



Fatigue life testing in gaseous hydrogen: crack initiation

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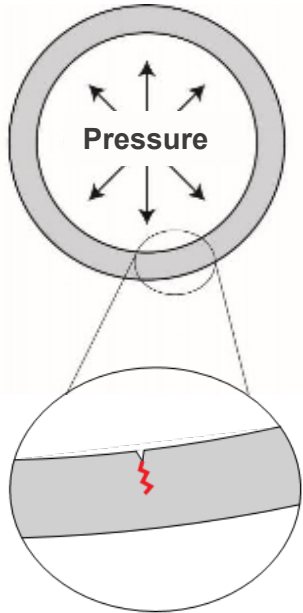
Bellevue, WA

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Motivation

Fatigue life = Crack initiation + Crack propagation + Fracture



Crack initiation often accounts for a significant part of the fatigue life, **but it is harder to assess and predict**

- Scatter in data
- Difficult to characterize
- Microstructure-dependent

➤ **How does H affect crack initiation?**



Study case – recently in ...

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Effects of hydrogen partial pressure on crack initiation and growth rate in vintage X52 steel

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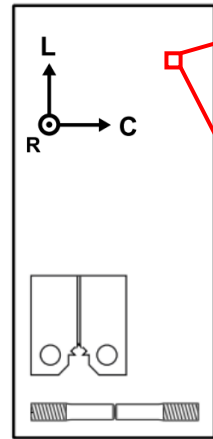
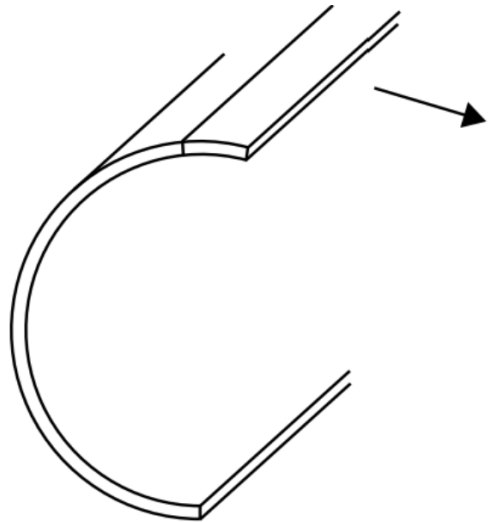
- Effects of hydrogen partial pressure
- Vintage pipeline steels



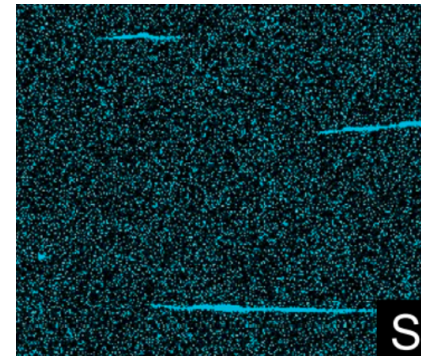
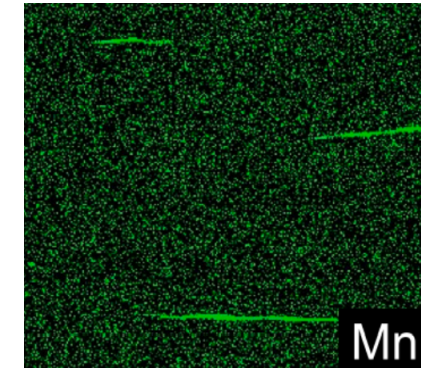
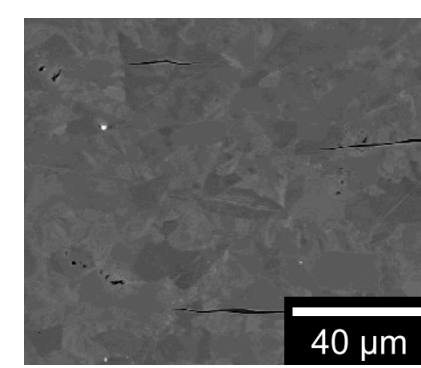
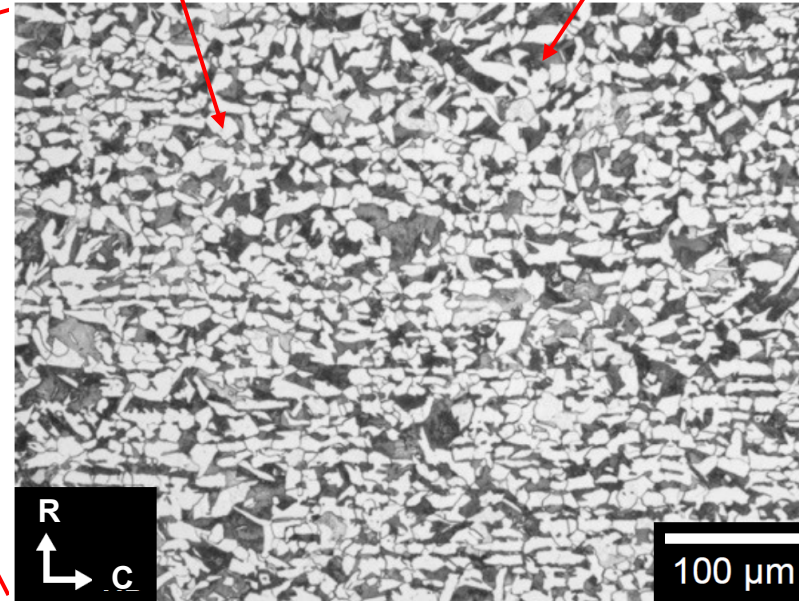
Material – Vintage (1962) X52 steel

Composition

Fe	C	Mn	Si	S	P
bal.	0.29	1.17	0.02	0.016	0.016



α - ferrite (white) Pearlite (grey)



NG pipeline

- Diameter: 0.91 m
- Thickness: 10.3 mm

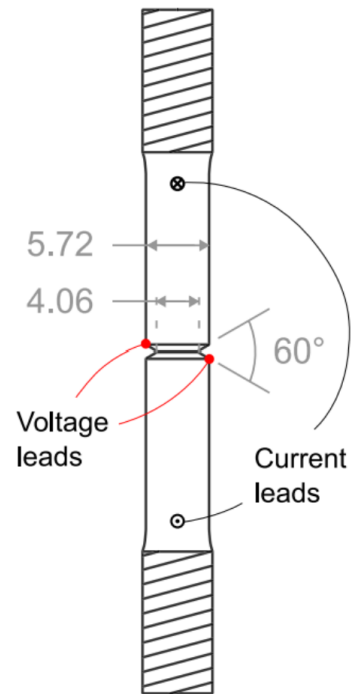
Microstructure

- Bands of ferrite + pearlite
- MnS inclusions

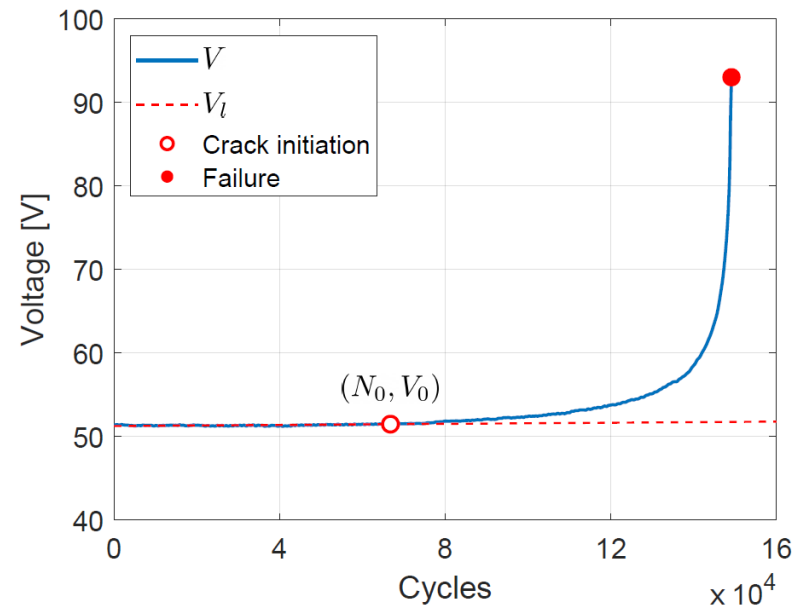


Test parameters

- Two test geometries:
 - **Circumferential notch tension (CNT)** → Crack initiation and failure



Direct Current Potential Difference (DCPD)



Automated approach to estimate the point of crack initiation by maximizing a gain function G

$$G = \sum_i G_i$$

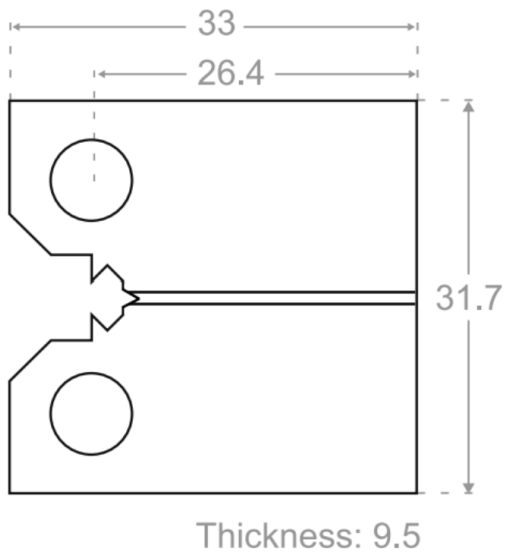
$$G_i = \begin{cases} 1 - \frac{|V_i - V_{l,i}|}{V_{co}} & , |V_i - V_{l,i}| < V_{co} \\ 0 & , |V_i - V_{l,i}| \geq V_{co} \end{cases}$$



Test parameters

- Two test geometries:
 - Circumferential notch tension (CNT) → Crack initiation and failure
 - **Compact tension (CT)** → Crack growth rate

Standard ASTM E647



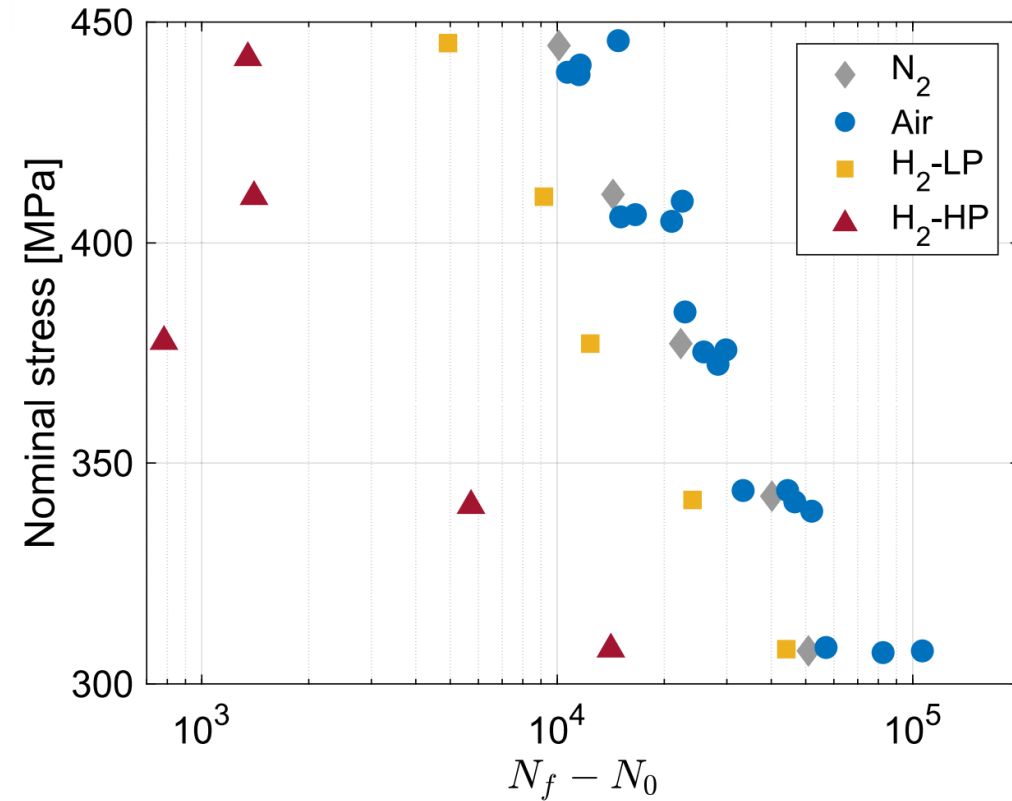
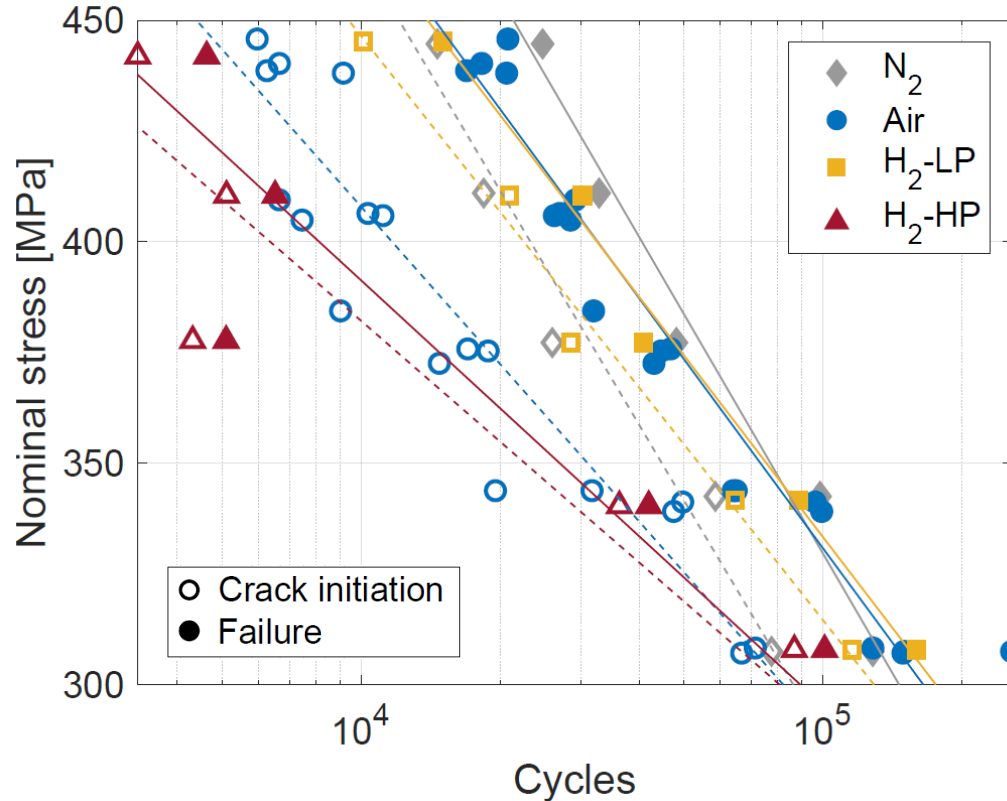


Test parameters

- Two test geometries:
 - Circumferential notch tension (CNT) → Crack initiation and failure
 - Compact tension (CT) → Crack growth rate
- Four atmospheres:
 - N_2 34 bar → Baseline
 - **Air** → Effects of O_2 and moisture
 - **H_2 -LP** N_2 -3% H_2 at 34 bar → Low H partial pressure (1 bar)
 - **H_2 -HP** H_2 at 207 bar → High H partial pressure (207 bar)
- Frequency of 1 Hz
- Loading ratio of $R = 0.1$



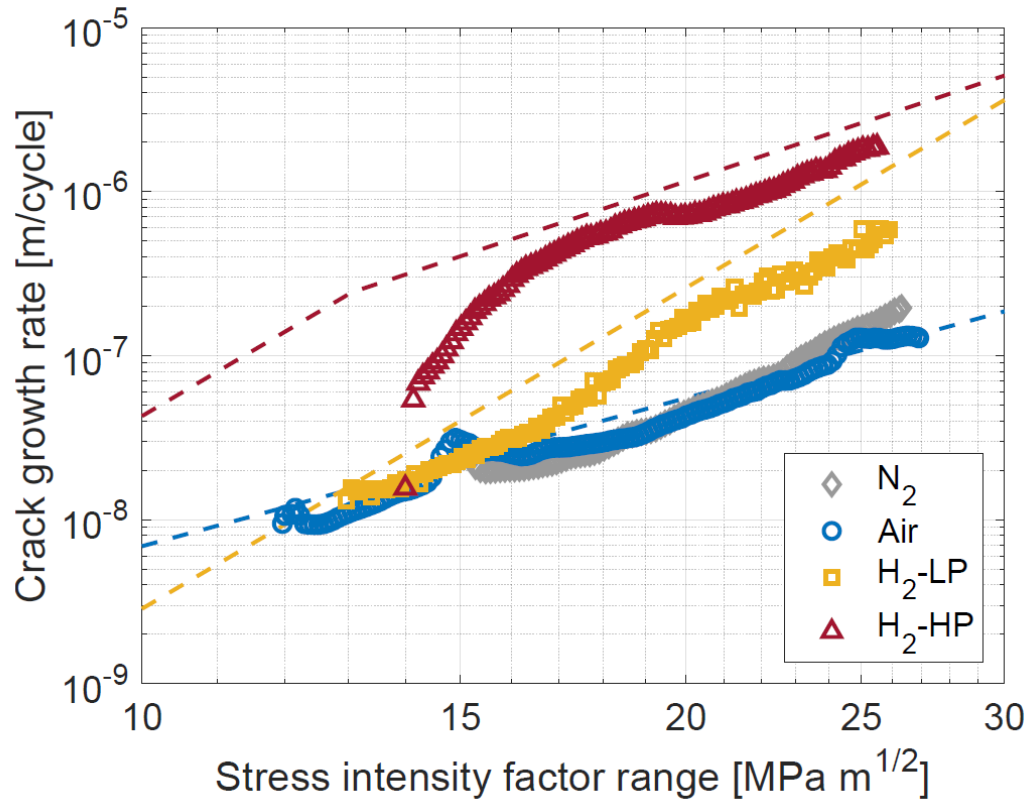
CNT results



- Trends:**
- **Air** accelerates crack initiation.
 - **H_2 -LP** accelerates crack growth rate.
 - **H_2 -HP** accelerates both.



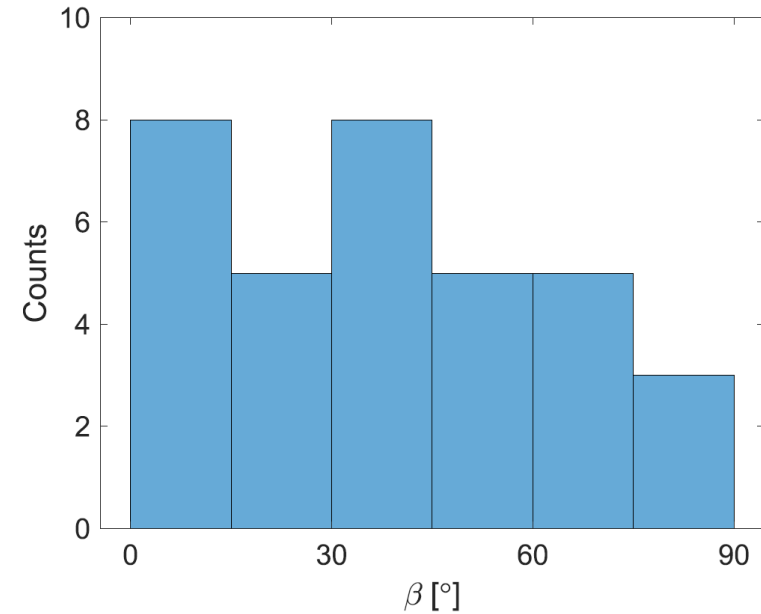
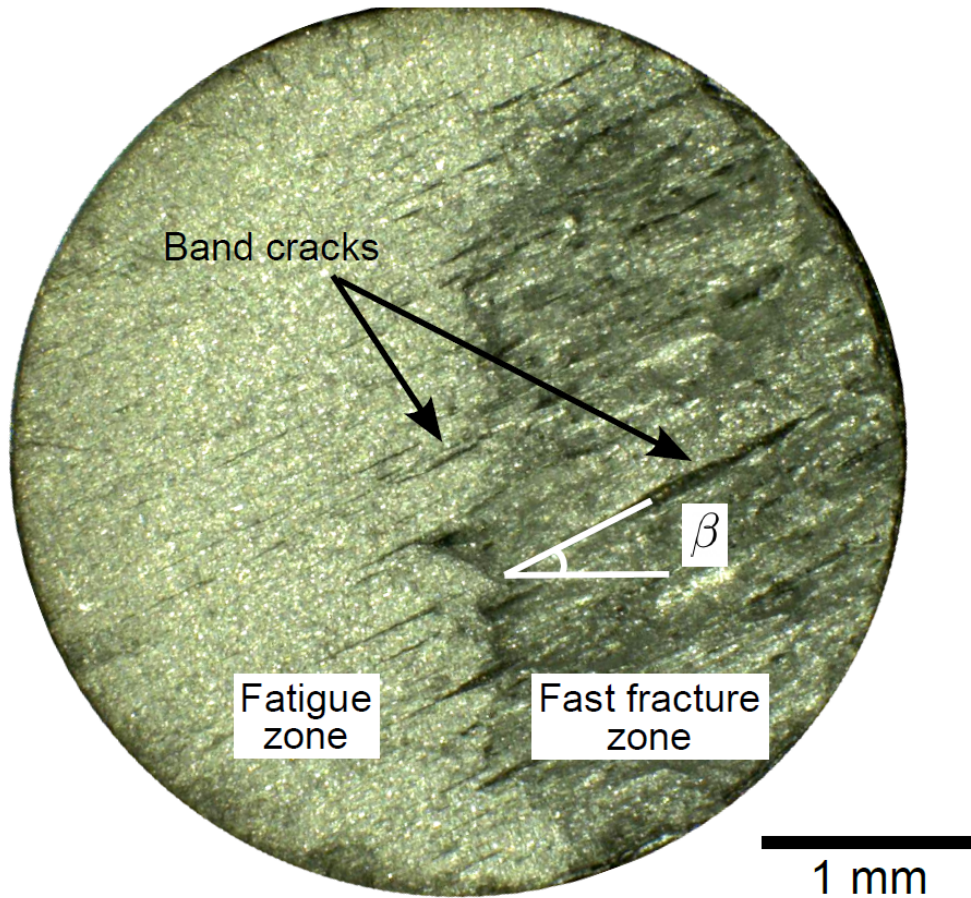
CT results



- N_2 and air curves match
- H_2 tests accelerate crack growth rates at large stress intensity factor ranges ΔK .
- Faster crack growth rates develop for larger pressures.
- ❖ The dashed lines represent design curves:
 - API 579-1/ASME Fitness-For-Service-1 (air)
 - ASME Code Case 2938 with pressure-compensation (H_2)



Crack initiation and evolution



- Crack initiation appears to be independent of microstructural band orientation.
- Crack initiation may originate near MnS inclusions.



Conclusions

- H effects on crack initiation differ from those on crack propagation.
- Low H partial pressure (1 bar) has a negligible effect on crack initiation, but it accelerates crack growth rate.
- Damage in low H partial pressures may be small enough for the repurposing of vintage pipelines for use with H blends.



Discussion points

- Is there a need for fatigue life S-N curves?
- Smooth vs. notched specimens
- What is needed to incorporate crack initiation into codes and standards?
 - Standard geometry (e.g. smooth, CNT, transverse circular hole)
 - Standard loading parameters ($R = -1$)
 - Higher testing throughput
 - Better predictions of short crack growth rate behavior
- What is the role of component defects? E.g. dents, scratches, etc.

Thanks!

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