MARUBENI ITOCHU STEEL | Marubeni-Itochu Tubulars Oceania (MITO)

MI INSIGHTS

Welcome to MI Insights

With host Christian Tedaldi

MARUBENI ITOCHU STEEL | Marubeni-Itochu Tubulars Oceania (MITO)

MARUBENI ITOCHU STEEL | Marubeni-Itochu Tubulars Oceania (MITO)

Dedicated to delivering customer solutions across resource and energy industries in Australia and New Zealand

tubestream® | pipesales

Our Product Offer

OCTG

Casing Accessories

Linepipe and Fittings

Sucker Rod

MARUBENI ITOCHU STEEL | Marubeni-Itochu Tubulars Oceania (MITO)

MI INSIGHTS

Introducing our Guest Speaker

Nick Kastelein

Lead Mechanical Engineer

GPA

"Detailing a design dilemma – Managing the effect of hydrogen on pipeline steels"

MARUBENI ITOCHU STEEL

GPA

Detailing a design dilemma

Managing the effect of hydrogen on pipeline steels

Consult
Engineer
Deliver

Ideas
Realised

Contents…

1. Changes to carbon steel properties
2. Impact on pipeline performance
3. Potential design remedies
4. Role/need for further research

Jemena's Western Sydney Green Gas Project – hydrogen pipeline risers

GPA

MARUBENI ITOCHU STEEL

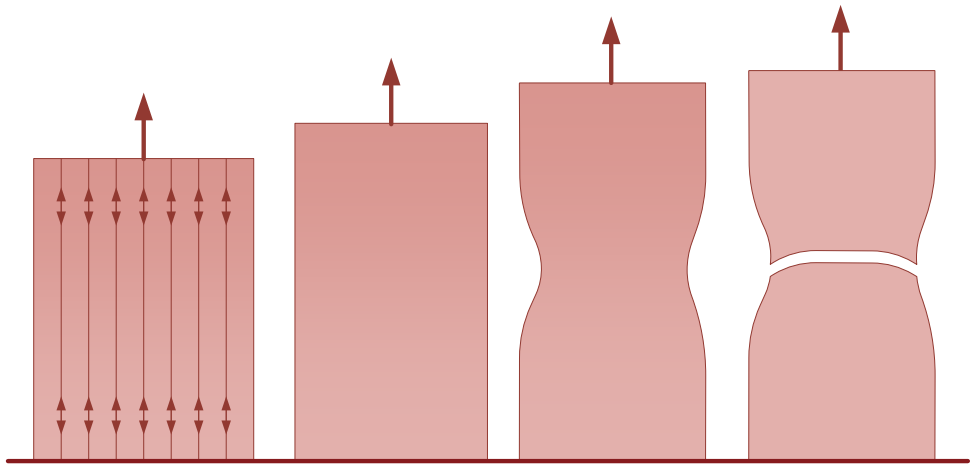
Consult
Engineer
Deliver

Ideas
Realised

Changes to carbon steel properties…

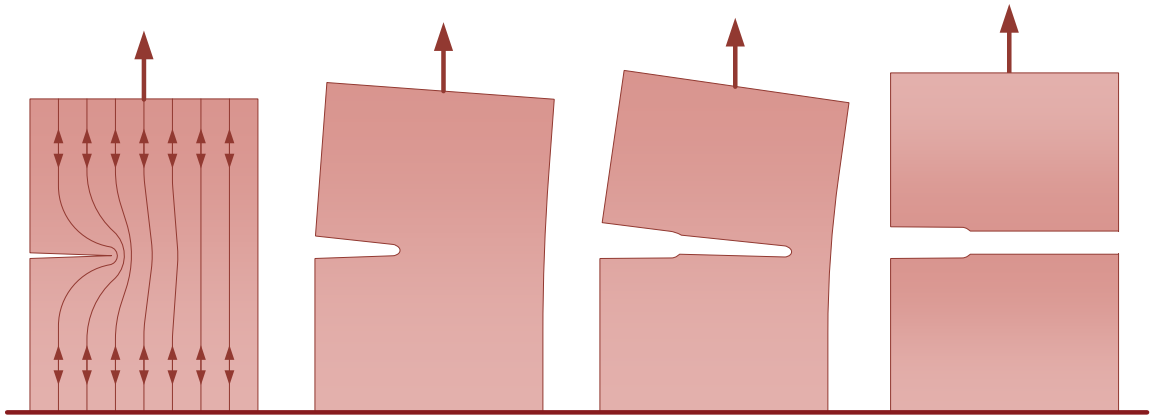
Hydrogen affects carbon-steel

A reduction in material resistance to **cracking**.



Strength

Failure due to stress in a material.



Toughness

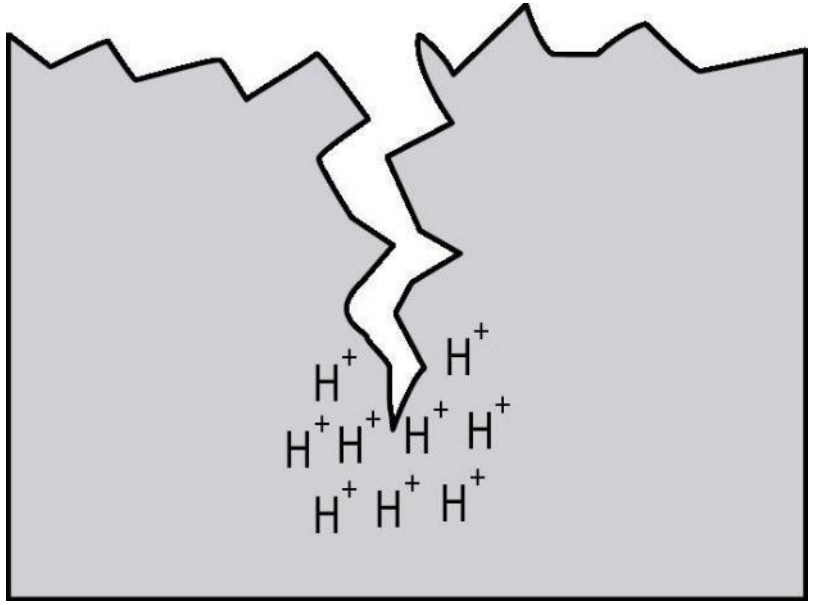
Failure where there is a **crack**.

Carbon-steel properties are altered

Three effects to discuss:

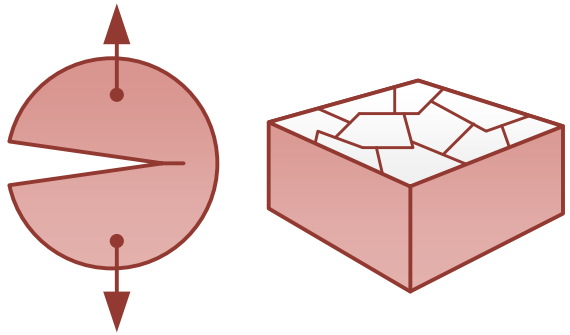
1. Toughness reduction
2. Fatigue crack growth acceleration
3. Ductility reduction

The change is not permanent after the hydrogen source is removed.



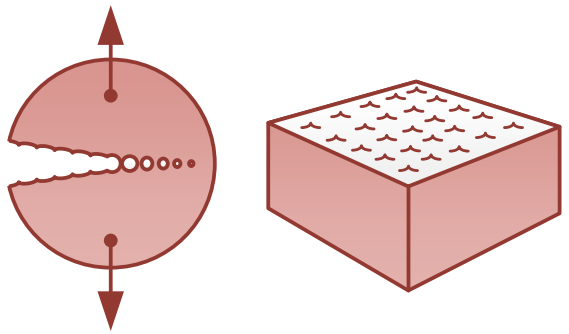
Traditional brittle vs. ductile fracture

Resistance to fracture depends on the mechanism at the crack tip:



Brittle

Low resistance

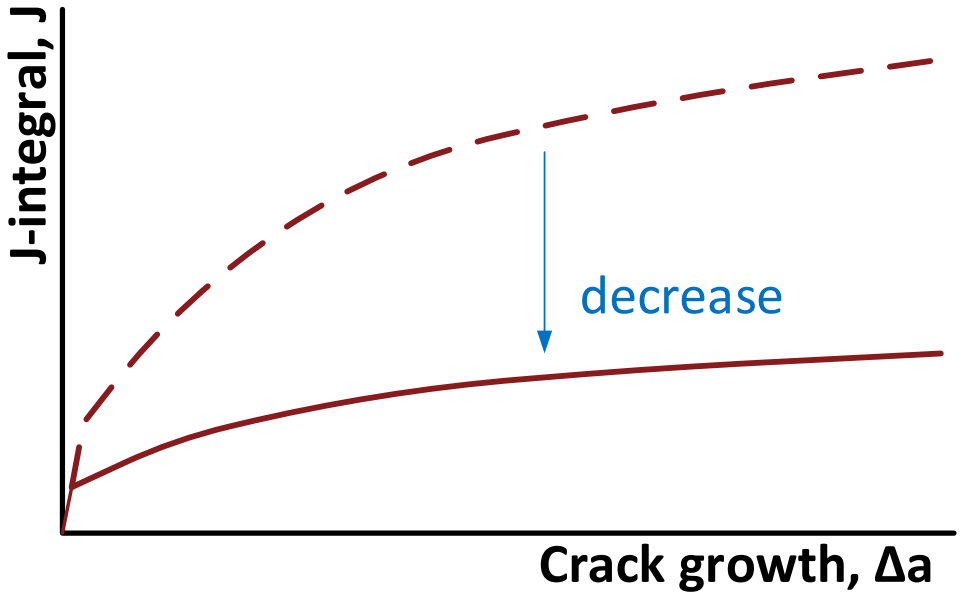


Ductile

Higher resistance

Toughness reduction – hydrogen embrittlement

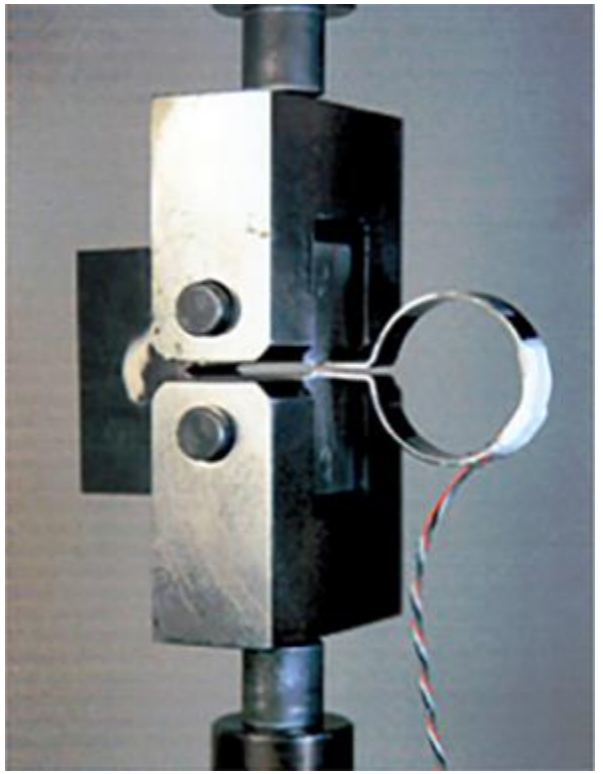
Unstable fracture:



- Resistance increases as the crack grows
- Variables that matter:
  - Hydrogen partial-pressure
  - Strain rate
  - Steel hardness / UTS
  - Microstructure
- Repeatability?
  - Hydrogen the “equalizer”
- Measurement is difficult!

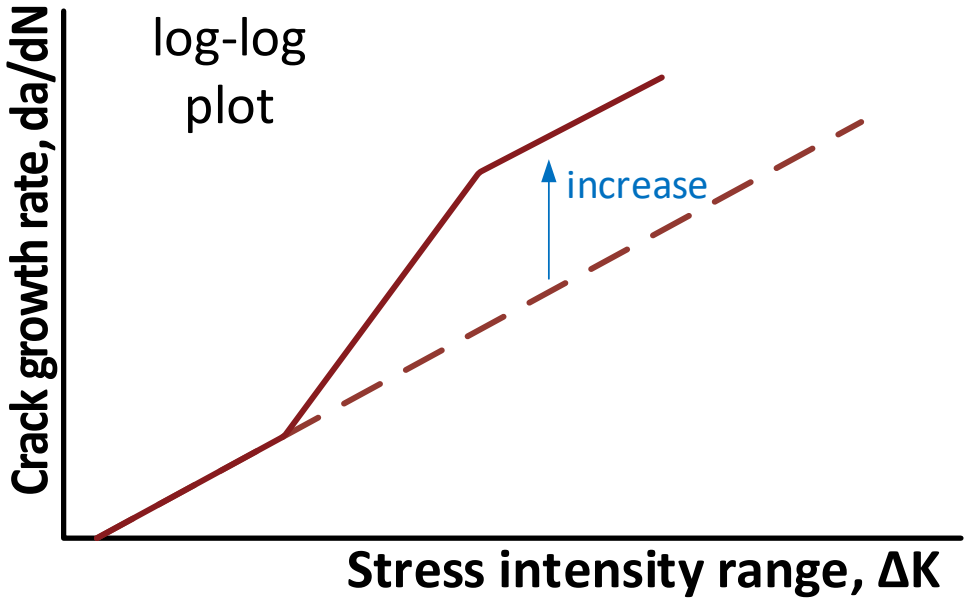
Measuring toughness in hydrogen

- Traditional: Charpy test.
  - No good in hydrogen!
- ASME B31.12 required (for Option 2) – ASTM 1681
  - Questionable relevance due to methodology.
  - Low threshold (55 $MPa(m)^{0.5}$)
- FFCRC Code of Practice recommended – ASTM 1820
  - Difficult test to conduct
  - Complexity for interpretation



Hydrogen-assisted fatigue crack growth (HA-FCG)

Fatigue crack growth:

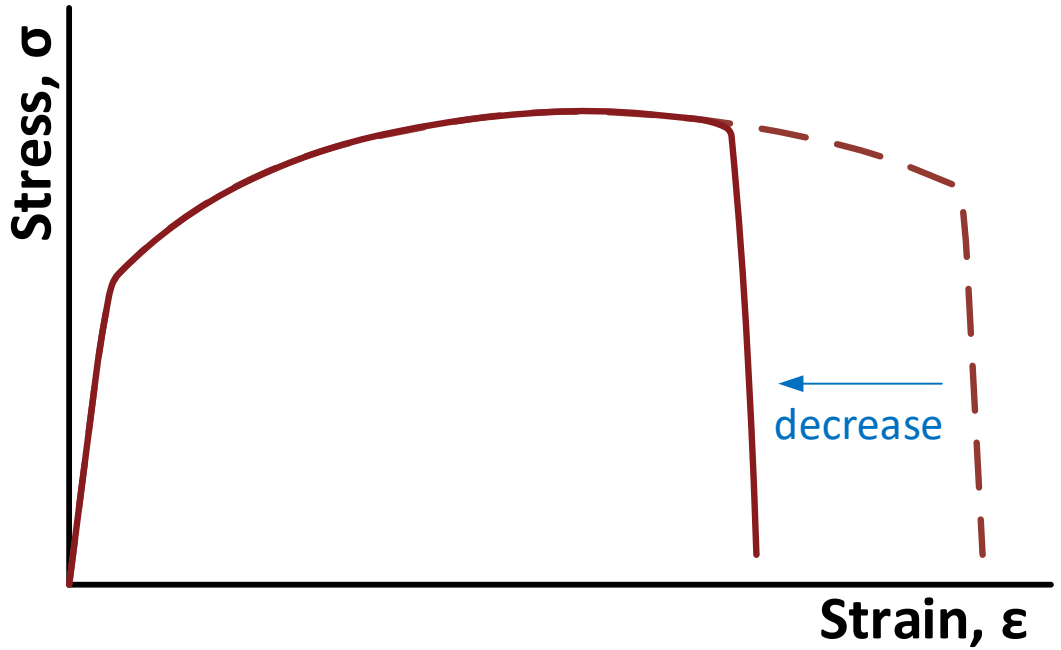


Elements:

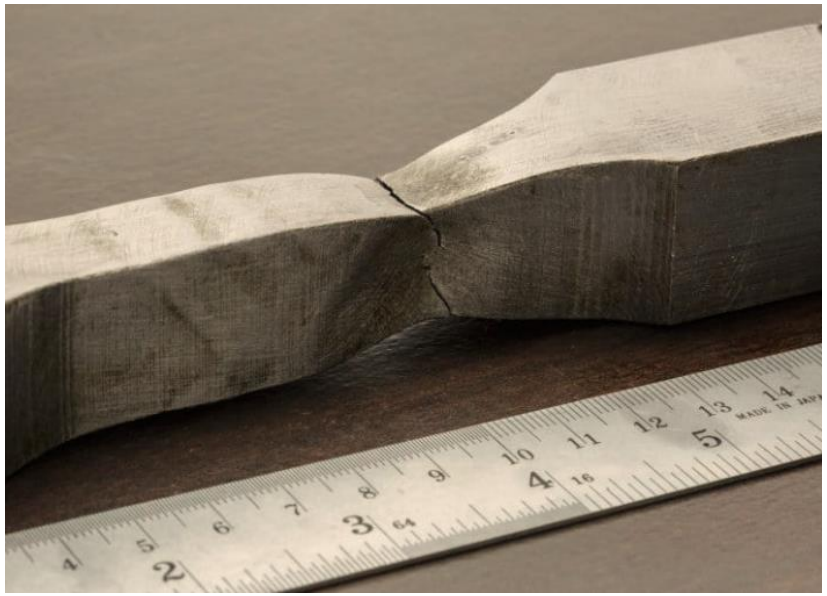
- Formation of new cracks at a surface.
- Growth of existing cracks.
  - Fatigue acceleration, called HA-FCG
  - Experimentally repeatable ✓
  - Prominent model: ASME CC220
- Variables that matter:
  - Hydrogen partial-pressure (minor)
  - Cycling ratio / mean stress

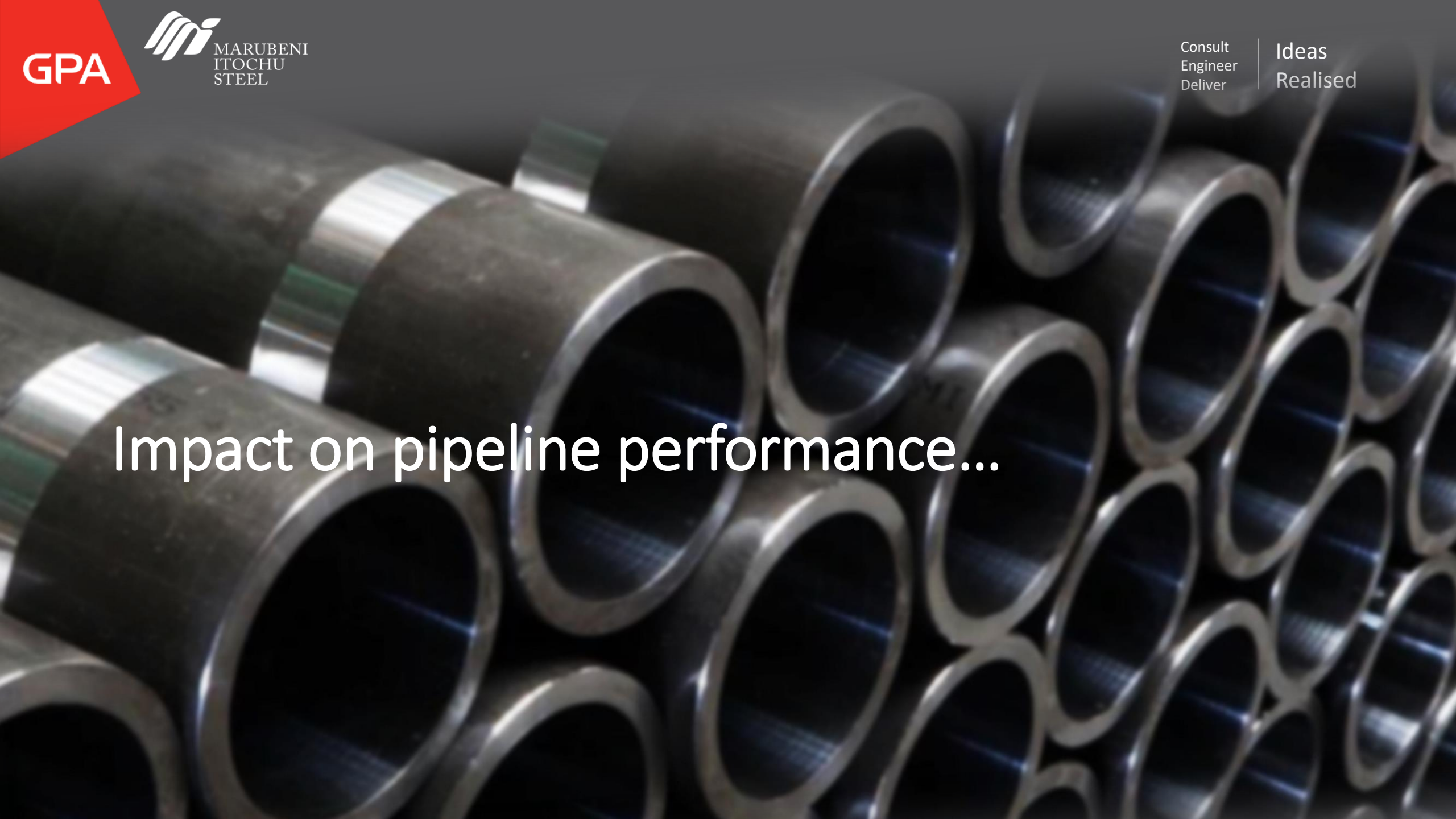
Loss of ductility

Ductility reduction



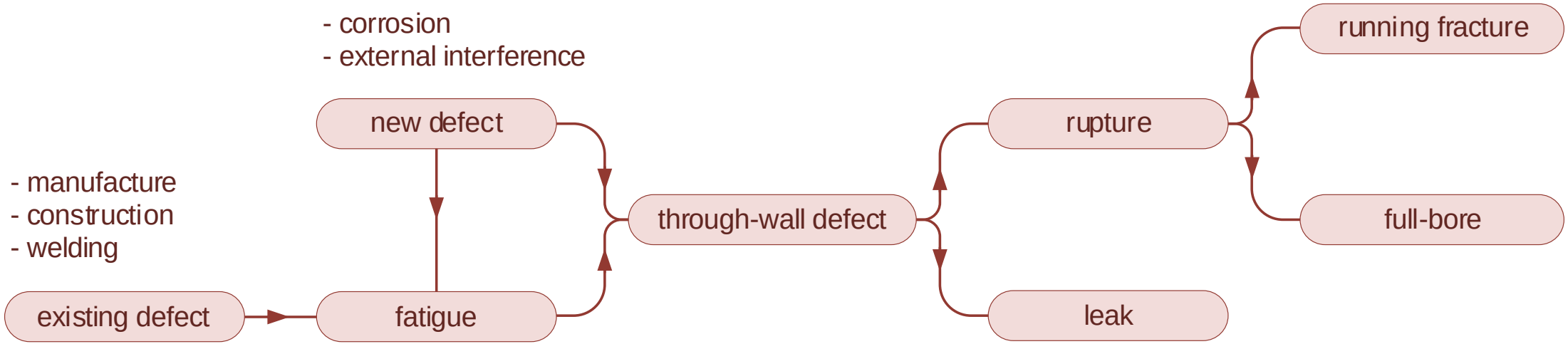
› Above the ultimate tensile stress, failure in hydrogen occurs at a lower total strain.




GPA
MARUBENI
ITOCHU
STEEL
Consult
Engineer
Deliver
Ideas
Realised
Impact on pipeline performance…

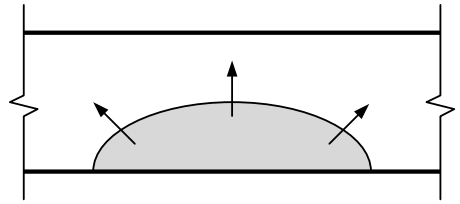
Fractures dominate failure

Traditional pipeline designs *rely* on toughness in several scenarios…



Part-Through-Wall defects

…when a shallow crack breaks and becomes a leak.



H_2: Critical depth is reduced!

- for *sharp* defects only (cracks)
- toughness reduces *after* hydrotest, hence no longer a “proof test”

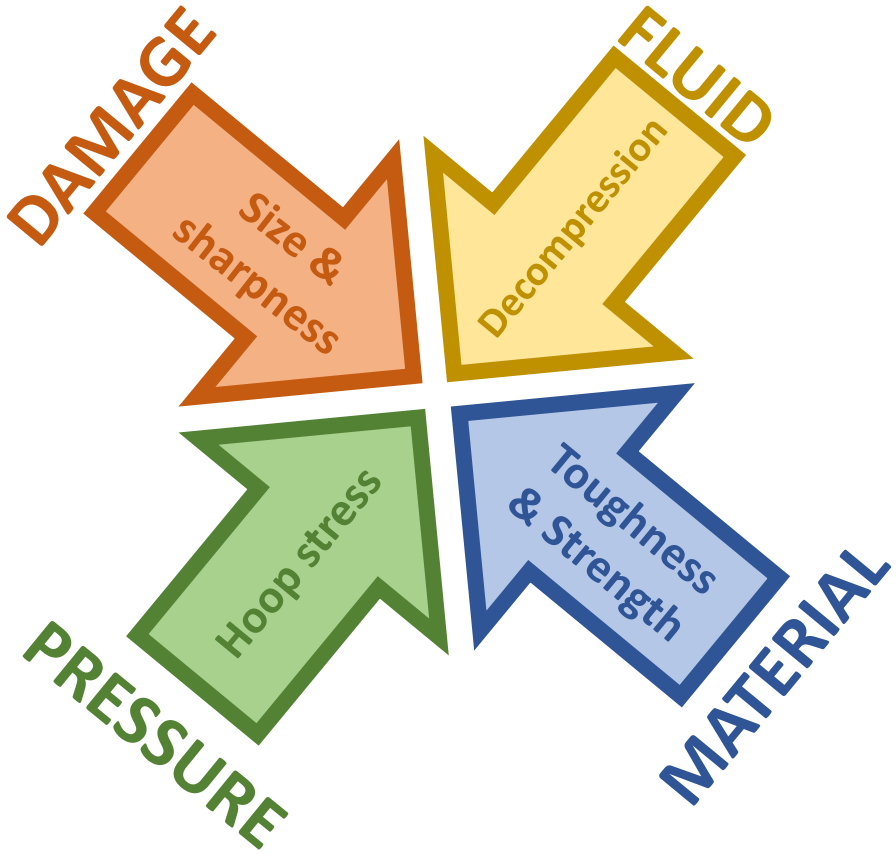
(Blunt defects can *become* sharp defects due to fatigue)

Through-Wall defects

…when a through-wall defect (leak) bursts, becoming a rupture.

H_2: Critical defect length is reduced!

- Critical for determination of *consequence* and *risk*
- High stain rate may alleviate some concern

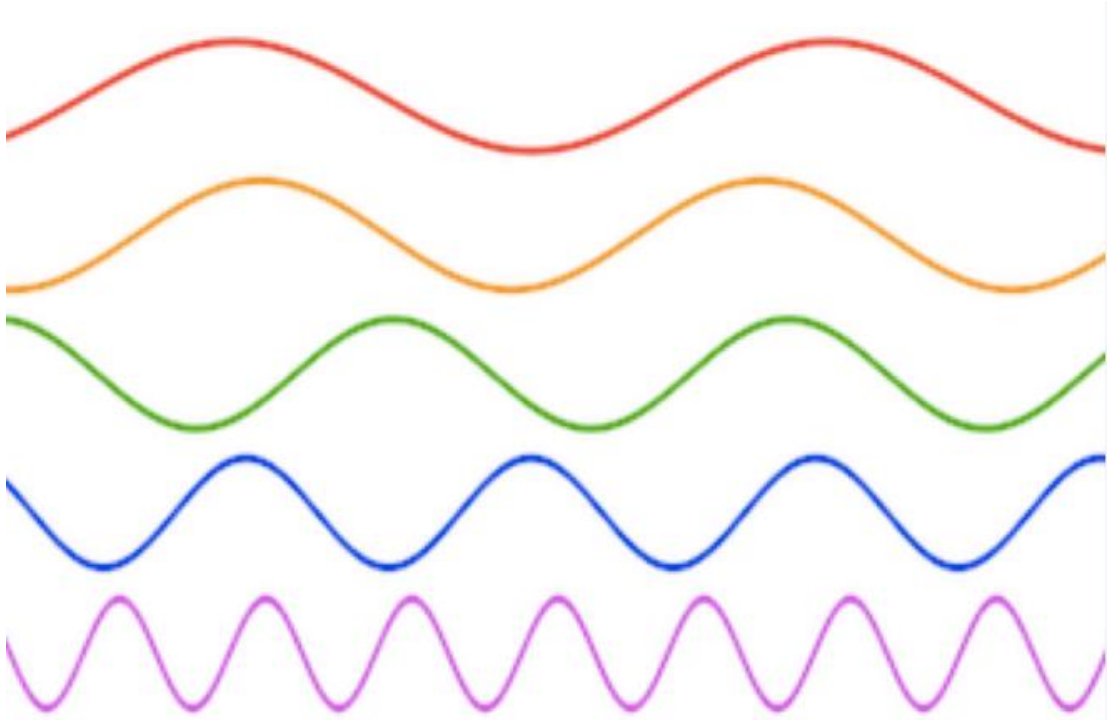


Fatigue

…when cyclic loading grows cracks to failure.

H_2: Fatigue life is reduced!

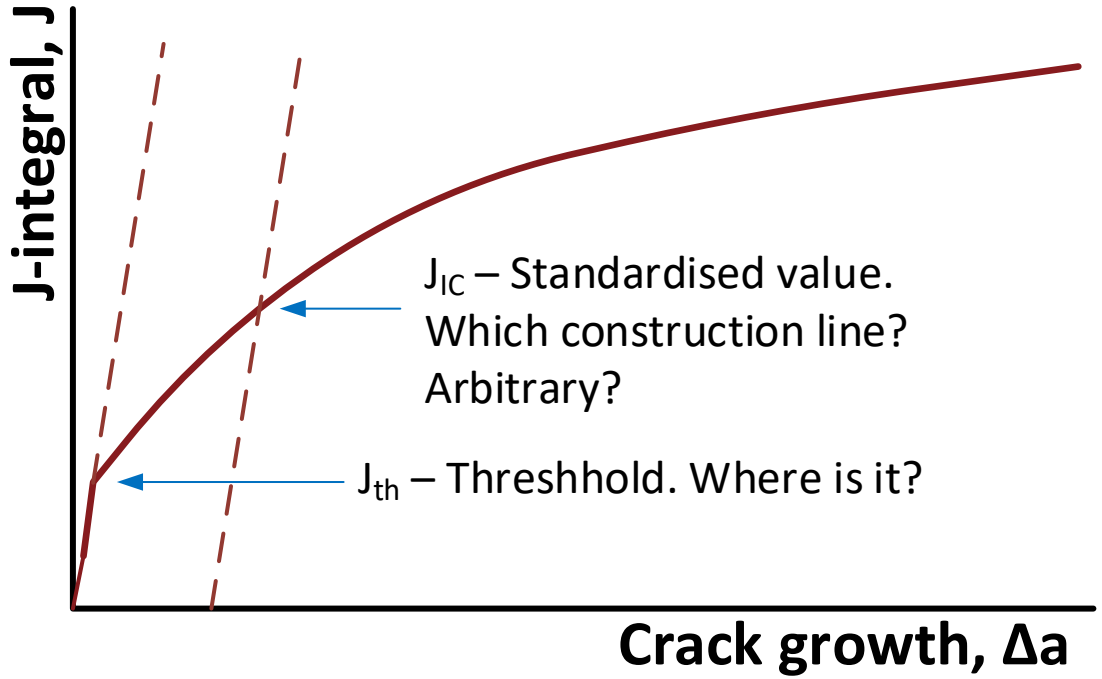
› Increased crack growth rate
› Decreased final crack depth



Fatigue life also depends on toughness

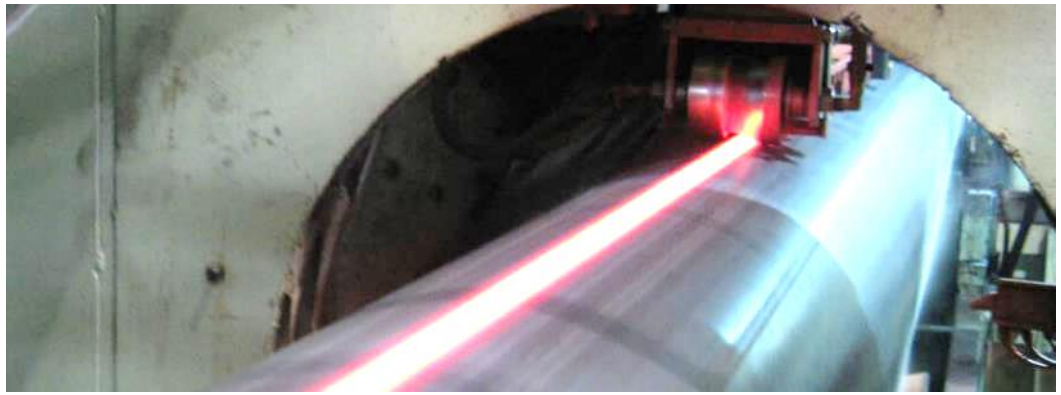
Termination of fatigue growth

› The toughness that should be used to terminate fatigue analysis is contested and has a *big* impact on results.



Defects in welds

H_2: Welds are affected similarly to parent material, but



Welds have additional concerns :

<u>Relevant factors:</u>

- Range of potential defects
- Stress concentration due to geometric tolerances
- Residual stress

<u>Probably less relevant:</u>

- Lower initial toughness material prior to embrittlement
- High hardness regions

Undermatched welds

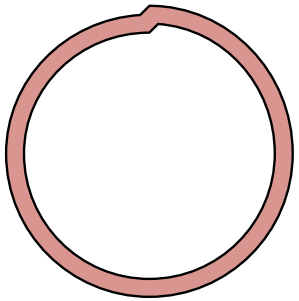
…when a weld has less net strength than the parent pipe.

Girth weld matching…

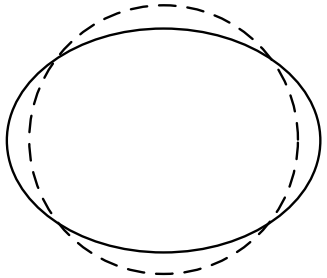
- You may think of matching as a strength issue.
- Where weld defects apply, matching is a *toughness* issue.
- **H_2:** Reduces weld toughness.

Dimensional tolerances

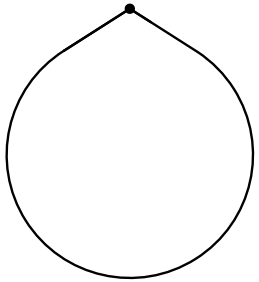
Pipeline dimensional discontinuities amplify stress.



Missalignment
Tension on the convex geometry

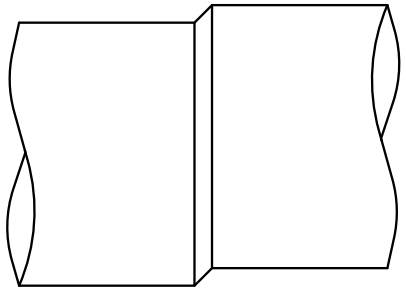


Ovality
Pressure makes the pipe circular

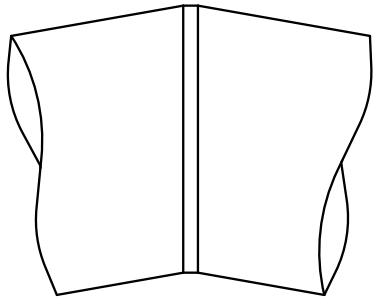


Peaking
Pressure bends the weld

Seam weld



Missalignment
Tension on the convex geometry



Ang. Missalignment
Bending at the joint

Girth weld

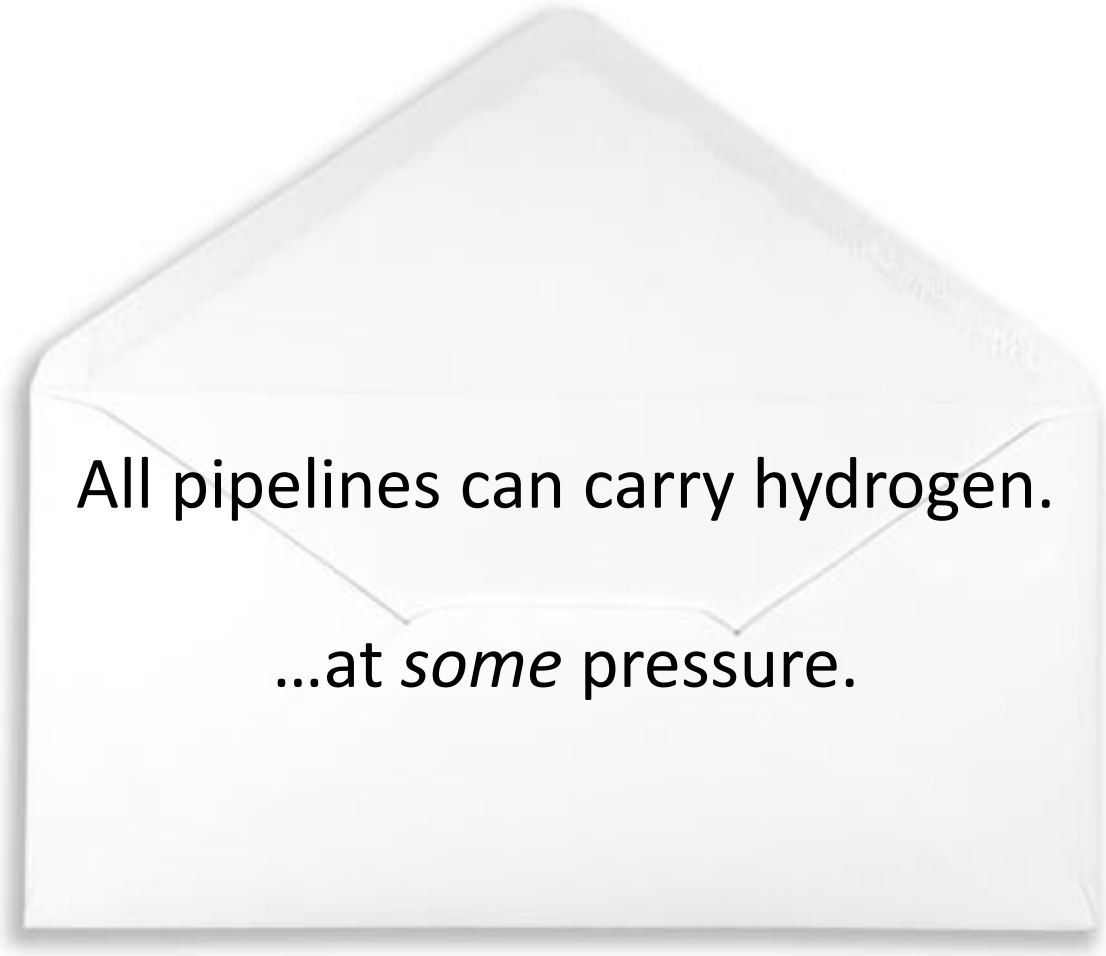
Running fracture

…when a ruptured pipeline "unzips".

- Due to high strain rate, unlikely significant impact on fracture speed (cautious consensus)
- Pure hydrogen accelerates decompression
- In blends, decompression may increase *or* decrease speed


Potential design remedies…

Defining the operating envelope



Defining the operating envelope

Maximum pressure → Hoop stress

Pressure cycling → Fatigue load

H2 fugacity (concentration) → Embrittlement severity

Temperature cycling → *Girth weld* fatigue

Know/control your loads. What is the toughness / fatigue-life *demand*.

H_2 storage pipelines face a significant hurdle.

Pipeline design

Move beyond compliance - see the big picture!

Know/control your loads. What is the toughness / fatigue-life *demand*.

Design – selection of thickness and material.

- Is ‘design factor’ relevant? Or is design fatigue-dominated
- Maximise or minimize material strength?
- Effect of hydrogen: Early estimates, later confirmation, sensitivity > risk
- Risk of failure – leak or break, location, supply criticality

H_2 storage pipelines face a significant hurdle: *fatigue-critical design*.

Material selection / specification

The steel material…

- The effect of hydrogen relates to fugacity, *unavoidable*
- Specific compositional factors not well known
- High hardness / UTS may exacerbate hydrogen vulnerability
- High-strength materials are still *unprecedented* in practice

- (Some stainless and other steel options have significantly different susceptibility)

Pipe specification

The pipe manufacture…

- Control defect size
- Tighten or bias geometric tolerances
- Remove weld toe
- Decrease residual stress, or
- Define residual stress in more detail
- Understand superposition of tolerances
- Innovate!

Opportunities for more science

Many questions are being addressed and will improve understanding over time…

- Are external and internal cracks affected the same?
- Can we forecast embrittlement without testing each material?
- Steel microstructure factors (data, data, data…)
- What is the role of restraint / orientation on fracture resistance?
- *How much* better are high strain rates?

Q&A

MARUBENI ITOCHU STEEL

Thank You

MARUBENI ITOCHU STEEL