Proposed test method to establish hydrogen compatibility of materials for fuel cell vehicles

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In collaboration with SAE Fuel Cell Safety Task Force

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Motivation: *establish materials compatibility for high-pressure hydrogen service in context of hydrogen fuel cell electric vehicles*

Status:

- **Test methodology for materials compatibility evaluation has been submitted for review**
- **Awaiting feedback from stakeholders**
  - **Please provide feedback by August 20, including technical basis for concerns**
  - **Technical discussion being organized to coincide with next SAE Fuel Cell Safety Task Force Meeting**

Goals of testing

- Slow strain rate tensile (SSRT) test
  - *Screening test for strength and ductility*
  - Demonstrate that specified minimum strength properties are satisfied
  - Demonstrate sufficient ductility
- Fatigue life test (two options)
  - *Screening test for fatigue life*
  - Smooth: demonstrate that fatigue limit is not changed in hydrogen
  - Notched: demonstrate that fatigue life is conservative by greater than 9 times (in life)

Open questions and lack of consensus

1. Modify test pressure for SSRT
2. Eliminate verification of gas quality
3. Eliminate allowance for welds, or prescribed additional details
4. Eliminate notched fatigue life test option
5. Add stress corrosion cracking of aluminum in humid gas (HG-SCC)

Open questions and lack of consensus

1. Test pressure
   - *Increase test pressure of SSRT*
     - SSRT: 1.5 x NWP (initially 1.25 x NWP)
     - Fatigue life: 1.25 x NWP

- Increasing pressure may limit the applicability of previously acquired data
  - Previous tests have been performed at pressure < 1.5x NWP

Technical evaluation: Addressable
SSRT testing at the higher pressure is unlikely to change outcome of testing

Open questions and lack of consensus

2. Verification of gas quality
   - Remove requirement to sample test gas

- Gas purity is known to affect properties measured in gaseous hydrogen [*ref. Somerday*]
- Characterization of source gas is not sufficient to establish purity of test gas
  - Purity of test gas depends on purging process prior to each test

Technical evaluation: Addressable with further technical discussion

- Confirmation of purity of test gas is essential
- *Proposed solution*: periodic evaluation of test gas (not every test), consistent with CSA CHMC1

Open questions and lack of consensus

3. Allowance for welds
    - One contracting party does not allow welds.
    - Concern also about precise definition of weld and test specimens.

Technical evaluation: relevant and addressable

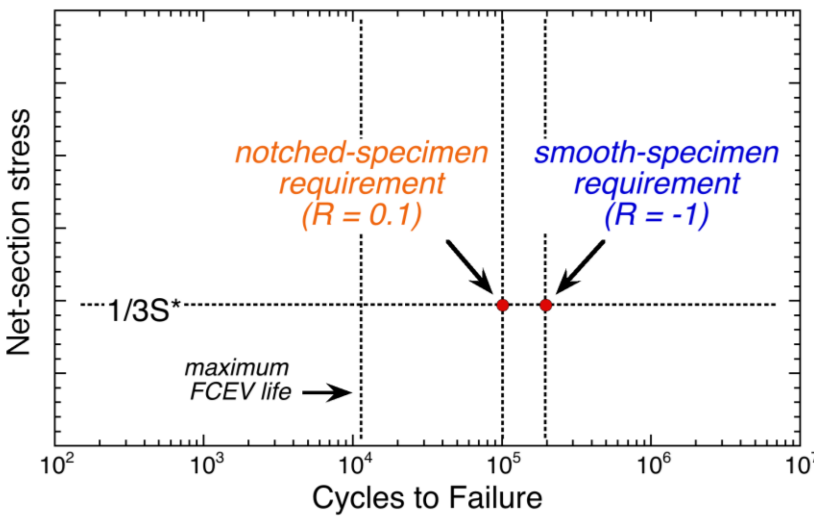
- Potential solutions: (two options)
    1. provide generic performance-based language
    2. Establish prescriptive definition of welding processes and specimen extractions for all weld configurations

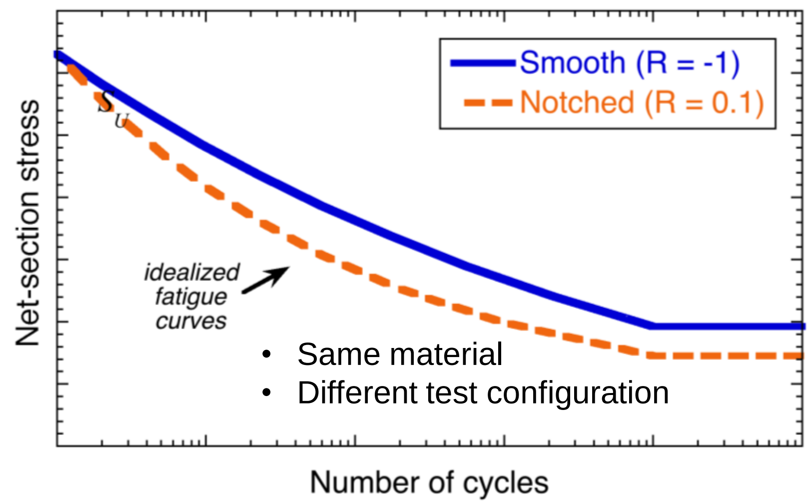
Contracting Party Question: Will welds be allowed if the technical issue is resolved?

Open questions and lack of consensus

4. Fatigue life test options

- Current approach allows two equivalent options
  1. Notched-specimen (R=0.1)
  2. Smooth-specimen (R=-1)
- One contracting party has expressed dissatisfaction with notched-specimen option





Contracting Party Question: Is there an approach to resolve?

Open questions and lack of consensus

5. **Stress corrosion cracking of aluminum in humid gas (HG-SCC)**
   - **Topic of separate presentation**

- **High-strength aluminum alloys are known to be sensitive to "wet" hydrogen [*ref. Speidel*]**
- **Hydrogen vehicle fuel can have as much as 5 ppm H2O**
  - **Open technical question: Is 5 ppm H2O in H2 at pressure of 1.5 x NWP sufficient to induce stress corrosion cracking (HG-SCC) in high-strength aluminum alloys?**
    - **High-strength aluminum alloys are a desirable option for valves and fittings**
    - ***More test method development is needed***

Ref: Speidel, in: Hydrogen Embrittlement and Stress Corrosion Cracking (1984), ASM, Metals Park.

Summary

- Relatively simple screening test metrics drafted for
  1. Strength and ductility (SSRT)
  2. Fatigue life (two options: smooth and notched)

- 5 questions are currently being considered
  - Input from contracting parties required on 2 items.
    1. Approach to handle smooth or notched-specimens for cycle testing?
    2. Will welds be allowed if properly addressed or not?

- Awaiting additional feedback from stakeholders
  - Feedback by August 20 to prepare for SME discussion on September 10 in Troy MI (participation is encouraged)

Backup Slides

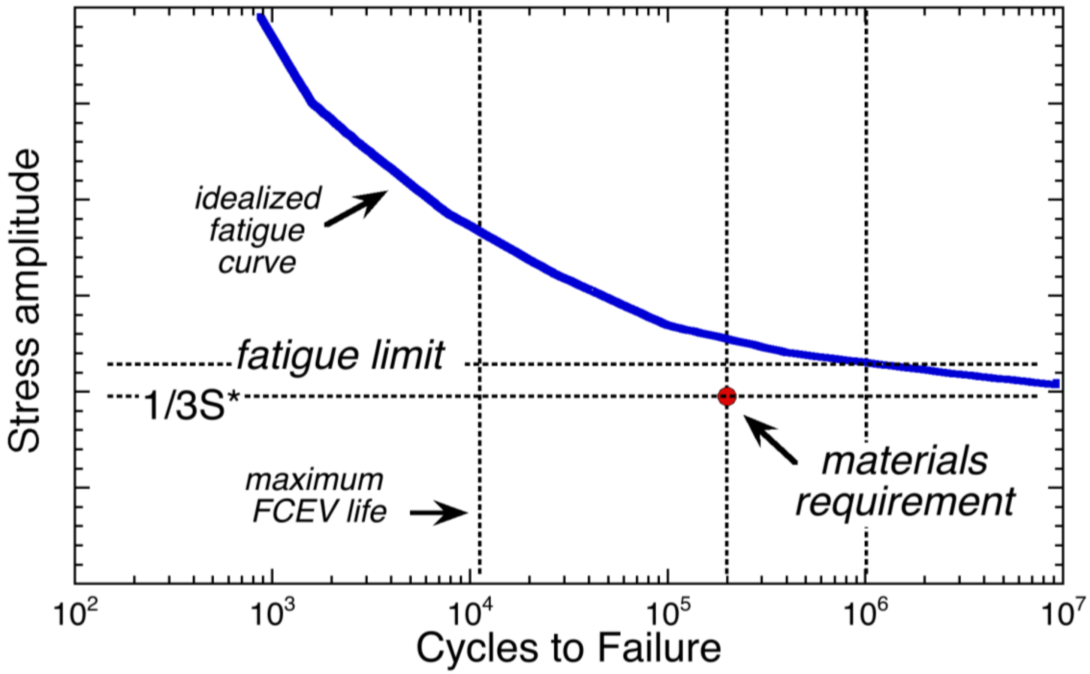
Summary of requirements to demonstrate hydrogen compatibility

	Slow strain rate tensile (SSRT)	Fatigue Life
Test conditions	• H2 pressure ≥ 1.5 NWP • Temperature: varies • Displacement rat ≤ $5x10^{-5}$ s^{-1}	• H2 pressure ≥ 1.25 NWP • Temperature: varies • Net-section stress ≥ 1/3S* • Frequency = 1 Hz
Number of tests	3	3
Requirements for each test	1. Yield strength > Sy 2. Tensile strenth > Su 3. Tensile/yield > 1.07 4. Elongation > 12%	1. Either (a) or (b) a) Smooth: N > $2x10^5$ b) Notchted: N > 10^5

Note: Sy and Su are specified minimum yield and tensile strength respectively; S* is measured tensile strength

Open questions and lack of consensus

4. **Fatigue life test options**
   - **Smooth-specimen fatigue life test:** ***establish that hydrogen does not change the fatigue limit***

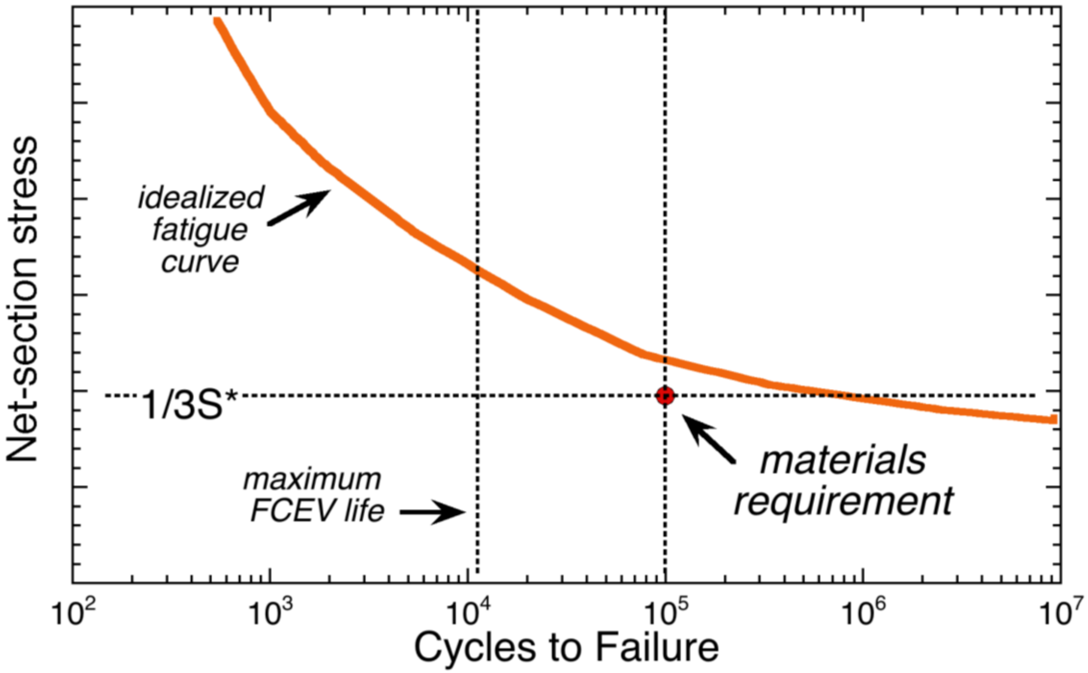


- **Maximum FCEV life = 11,000 cycles**
- **Materials requirement = 200,000 cycles at stress of 1/3S***
  - **smooth specimen with R = -1**

Ref: San Marchi et al, ASME PVP2018-84898.

Open questions and lack of consensus

4. **Fatigue life test options**
   - **Notched-specimen fatigue life test: *establish fatigue life 9x greater than maximum FCEV life***



- **Maximum FCEV life = 11,000 cycles**
- **Materials requirement = 100,000 cycles at stress of 1/3S***
  - **notched specimen with R = 0.1**

Ref: San Marchi et al, ASME PVP2018-84898.