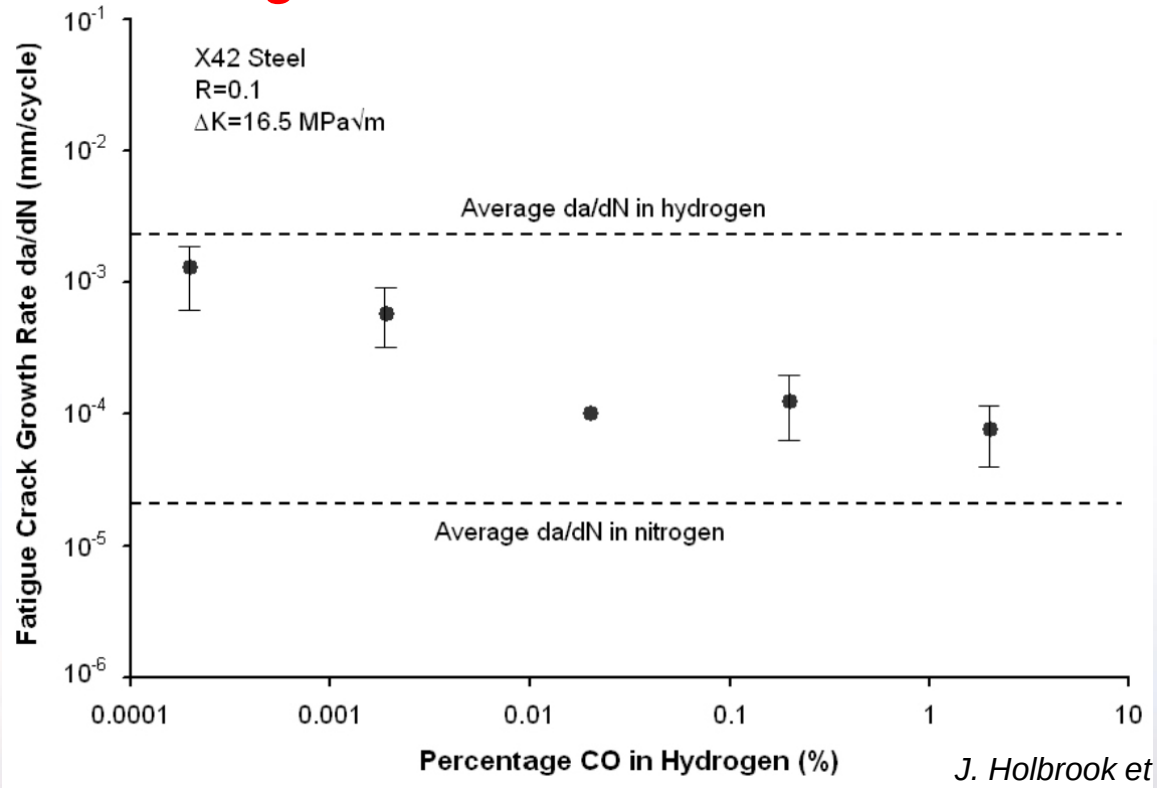
Constituents in CNG can inhibit H_2-assisted fatigue cracking

Gases such as O_2 and CO are known to inhibit H_2-assisted cracking







J. Holbrook et al., BNL report, 1986

- **Can CNG constituent such as CO ensure resistance to H_2-assisted fatigue cracking?**

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Summary

- **No concerns for HCNG in steel storage tanks if material strength is < 950 MPa**
- **Recommend evaluating H_2-assisted fatigue cracking in higher strength steels at H_2 partial pressure in blend**
  - Limited fatigue testing on higher strength steel cylinders in H_2 shows promising results
- **Impurities in CNG (e.g., CO) may provide extrinsic mechanism for mitigating H_2-assisted fatigue cracking in steel tanks**

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