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Structural Materials Challenges in the Deployment of Hydrogen Pipelines

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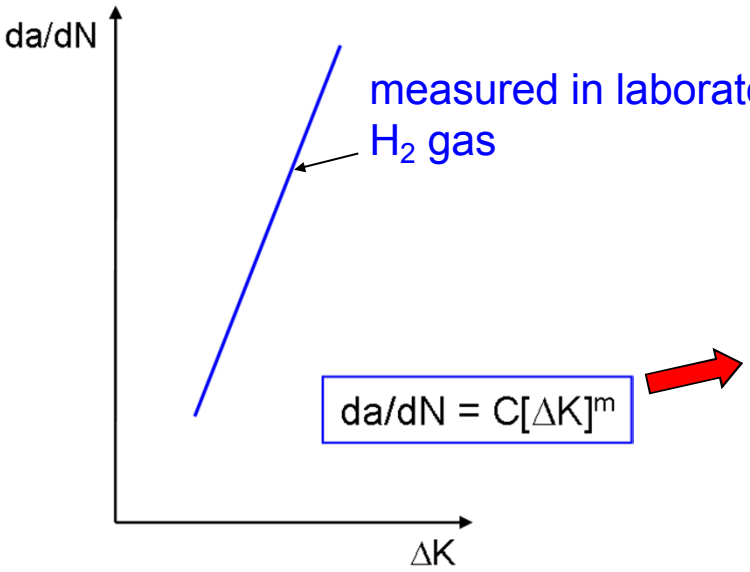
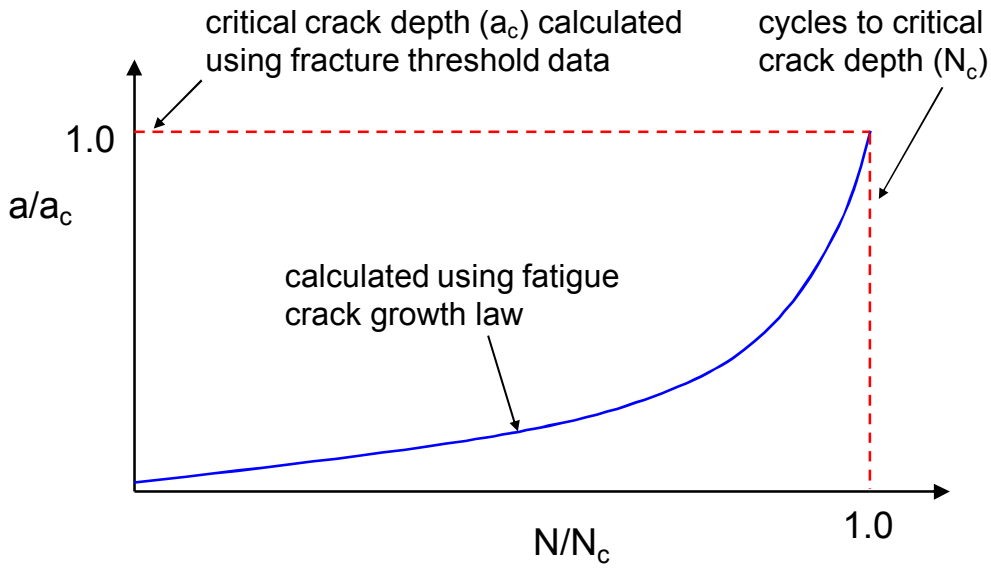
Two principal materials-related challenges for steel hydrogen pipelines: reliability and cost

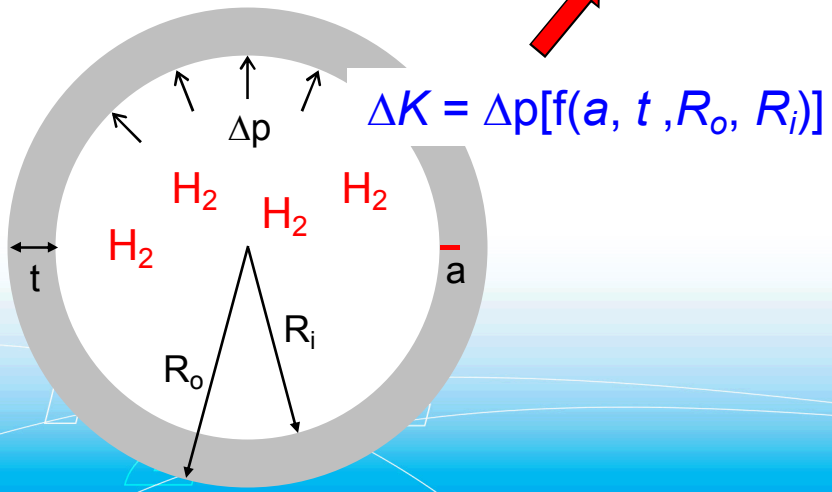
- Prominent reliability issue is potential for hydrogen embrittlement
  - No hydrogen embrittlement-related failures in existing steel hydrogen pipelines operated at static pressure
  - Steel hydrogen pipelines subjected to pressure cycling may be susceptible to fatigue crack growth aided by hydrogen embrittlement
- Two material-related contributions to cost
  - Steel
  - Welds

Reliability and cost can be intertwined

Reliability framework based on fracture mechanics and associated material property measurements



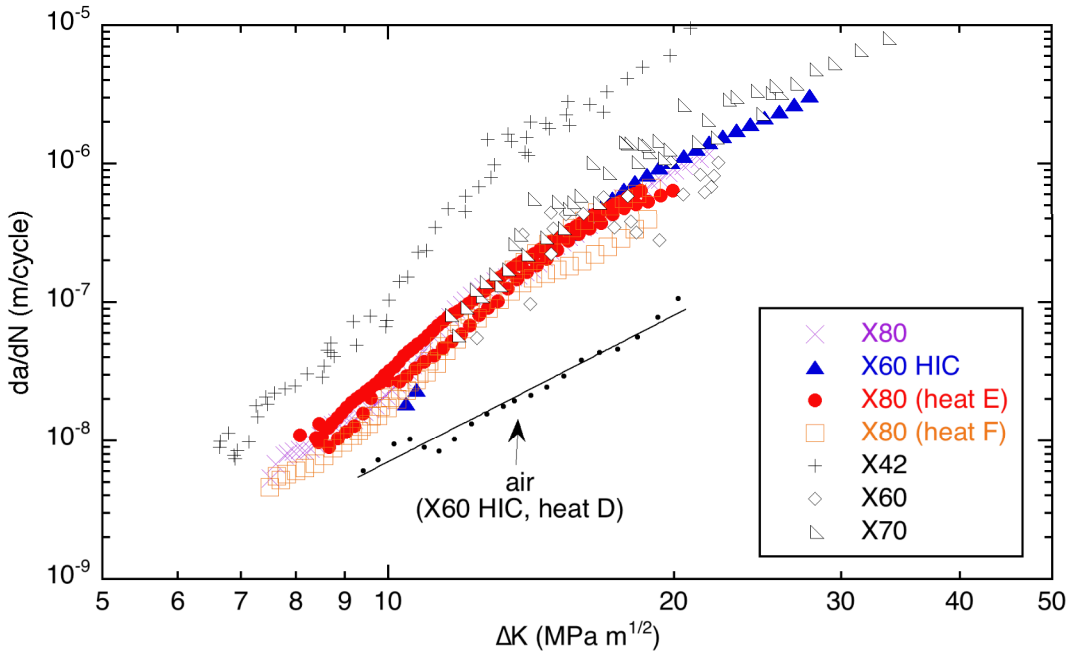




$\Delta K = \Delta p[f(a, t, R_o, R_i)]$

- Two fracture properties in H_2 needed
  - Fatigue crack growth law
  - Fracture threshold
- Reliability/assessment framework accommodates H_2 embrittlement

Cost of pipelines can be reduced with high-strength steels, but reliability must be established



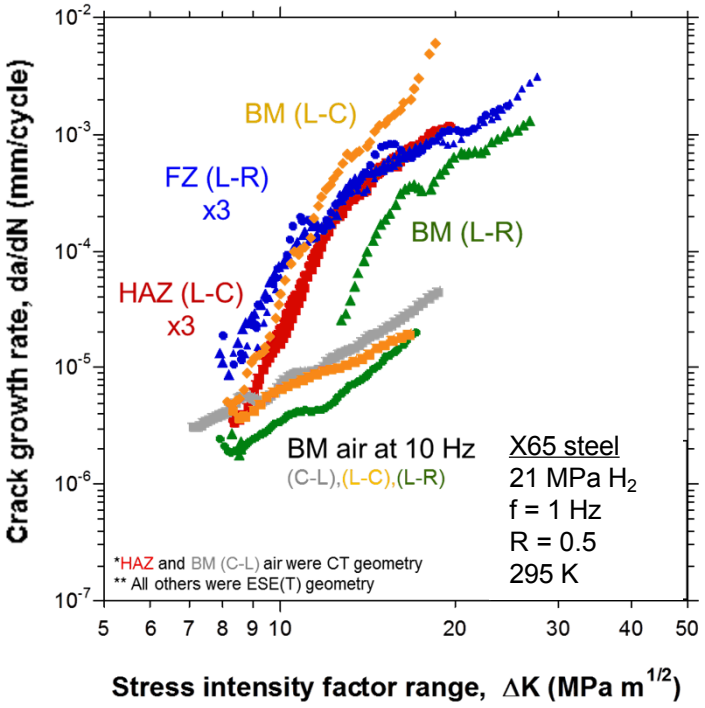
San Marchi et al., ASME 2011 Pressure Vessels & Piping Division / K-PVP Conference, PVP2011-57684

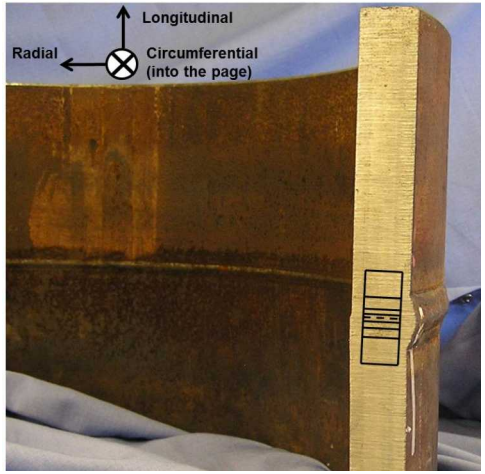
X80, X60 HIC → 3,000 psi H_2

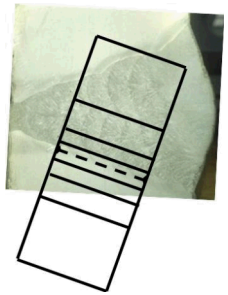
X70, X60, X42 → 1,000 psi H_2

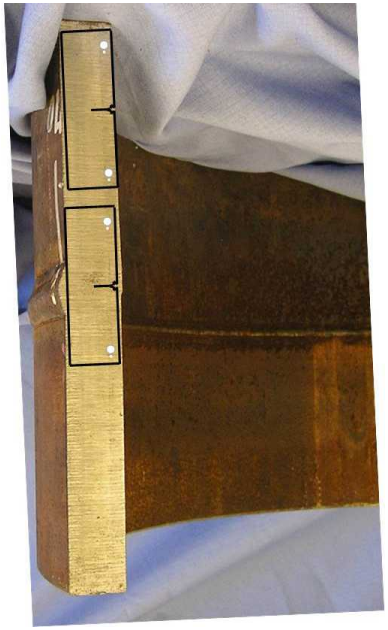
- Questions:
  - How much data are needed to conclusively demonstrate hydrogen-assisted fatigue crack growth behavior for high-strength steels?
  - Can fundamental relationships between material characteristics and hydrogen-assisted fatigue crack growth behavior be established?

Cost of pipelines may be reduced with new weld technologies, but reliability must be established









- Questions:
  - Can fatigue crack growth relationships of welds be measured with confidence?
  - Can fundamental relationships between material characteristics and hydrogen-assisted fatigue crack growth behavior be established?

Possible R&D activities for steel H_2 pipelines

- Develop methods for measuring fatigue crack growth relationships of welds
- Determine bounds in hydrogen-assisted fatigue crack growth behavior for pipeline steel base metal and welds
- Relate hydrogen-assisted fatigue crack growth behavior trends to material characteristics
  - Establishing fundamental relationships between hydrogen-assisted fatigue crack growth and material characteristics can enhance reliability of new materials and welding practices