SGS 7 -08

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

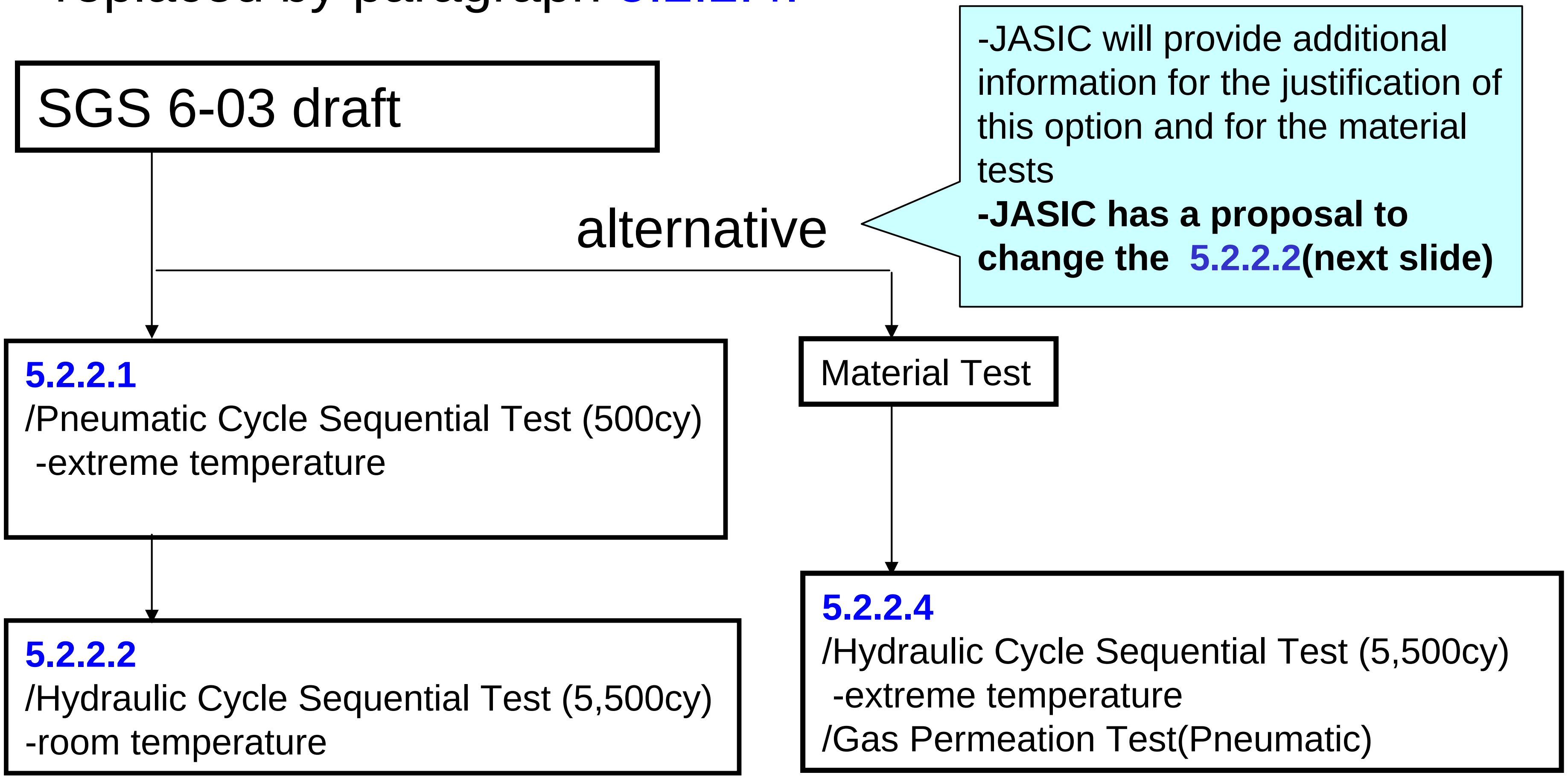
3 JUL, 2009

JASIC

Remainder

SGS 6-03 draft

/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.



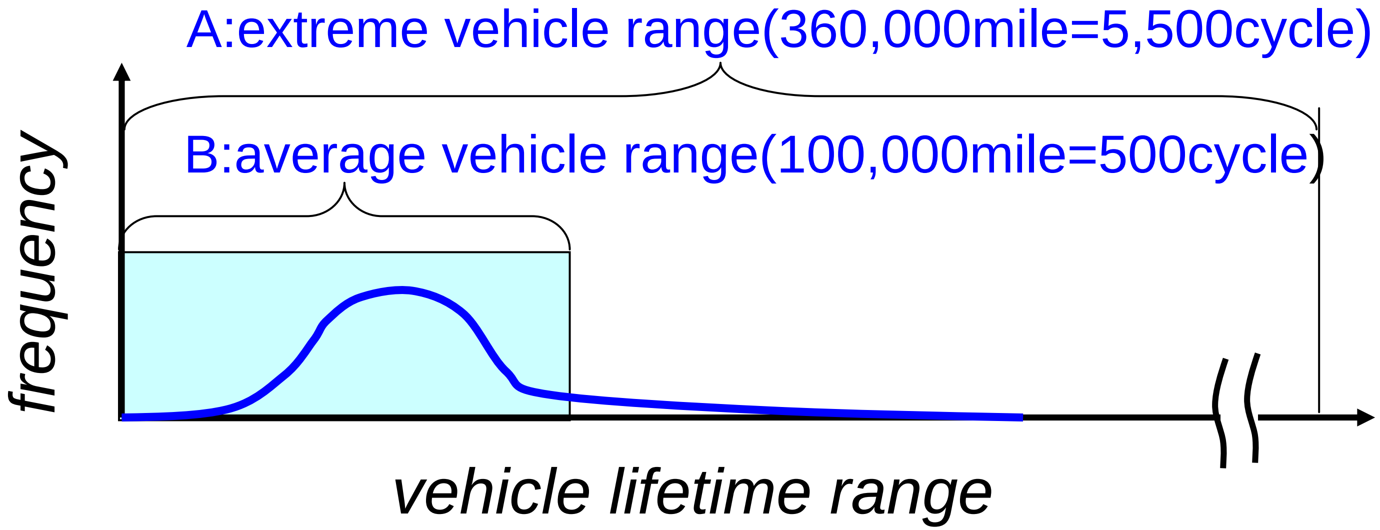
Proposal for the 5.2.2.2(Hydraulic Cycle Sequential Test)

/JASIC propose to change the 5.2.2.2.

/ JASIC think hydraulic test(5,500cy) 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 (500cy) and hydraulic test with room temperature is not enough to validate the end of life safety.

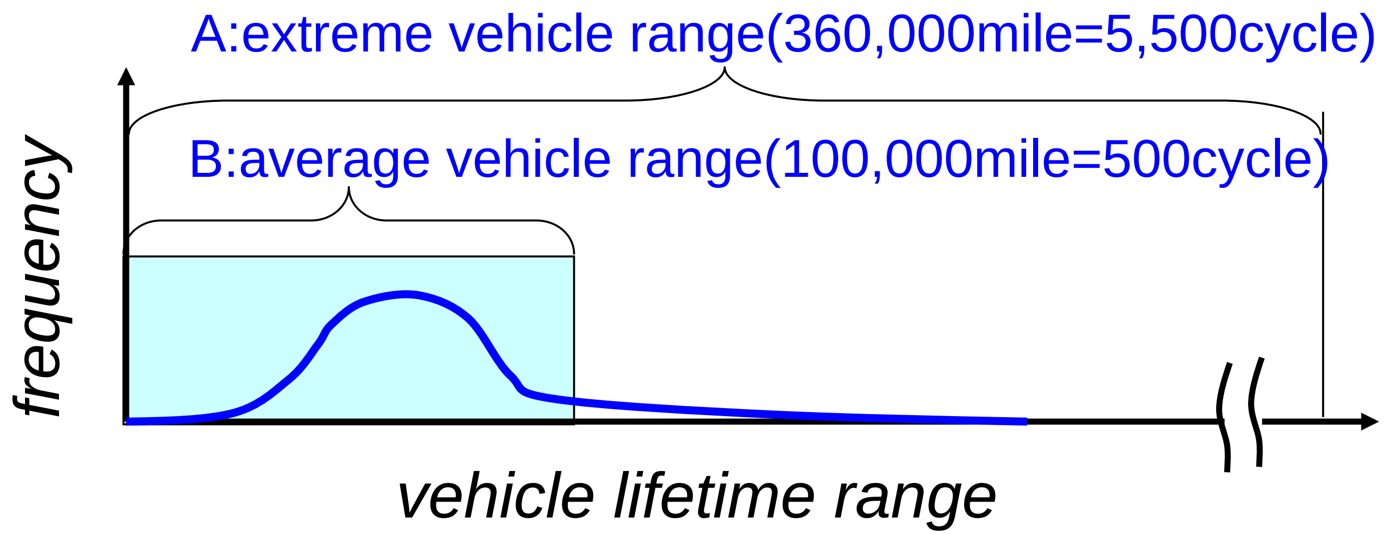
/Pneumatic cycle test(100,000mile=500cycle) is appropriate to validate the fails which could not be validated by hydraulic test.



Proposal for the 5.2.2.2(Hydraulic Cycle Sequential Test)

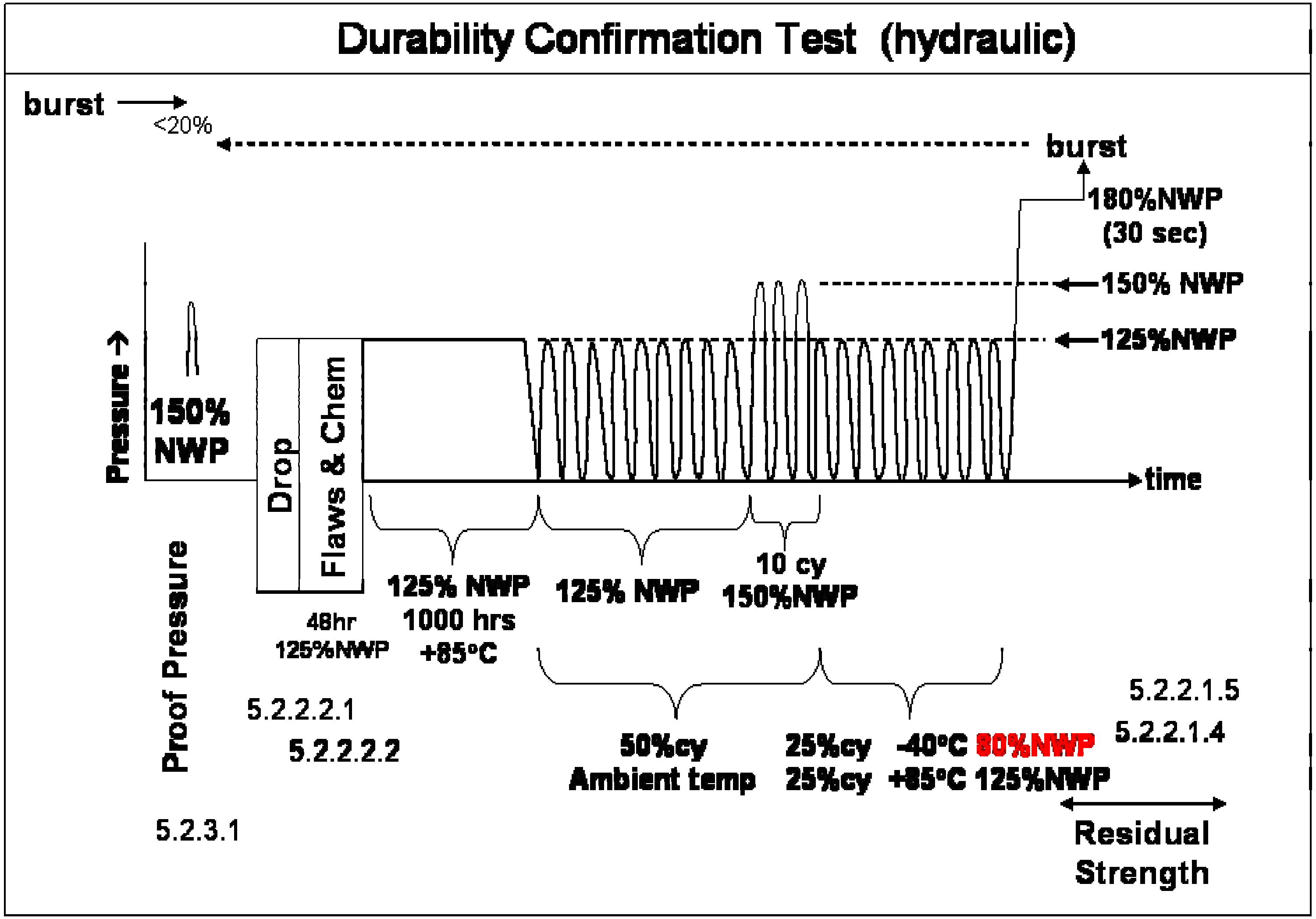
JASIC propose to change the 5.2.2.2.
Hydraulic test(5,500cy) shall be to validate the safety at end of life(15 years, extreme vehicle range)

	SGS 6-03 draft	proposal	comment
5.2.2.2	Hydraulic Cycle Sequential Test (5,500cy) -room temperature	1)Hydraulic Cycle Sequential Test (5,500cy) -extreme temperature 2) Add static pressure test of 1000hr and 85C.	Hydraulic test(5,500cy) with extreme temperature and static pressure test (1000hr,85c)shall be to validate the safety at end of life(15 years, extreme vehicle range)



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.

Proposal to add Maximum Defect Size Inspection Test(5.2.2.3.5)

/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.

Proposal to change 5.2.2.3.4 (Ambient cycling test in design qualification test)

/This test is to validate the failure mode which is not burst but leakage over the usage of extreme vehicle range(360,000mile=5,500cycle)

/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

5.2.2.1	Expected Service (Pneumatic) Performance Test
5.2.2.1.1	Fueling Performance Verification Test: Gas Pressure Cycling at Environmental Temperature Limit 5.2.2.1.1.a and 5.2.2.1.1.b
5.2.2.1.2	Parking Performance Verification Test: Static Gas Pressure Exposure at Extreme Temperature 5.2.2.1.2.a and 5.2.2.1.2.b
5.2.2.1.3	Leak/Permeation Test
5.2.2.1.4	Proof Pressure Test (Hydraulic and / or Pneumatic to be done in 5.2.2.1 and 5.2.2.2
5.2.2.1.5	Residual Strength Burst Test (Hydraulic) to be done in 5.2.2.1 and 5.2.2.2.
5.2.2.2	Durability (Hydraulic) performance Test
5.2.2.2.1	Drop (Impact) Test
5.2.2.2.2	Surface damage and Chemical Exposure Test
5.2.2.2.3	Extreme Fueling Usage; Extended Pressure Cycling Test **
5.2.2.3.1	Engulfing Fire (Bonfire) Test
5.2.2.3.2	Penetration Test
5.2.2.3.3	Ultimate Burst Pressure
5.2.2.3.4	Ambient Cycling Test in Design Qualification Test (Leak Before Break test)
5.2.2.3.5	Maximum Defect Size Inspection Test in Design Qualification Test
	Material test
5.2.3.1	1 Routine Production Quality Tests * *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

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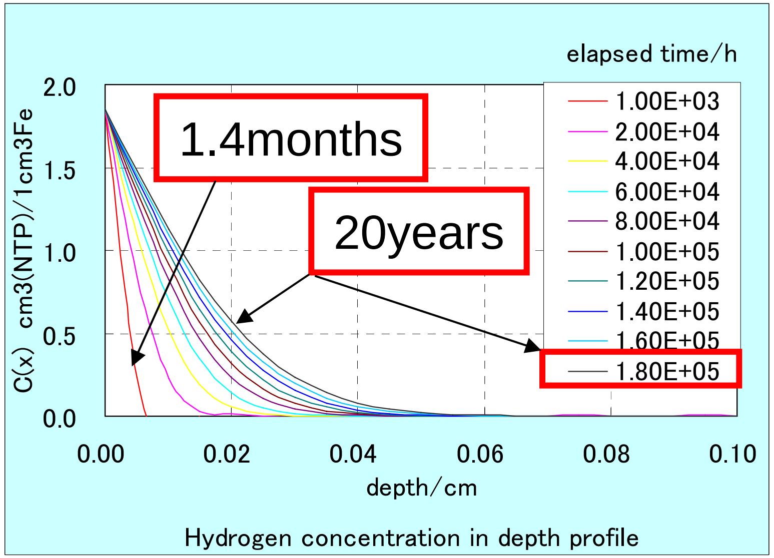
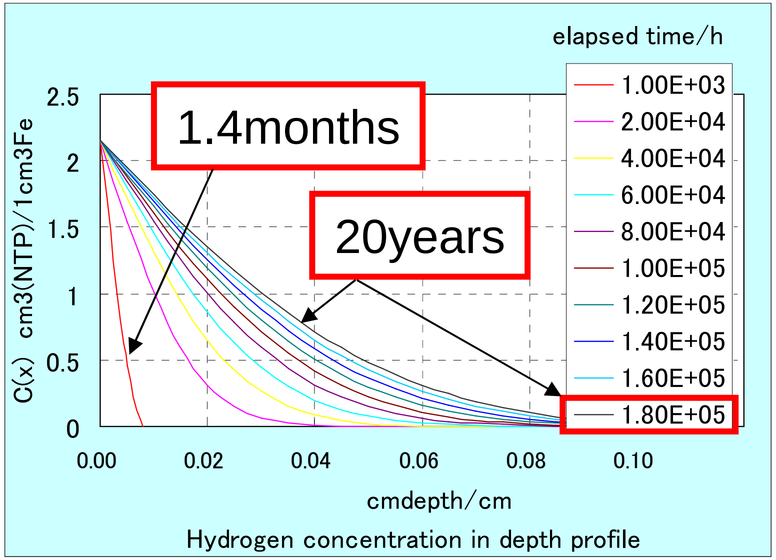
Ex.) Hydrogen Diffusion into Material

Material test with hydrogen pre-charged can evaluate hydrogen effect of all kinds of metal in reasonable period.

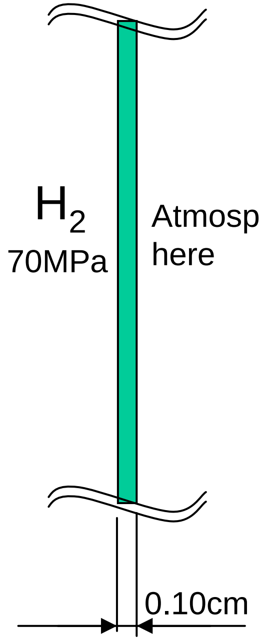
Container test of several months level can not assure the safety of the container , because hydrogen diffusion into austenitic stainless-steel is extremely slow.



70MPa 30℃



70MPa 50℃



Hydrogen diffusion into stainless-steel(SUS316L)
（One-dimensional simulation for a plate 1mm thick）

Data from ; Hasegawa et al :Boushokugizyutu 29 (1980) P.463

A. tahara Y. Hayashi : Journal of the Japan Institute of Metals 1985.49[4].248-52

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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

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Complimentary Material Test

Long term hydrogen compatibility (hydrogen embrittlement) shall be evaluated by material tests to guarantee the End of Life Safety.

<u>In future:</u>

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

<u>Current:</u>

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

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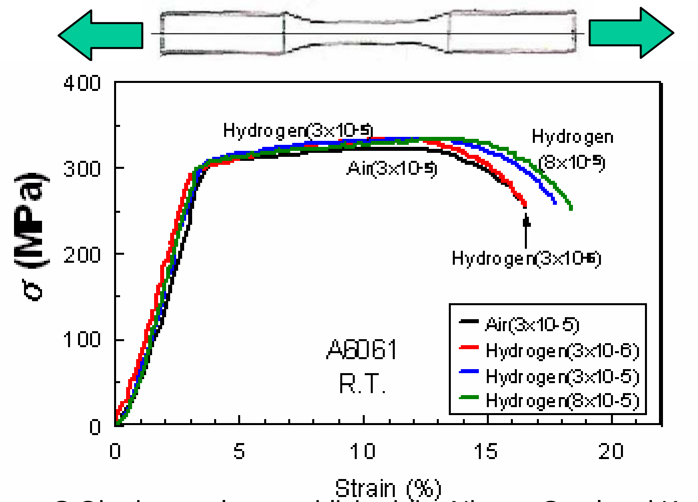
Ex.) Material Test in High Pressure Hydrogen

Current:

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

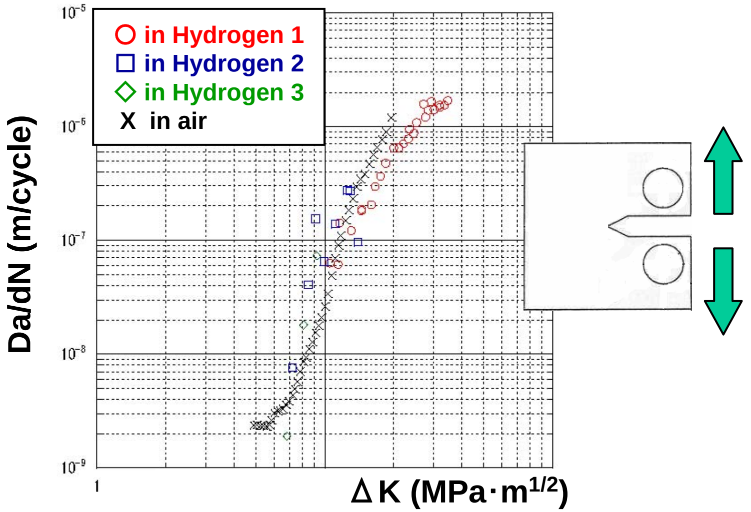
Example (The data acquired when the regulation of 35MPa was examined.)
90MPa data is under acquiring now.

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



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

SSRT（**Slow Strain Rate Technique**）



S.Ohmiya and H.Fujii ; Proc. of PVP2005, (2005) CD-ROM, Paper No.71735

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-).

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

1) Complementary material tests
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   /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

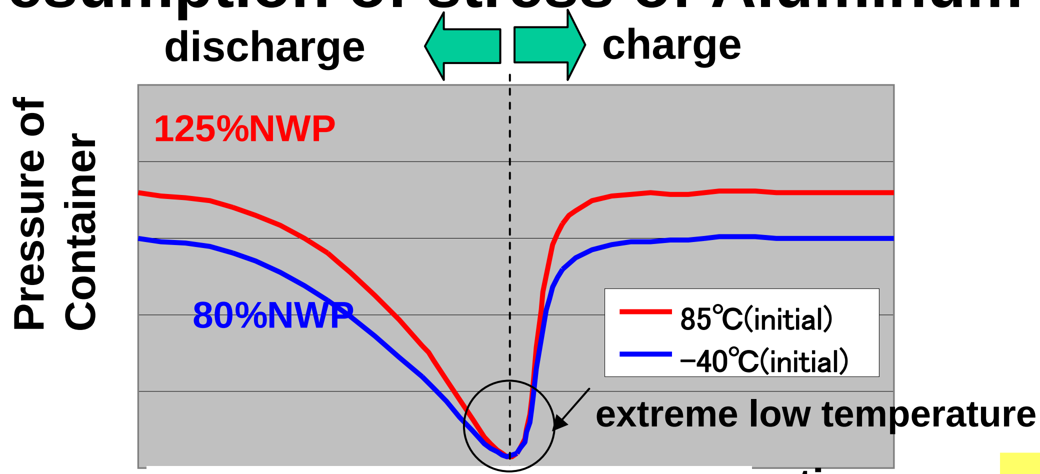


Fig.1 Pressure of Container

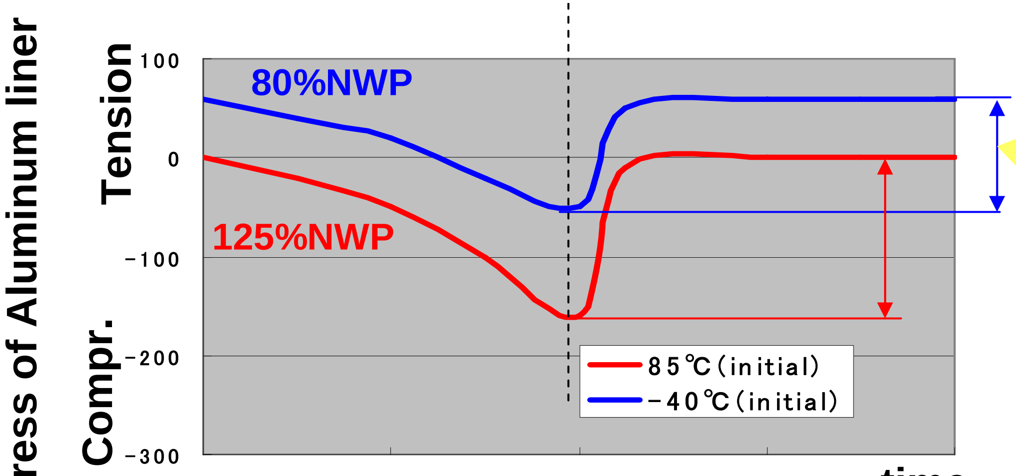


Fig.2 stress of Aluminum liner

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 between①and②in Fig.3. The liner stress of hydraulic cycle test at -40C change between①and③. Similar to ④⑤⑥at 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.

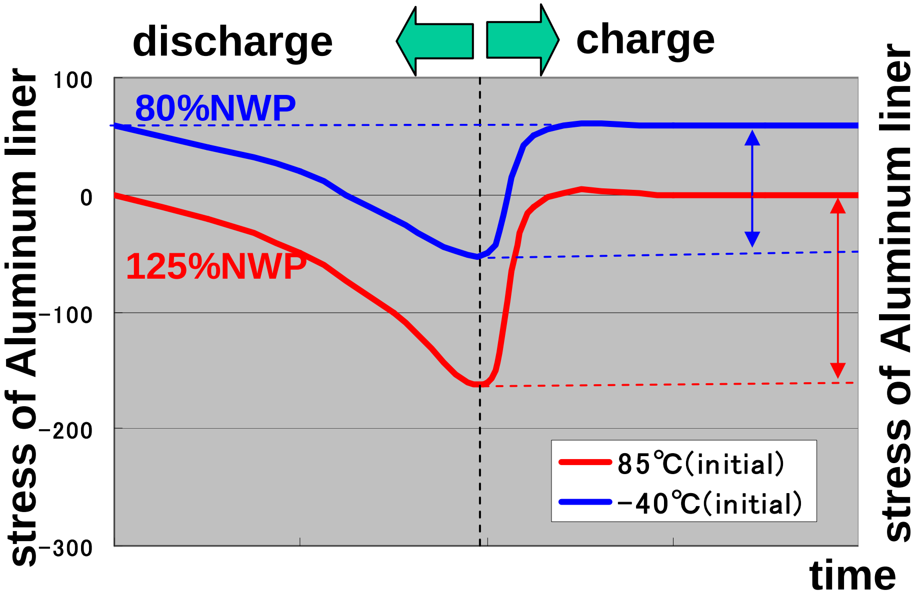


Fig.2 stress of Aluminum liner

Data by JARI

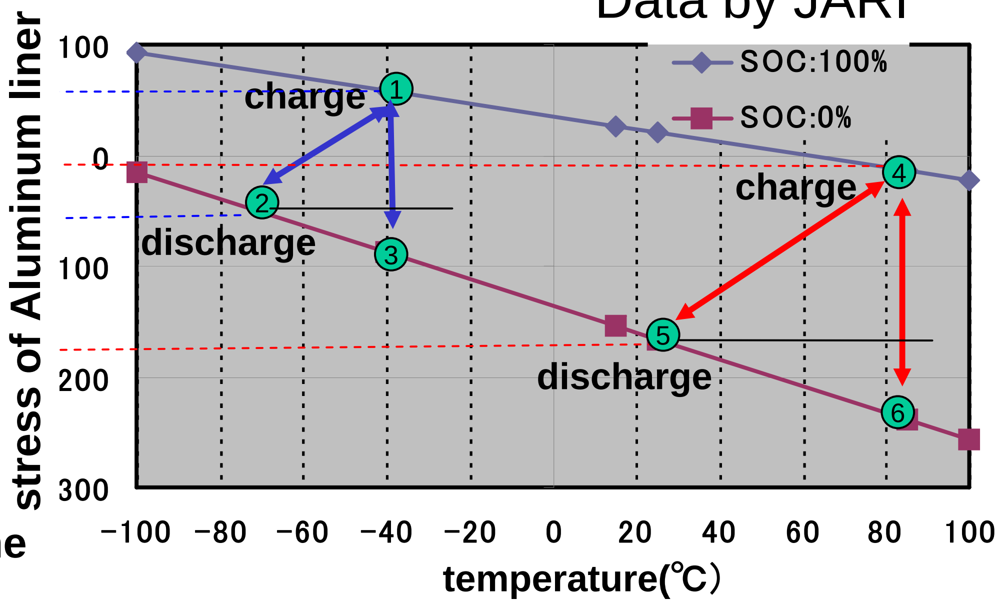
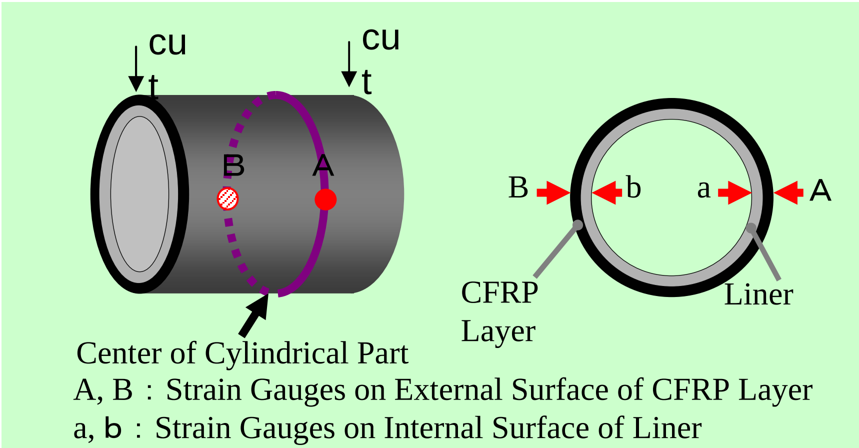
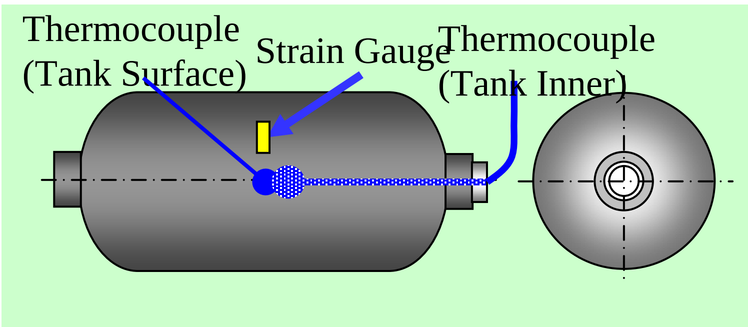


Fig. 3 stress change by temperature

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 Page23.

<table>
<tr><th></th><th>Experiment and simulation condition</th><th>Purpose</th></tr>
<tr><td>TEST1</td><td>


</td><td>/ to make clear aluminum liner stress by heat with inside and out side strain gage
/ to validate a simulation method by experiment result</td></tr>
<tr><td>TEST2</td><td>


</td><td>/ to simulate aluminum liner stress under pressure and low&high temperature
/ to validate a simulation result by out side strain gage</td></tr>
</table>

Hydraulic Pressure Cycle Test as an Alternative

Schedule

These test are performed by JARI

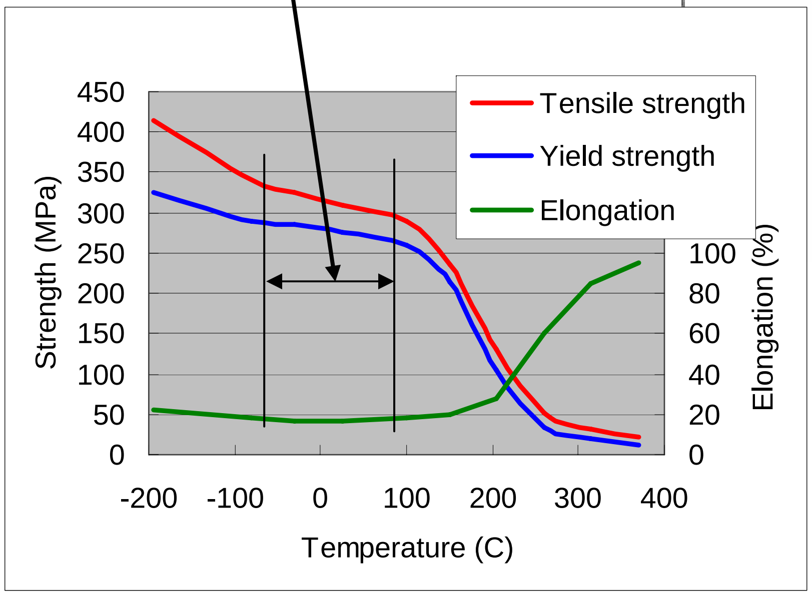
	2009												2010		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
Simulation(Test1) / to make clear aluminum liner stress by heat with inside and out side strain gage															
Simulation(Test2) / to simulate aluminum liner stress under pressure and low&high temperature															
Leak Before Brake ①-40℃、85℃ hydraulic ②pressure：2MPa～100%SOC															
Judgment															

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.

Range of temperature used



Wrought Aluminum Alloys **6•37**

Alloy and temper	Temperature °C	Temperature °F	Tensile strength MPa	Tensile strength ksi	Yield strength(b) MPa	Yield strength(b) ksi	Elongation, %(c)
	315	600	75	11	52	7.5	110
	370	700	41	6	29	4.2	130
6061-T6, -T651	−195	−320	415	60	325	47	22
	−80	−112	340	49	290	42	18
	−30	−18	325	47	285	41	17
	25	75	310	45	275	40	17
	100	212	290	42	260	38	18
	150	300	235	34	215	31	20
	205	400	130	19	105	15	28
	260	500	52	7.5	34	5	60
	315	600	32	4.6	19	2.7	85
	370	700	21	3	12	1.8	95

Data source:
Howard E. Boyer and Timothy L. Gall: METALS HANDBOOK Desk Edition, American society for metals, 1996

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END