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

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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 by international materials experts**
- **Discussion with international materials experts (September 2018, Troy MI)**

Goal of testing

Performance-based evaluation of structural metals to meet minimum expectations for high-pressure hydrogen service

- **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. Requirements for SSRT

   1b) New proposal on requirements
2. Verification of gas quality
3. Allowance for welds, or prescribed additional details
4. Notched fatigue life test option
5. 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)**
       - **Recognizing that the maximum pressure in the container durability test is 1.5 NWP**
     - **Fatigue life: 1.25 x NWP**

Technical resolution:

- **The effect of pressure is small for pressure between 1.25 and 1.5 NWP, when NWP is large**
- **For simplicity and consistency, experts generally agreed to keep the same pressure for both test methods: test pressure = 1.25 NWP**

Status: seemingly RESOLVED

NEW

Open questions and lack of consensus

1b. SSRT should evaluate relative response

- and absolute properties should not be required

- **Strong disagreement on the premise that relative properties are sufficient**
  - ***Example: yield can be unchanged by hydrogen, but ductility in hydrogen can be very low – examples of such unacceptable materials can be found in NASA reports***

Proposed technical compromise:

- **Include both relative and absolute requirements:**
  1. **Yield strength > Sy**
  2. **Yield strength > 0.80 YS(T) – new relative requirement**
  3. **Tensile strength > Su**
  4. **Tensile/yield > 1.07**
  5. **Elongation > 12%**

Status: NOT RESOLVED

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 resolution:

- **Confirmation of purity of test gas is essential**
- **Gas purity shall be verified at least every 12 months**

Status: RESOLVED

Open questions and lack of consensus

3. **Allowance for welds**
   - **Concern also about precise definition of weld and test specimens**

Technical resolution:

- **Precise definition of weld practice, geometry, etc is beyond the scope of the GTR document**
- **Compromise:**
  - **Accept generic language**

Status: seemingly 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)**

Technical resolution:

- **Accept both methods as screening tests for hydrogen sensitivity**

Status: RESOLVED

Open questions and lack of consensus

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

Technical assessment:

- **High-strength aluminum alloys are known to be sensitive to "wet" hydrogen**
- **Limits on moisture for SCC are not known**
- **Proposed test method uses surrogate environment**
- **Surrogate environmental test method has not been verified**

Status: NOT RESOLVED

Summary

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

- **Currently, there are 6 documented questions about the proposed methods**
  - **4 resolved**
  - **2 not resolved**
    - **Proposed HG-SCC surrogate test method has not been verified**
    - **Disagreement on appropriate evaluation metrics for SSRT**

Resolution, as documented here, is based on the materials experts that have participated in the technical discussion. Other opinions are encouraged to (1) review the proposed procedures and requirements, (2) participate in the discussion, and (3) provide feedback.

Backup Slides

Summary of requirements to demonstrate hydrogen compatibility

	Slow strain rate tensile (SSRT)	Fatigue Life
Test conditions	• H2 pressure ≥ 1.25 NWP • Temperature: varies • Displacement rate ≤ $5x10^{-5}$ 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. Yield strength > 0.80 YS(T) 3. Tensile strength > Su 4. Tensile/yield > 1.07 5. Elongation > 12%	1. Either (a) or (b) a) Smooth: N > $2x10^5$ b) Notched: N > 10^5

Note: Sy and Su are specified minimum yield and tensile strength respectively; S* is measured tensile strength and YS(T) is the yield strength in air at temperature T as defined in section 2.3 Temperature