HYDROGEN EMBRITTLEMENT IN PIPELINE STEELS

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Cheaper vs Safe?: Does it have to be choice

- Steel is sold by the ton
- X80 costs about the same as a X42/ton
- Use less X80, therefore save money by using higher strength material, thinner wall
- BUT hydrogen piping code encourages use of X52, because of history of safe operation
- **Are higher strength steels safe?**
  - Not past UTS
  - BM Fatigue—probably, yes
  - Other properties or tests needed?

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EXTERNAL CHALLENGES

- Hydrogen degradation of materials
  - Lack of understanding, what mechanism(s)?
- Reluctance of industry to adopt the extent of the code
  - What would convince them? More data, better models, flashy advertising?
- 3rd party damage
  - Sensors, modeling?
- Public confidence
- Investment
- Alternative transportation
  - On-site, tanker truck, liquefaction?

INTERNAL CHALLENGES

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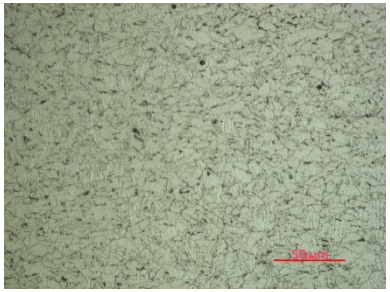
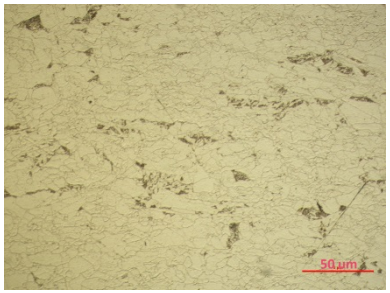
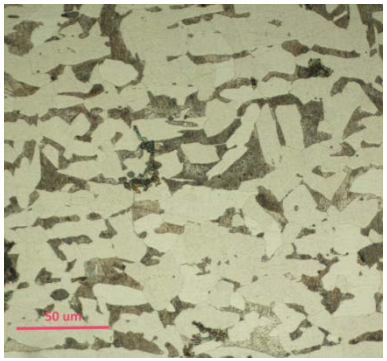
- Materials
  - Strength, microstructure
- Joining
  - Residual stresses, microstructure
- Pressure limit?
- Limited number of test facilities
- Codes
  - Girth welds?
    - Not mentioned
  - Fatigue, fracture







RD&D: Near-term

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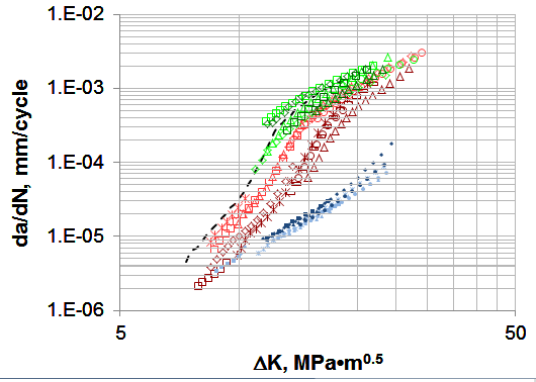
- Data for code modification
  - BM, Weld, HAZ
    - Tensile, fatigue, fracture
- Models for code modification
  - Phenomenological
    - More testing needed to calibrate each material, but it works now
  - Physics-based
    - Will we get there?
- Materials qualification?
- Model baseline material(s)? Model weld?
  - Pick 2 or 3 where we have good data?



RD&D: Longer-term

- Just do the tests for X52, X70, and X80 for qualification and declare victory!
- Future materials design

  Use microstructure and mechanisms work to direct new designs

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