Proposal on Drafting Hydrogen Storage System Part of the HFCV-gtr

3 JUL, 2009
JASIC
When hydrogen effect of the container can be evaluated by the material test, paragraph 5.2.2.1 and 5.2.2.2 may be replaced by paragraph 5.2.2.4.

-JASIC will provide additional information for the justification of this option and for the material tests.

-JASIC has a proposal to change the 5.2.2.2 (next slide).
Proposal for the 5.2.2.2 (Hydraulic Cycle Sequential Test)

/JASIC propose to change the 5.2.2.2.
/JASIC think hydraulic test (5,500 cy) with extreme temperature condition is appropriate to validate the safety at end of life (15 years, extreme vehicle range). *(The hydraulic cycle test will be severer condition than pneumatic test as a result of stress analysis, please find APPENDIX.)*

/On the other hand, the pneumatic cycle test (500 cy) and hydraulic test with room temperature is not enough to validate the end of life safety. /Pneumatic cycle test (100,000 mile = 500 cycle) is appropriate to validate the fails which could not be validated by hydraulic test.

<table>
<thead>
<tr>
<th>vehicle lifetime range</th>
<th>frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: extreme vehicle range (360,000 mile = 5,500 cycle)</td>
<td></td>
</tr>
<tr>
<td>B: average vehicle range (100,000 mile = 500 cycle)</td>
<td></td>
</tr>
</tbody>
</table>
Proposal for the 5.2.2.2 (Hydraulic Cycle Sequential Test)

JASIC propose to change the 5.2.2.2. Hydraulic test (5,500cy) shall be to validate the safety at end of life (15 years, extreme vehicle range)

<table>
<thead>
<tr>
<th>SGS 6-03 draft</th>
<th>proposal</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.2.2.2</strong></td>
<td>Hydraulic Cycle Sequential Test (5,500cy) with extreme temperature and static pressure test (1000hr, 85°C) shall be to validate the safety at end of life (15 years, extreme vehicle range)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1) Hydraulic Cycle Sequential Test (5,500cy) with extreme temperature and static pressure test (1000hr, 85°C) shall be to validate the safety at end of life (15 years, extreme vehicle range)</td>
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<tr>
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</tbody>
</table>

A: extreme vehicle range (360,000 mile = 5,500 cycle)

B: average vehicle range (100,000 mile = 500 cycle)
Proposal for the 5.2.2.2 (Hydraulic Cycle Sequential Test)

Proposed 5.2.2.2 test condition
Proposal for the 5.2.2.1 (Pneumatic Cycle Sequential Test)

(Comment: This pneumatic test is under investigation. The test condition of temperature and cycle number should be discussed.)

Expected Service (Pneumatic) Performance Test applies to the non-metal liner containers. If alternative test is technically effective for the failure, manufactures can select the alternative test instead of the pneumatic test.
Proposal for test structure

JASIC propose the below test structure. /The proposed 5.2.2.2 is same as 5.2.2.4(alternative), so alternative path is removed. /We have to consider the time effect on Hydrogen attack. Pneumatic test period is too short to evaluate the hydrogen embrittlement. Material test shall be necessary.

Proposed test structure

Material Test

5.2.2.1 (Comment: This pneumatic test is under investigation /Pneumatic Cycle Sequential Test (500cy) -extreme temperature

proposed 5.2.2.2

/ Hydraulic Cycle Sequential Test (5,500cy) -extreme temperature -static pressure test of 1000hr and 85C.

(Comment: This pneumatic test is under investigation. The test condition of temperature and cycle number should be discussed.)

Expected Service (Pneumatic) Performance Test applies to the non-metal liner containers. If alternative test is effective technically for the failure, manufactures can select the alternative test instead of the gas test.
JASIC propose to add Maximum Defect Size Inspection Test in Design Qualification Test because the pneumatic cycle test (5,500cy) is impossible for too long test period. This test is same as NGV.

The maximum defect size shall be calculated which does not lead to any damage from fatigue or burst during the use of the container for a period of 15 years in hydrogen atmosphere.
This test is to validate the failure mode which is not burst but leakage over the usage of extreme vehicle range (360,000 mile = 5,500 cycle).

Below red figure sentence (explanation by Maximum defect size inspection) is add to confirm the adequacy of design.

3. The ambient cycling test of Paragraph 1 shall meet the both of the following requirements.
   (1) The container does not fracture, and there are no damages to fiber.
   (2) There is no leakage from the container less than 5,500 cycles. (11,250 cycles for commercial vehicles)

When the cycle of the vessel in personal vehicles is less than 11,250 cycles, the manufacturer should explain the adequacy of test result by 5.2.2.3.5 Maximum Defect Size Inspection Test in Design Qualification Test.
## Proposal for test structure in detail

### Proposed test structure

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>5.2.2.1</td>
<td>Expected Service (Pneumatic) Performance Test</td>
</tr>
<tr>
<td>5.2.2.1.1</td>
<td>Fueling Performance Verification Test: Gas Pressure Cycling at Environmental Temperature Limit 5.2.2.1.1.a and 5.2.2.1.1.b</td>
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<tr>
<td>5.2.2.1.2</td>
<td>Parking Performance Verification Test: Static Gas Pressure Exposure at Extreme Temperature 5.2.2.1.2.a and 5.2.2.1.2.b</td>
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<tr>
<td>5.2.2.1.3</td>
<td>Leak/Permeation Test</td>
</tr>
<tr>
<td>5.2.2.1.4</td>
<td>Proof Pressure Test (Hydraulic and / or Pneumatic to be done in 5.2.2.1 and 5.2.2.2)</td>
</tr>
<tr>
<td>5.2.2.1.5</td>
<td>Residual Strength Burst Test (Hydraulic) to be done in 5.2.2.1 and 5.2.2.2.</td>
</tr>
<tr>
<td>5.2.2.2</td>
<td>Durability (Hydraulic) performance Test</td>
</tr>
<tr>
<td>5.2.2.2.1</td>
<td>Drop (Impact) Test</td>
</tr>
<tr>
<td>5.2.2.2.2</td>
<td>Surface damage and Chemical Exposure Test</td>
</tr>
<tr>
<td>5.2.2.2.3</td>
<td>Extreme Fueling Usage; Extended Pressure Cycling Test **</td>
</tr>
<tr>
<td>5.2.2.3.1</td>
<td>Engulfing Fire (Bonfire) Test</td>
</tr>
<tr>
<td>5.2.2.3.2</td>
<td>Penetration Test</td>
</tr>
<tr>
<td>5.2.2.3.3</td>
<td>Ultimate Burst Pressure</td>
</tr>
<tr>
<td>5.2.2.3.4</td>
<td>Ambient Cycling Test in Design Qualification Test ( Leak Before Break test)</td>
</tr>
<tr>
<td>5.2.2.3.5</td>
<td>Maximum Defect Size Inspection Test in Design Qualification Test</td>
</tr>
</tbody>
</table>

*still missing in the text - to be done in 5.2.2.1 and 5.2.2.2.
Appendix

JASIC will provide additional information for the justification of this option and for the material tests.
JASIC’s Approach

JASIC will conform that a hydraulic pressure cycling test will be equivalent to pneumatic cycling test by the below action.

1) Complementary material tests
2) Stress analyses
   - to make clear Pneumatic cycling stresses taking into account
     / extreme low temperature
     / steep thermal gradients
     / pressure gradients
     / cyclic fatigue
Material test with hydrogen pre-charged can evaluate hydrogen effect of all kinds of metal in reasonable period.

Container test of several months level can not assure the safety of the container, because hydrogen diffusion into austenitic stainless-steel is extremely slow.

Ex.) Hydrogen Diffusion into Material

**70MPa 30°C**  
Hydrogen diffusion into stainless-steel (SUS316L)  
(One-dimensional simulation for a plate 1mm thick)

Data from; Hasegawa et al: Boushokugizyutu 29 (1980) P.463  
JASIC’s Approach

JASIC will conform that a hydraulic pressure cycling test will be equivalent to pneumatic cycling test by the below action.

1) Complementary material tests
2) Stress analyses
   - to make clear Pneumatic cycling stresses taking into account
     / extreme low temperature
     / steep thermal gradients
     / pressure gradients
     / cyclic fatigue
Long term hydrogen compatibility (hydrogen embrittlement) shall be evaluated by material tests to guarantee the End of Life Safety.

In future:
Standard material test method shall be established to evaluate hydrogen compatibility by the Hydrogenius (Kyusyu University) and feed back to the test procedure.

Current:
Select appropriate materials such as SUS316L and A6061 that shows no difference on properties between in hydrogen and in Air.
Ex.) Material Test in High Pressure Hydrogen

Current:
Select appropriate materials such as SUS316L and A6061 that shows no difference on properties between in hydrogen and in Air.

Example  (The data acquired when the regulation of 35MPa was examined. )
90MPa data is under acquiring now.

A6061-T6  Temp : RT  Pressure : 45MPa  In H2 gas

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SSRT (Slow Strain Rate Technique)

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S.Ohmiya et al. ; unpublished (by Nippon Steel and Kyushu Univ.)


Crack growth rate

* NOTE: The data were obtained by the research group on hydrogen-related materials organized by the Japan Research and Development Center for Metals (JRCM) in the following three projects administrated through New Energy and Industrial Technology Development Organization (NEDO) with funding from Ministry of Economy, Trade and Industry (METI) of Japan; the International Clean Energy Network Using Hydrogen Conversion (1993-2003), the Development for Safe Utilization and Infrastructure of Hydrogen (2003-2005), and the Establishment of Codes & Standards for Hydrogen Economy Society (2005-).
JASIC will conform that a hydraulic pressure cycling test will be equivalent to pneumatic cycling test by the below action.

1) Complementary material tests
2) Stress analyses
   - to make clear Pneumatic cycling stresses taking into account
     / extreme low temperature
     / steep thermal gradients
     / pressure gradients
     / cyclic fatigue
Hydraulic Pressure Cycle Test as an Alternative

The temperature at the end of discharge shows extreme low, but stress range of low temperature condition is smaller than high temperature.

Presumption of stress of Aluminum liner

Stress range of low temperature condition is smaller than high temperature due to decrease of pressure and Aluminum liner’s contraction.
Hydraulic Pressure Cycle Test as an Alternative

Stress analysis and experiment (Leak Before Break)

The stress of aluminum liner by cycle test (pneumatic) at -40C will change between ① and ② in Fig.3. The liner stress of hydraulic cycle test at -40C change between ① and ③. Similar to ④ ⑤ ⑥ at 85C.

The hydraulic cycle test will be severe condition because of large stress range. So JASIC think the hydraulic pressure cycling test can simulate the pneumatic cycling test.

JASIC will conduct LBB test and confirm the container life depend on stress range but not on temperature.

Data by JARI
## Hydraulic Pressure Cycle Test as an Alternative Stress Analysis by Simulation

JASIC (JARI) will simulate TEST1 & TEST2 condition to improve the accuracy of Fig.3 in Page 23.

<table>
<thead>
<tr>
<th>Experiment and simulation condition</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TEST1</strong></td>
<td>/ to make clear aluminum liner stress by heat with inside and outside strain gage</td>
</tr>
<tr>
<td></td>
<td><img src="image1" alt="Diagram of TEST1" /></td>
</tr>
<tr>
<td></td>
<td>Center of Cylindrical Part A, B : Strain Gauges on External Surface of CFRP Layer a, b : Strain Gauges on Internal Surface of Liner</td>
</tr>
<tr>
<td><strong>TEST2</strong></td>
<td>/ to simulate aluminum liner stress under pressure and low &amp; high temperature</td>
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<tr>
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<td><img src="image2" alt="Diagram of TEST2" /></td>
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Hydraulic Pressure Cycle Test as an Alternative

Schedule

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<tr>
<td>Simulation(Test1)</td>
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<tr>
<td>/ to make clear aluminum liner stress by heat with inside and outside strain gage</td>
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<td></td>
</tr>
<tr>
<td>Simulation(Test2)</td>
<td></td>
<td></td>
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<tr>
<td>/ to simulate aluminum liner stress under pressure and low &amp; high temperature</td>
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<tr>
<td>Leak Before Brake</td>
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<tr>
<td>①-40°C, 85°C hydraulic</td>
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<tr>
<td>② pressure : 2MPa ~ 100%SOC</td>
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<tr>
<td>Judgment</td>
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</table>

These tests are performed by JARI

JASIC can judge whether hydraulic pressure cycle test is acceptable or not.
Temperature Characteristic of Aluminum Material Strength

There is little change in a significant strength characteristics.

Data source:
END