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HYDROGEN-READY LINE PIPE

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Hydrogen-Ready?

- What does steel pipe need to be ready for?
- What is the Australian industry asking for?
- What are line pipe manufactures doing?
- What can designers specify?

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Hydrogen Already…

- World-wide approximately 4500km of hydrogen pipelines
- Mainly in US and EU
- Collective Wisdom:
  - Small OD: DN100 – DN300
  - Low strength: X52 and lower
    - ASME B31.12 Option A penalizes higher grades
    - IGC Doc 121/14 prohibits higher grades
  - Low operating stress: ~30% SMYS
- Small and inefficient

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Ready for what?

- Future:
  - Larger OD: DN500 and greater
  - High strength: X65, X70 and higher?
  - High operating stress: ~72% SMYS
  - Potential for pressure cycling = fatigue
- Hydrogen embrittlement
  - Susceptible material + hydrogen + stress

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What makes a steel susceptible?

- Modern X52 steel and X70 steel are part of a spectrum
  - Fine grained ferrite, micro-alloyed, lean composition
- Hydrogen accumulates at microstructural discontinuities
  - pre-existing defects
  - grain boundaries
  - impurities, etc.
- Inclusion ratings, sulphur content, segregation levels
- Martensitic microstructures (hard and brittle)

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Existing Solutions

- ASME B31.12 Appendix G
  - Microstructure of polygonal ferrite and acicular ferrite uniformly distributed through the cross-section
  - C <= 0.07%
  - Nb microalloyed
  - Low Pcm
  - Centerline segregation rating of 2 or better on the Mannesmann scale
  - Thermo-mechanical controlled processing (TMCP)
  - Grain size of ASTM 9 or finer

- Sour Service Practice
  - Microstructure of polygonal ferrite
  - Low C (~0.04%)
  - Low S (<=0.001%)
  - Microalloyed (generally Nb)
  - Low Pcm
  - Centerline segregation rating of 2 or better on the Mannesmann scale
  - Thermo-mechanical controlled processing (TMCP), or Q+T
  - Grain size of ASTM 11
  - Hardness limits

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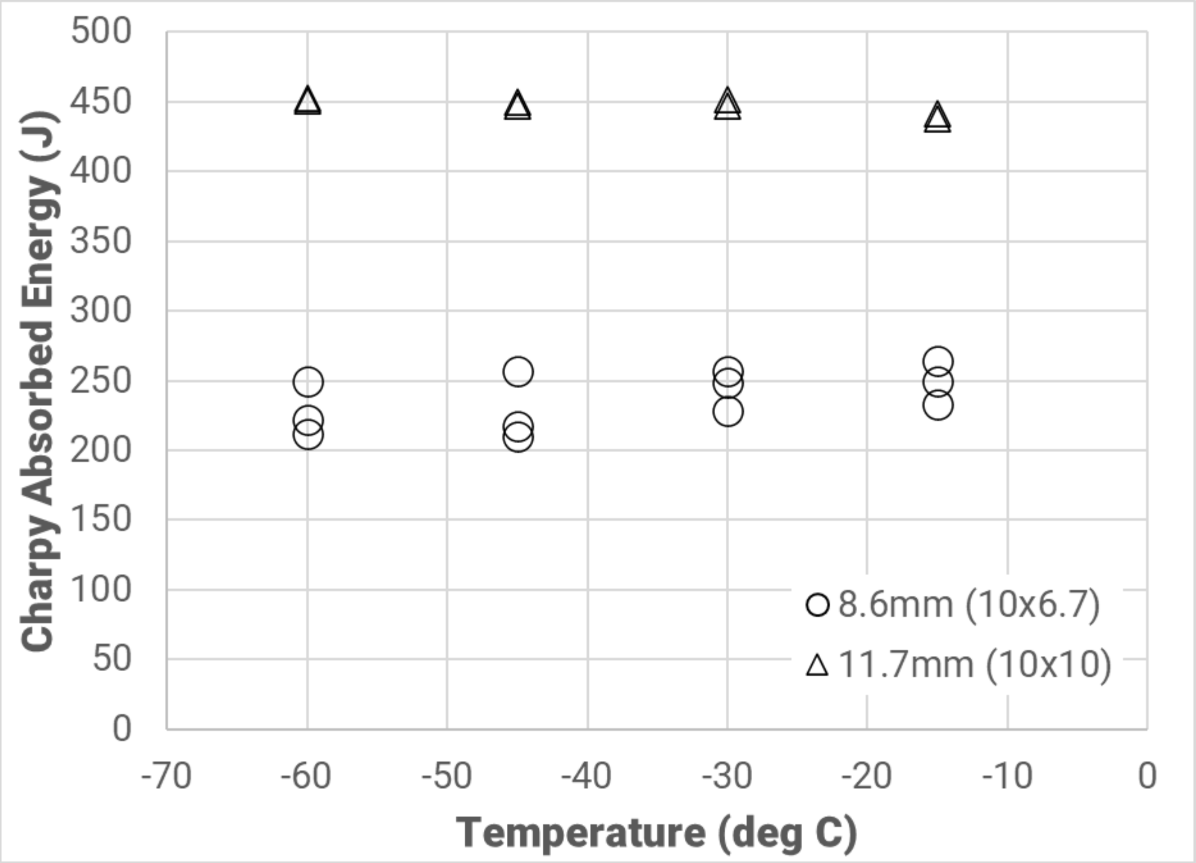
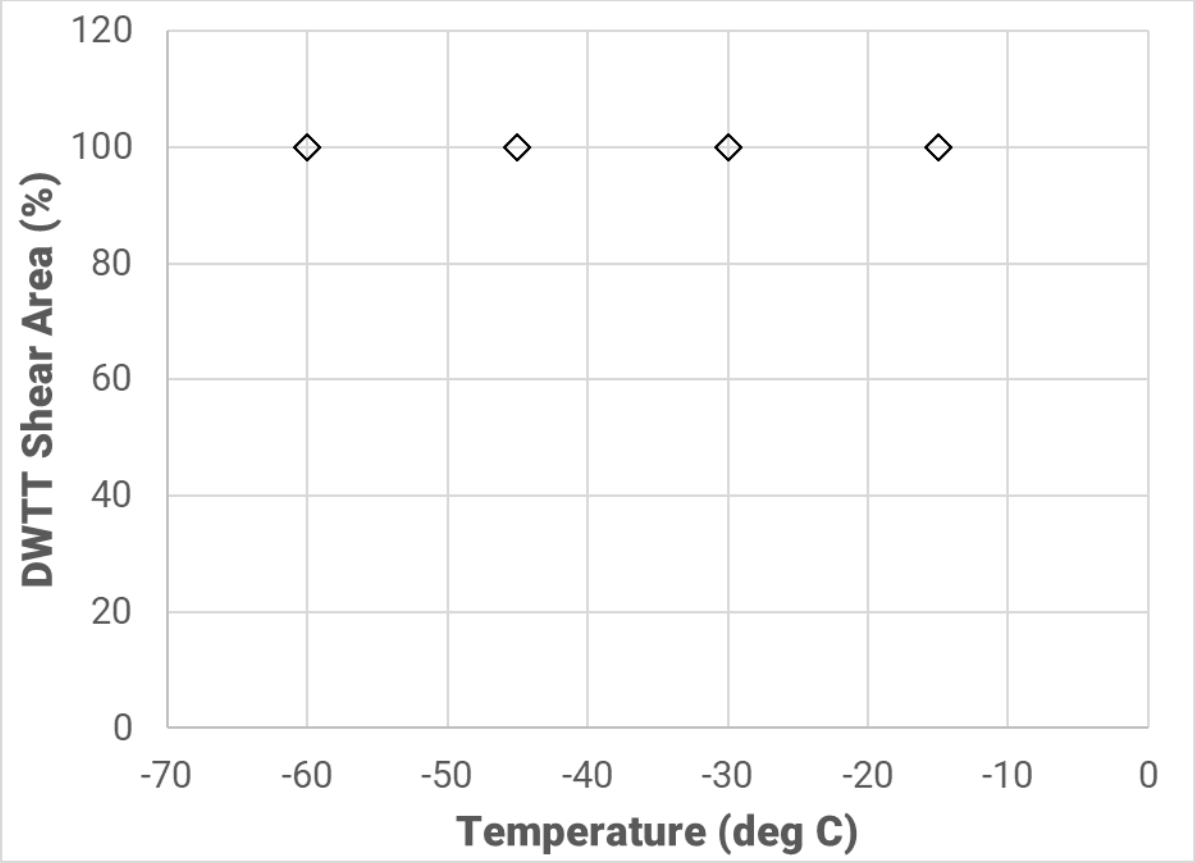
What does that get you?

DN250 X65 Sour Service HFW





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What are the gaps?

- ASME B31.12 Option B specifies a threshold fracture toughness
- Hydrogen-Assisted Fatigue Crack Growth Rates

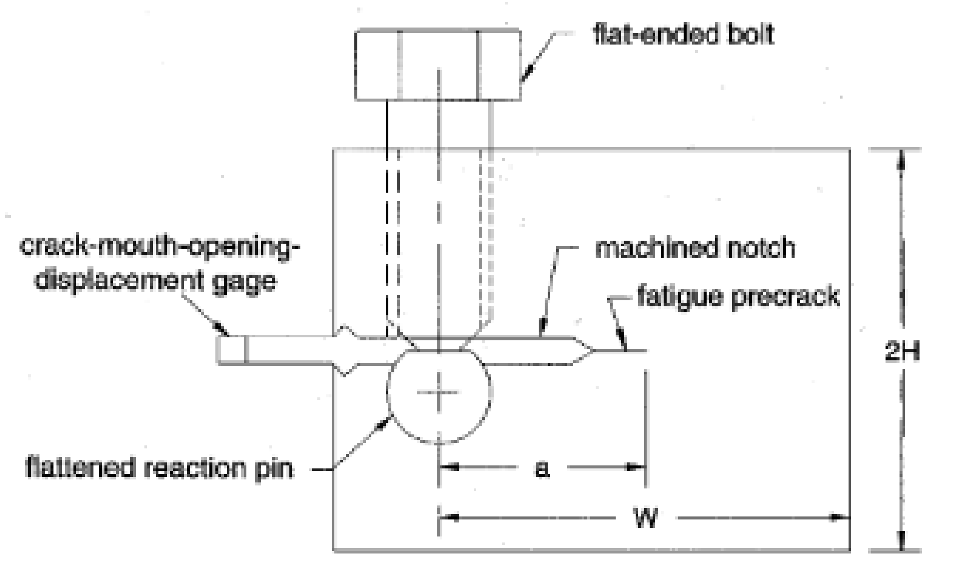
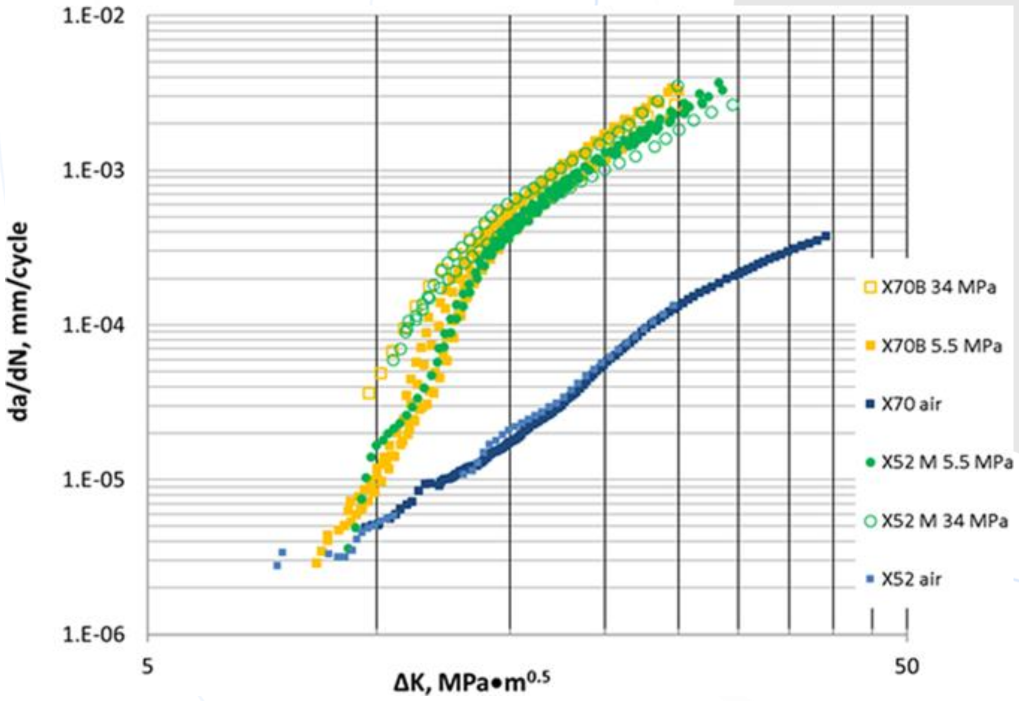


FIG. 3 Typical Test Arrangement for Constant Displacement K_{IEAC} Tests with Modified Bolt-Load Compact Specimen; H/W = 0.486



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What is the Australian Industry specifying?

- APGA Hydrogen Pipeline CoP
- Fracture Toughness
  - Not the same test method as ASME B31.12 Option B
- Benefits:
  - Gives an actual fracture toughness value, not just a threshold
  - More representative test of hydrogen embrittlement

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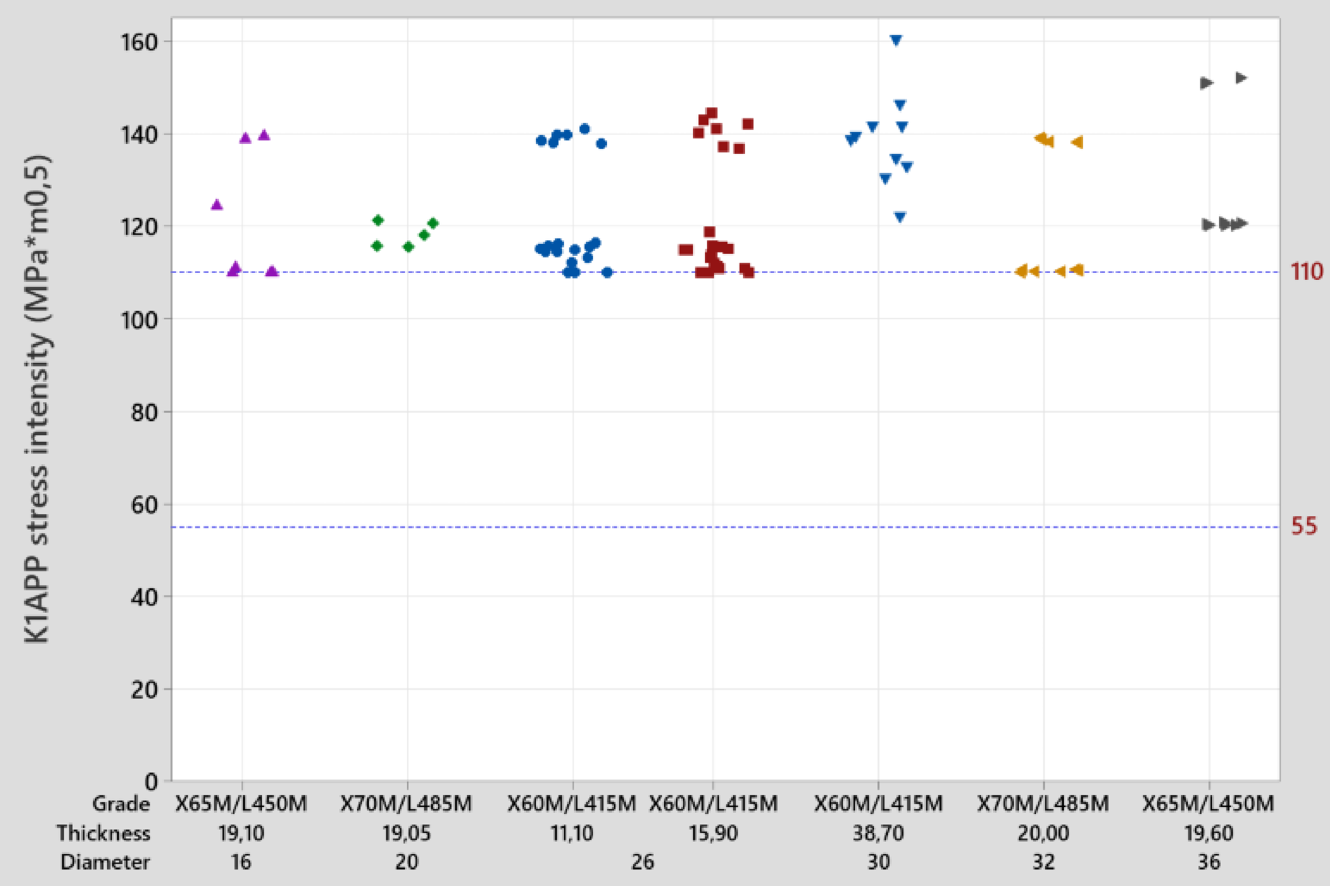
What are pipe manufacturers doing?

- Test programs using ASME B31.12 methods



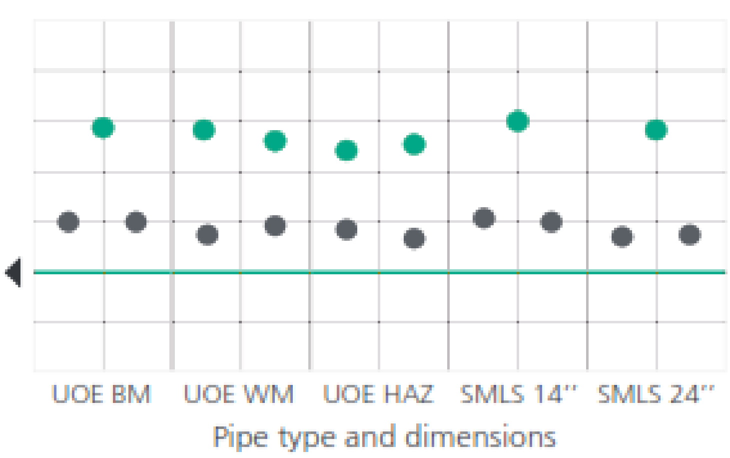


Figure 2 – K_{IH} results as a function of $K_{I\,applied}$

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What are pipe manufacturers doing?

- Test programs using ASME B31.12 methods
  - "Qualification" defined as $K_{IH} \geq 55MPa.m^{½}$
  - Excludes the "other side": calculating the required K_{IA}
- Installing test equipment in their laboratories
  - No longer just research labs
  - ASME B31.12 methods are becoming the "default" test methods
  - Likely to become an accepted MPQT

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What’s the Spec?

- Consider the size of the pipeline
- Specification precedents already exist
  - Sour service practice
  - ASME B31.12 Appendix G guidelines
- Defect size base-lines
  - ≥95% SMYS hydrostatic tests?
  - API 5L Annex K weld seam NDT
  - Full body NDT?
- “Standardised” fracture toughness test methods

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Hydrogen-Ready.

- Pipe steels exist to mitigate hydrogen embrittlement
- Pipeline design methods exist to mitigate hydrogen embrittlement
- Fatigue is main issue
  - Needs to be dealt with in design
- Australian Industry taking a leading approach to specification

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Thank you