Submitted by the expert from Republic of Korea

Informal document GRSP-73-23-Rev.1
(73rd GRSP, 15-19 May 2023
agenda item 3)

[GRSP]

Proposing methods to shorten verification test time of expected on-road performance and performance durability for Compressed Hydrogen Storage System under GTR No.13

[First topic]

A Filler Method of Reducing Hydrogen Storage Container Volume to Shorten Gas Pressure Cycling Test Time

Korea Gas Safety Corporation
Hyundai Motor Company

2023.05

▣ Outline

I. Background and purpose of research (Pneumatic)

II. Research Contents
- Test concept
- Test process
- Test result & Proposal

▣ Background and purpose of research (Pneumatic)

Verification Test takes a lot of time and cost

Ambient and Extreme Temperature Gas Pressure Cycling Test

Roughly months to a year, almost few hundreds of millions.

Test procedure

	GTR No.13	SAE J2579
Test procedure	▪ 500 cycles, 1st + 2nd Group ▪ Hydrogen gas temperature ≤-40℃ ▪ Stabilize environment for at least 24 hours ▪ Pressure: 20 (+0/-10) bar to target pressure (±10 bar) ▪ Fill rate: 3min ramp, < 60g/s (Fill rate↓ when gas temperature 85℃)	▪ 500 cycles for light-duty, 1st + 2nd Group ▪ Hydrogen gas temperature ≤-35℃ ▪ Stabilize environment for at least 24 hours ▪ Pressure: 20 (+0/-10) bar to target pressure ▪ Maintain Exhaust Speed (Manufacturer Presented)

GTR No.13

	1st Group (250cycles)		2nd Group (250cycles)
25cycles (5%)	Stabilize environment : ≤-40℃ ▷ Tank conditions ... ≥NWP X 80% ▷ Gas conditions ... First 5cycles, ≥20±5℃ ... Next 5cycles, ≤-40℃	25cycles (5%)	Stabilize environment : ≥50℃, 95% RH ▷ Tank conditions ... ≥NWP X 125%
25cycles (5%)	Stabilize environment : ≥50℃, 95% RH ▷ Tank conditions ... NWP X 125% ▷ Gas conditions ... First 5cycles, ≤-40℃	25cycles (5%)	Stabilize environment : ≤-40℃ ▷ Tank conditions ... NWP X 80%
200cycles (40%)	Stabilize environment : 20±5℃ ▷ Tank conditions ... NWP X 125%	200cycles (40%)	Stabilize environment : 20±5℃ ▷ Tank conditions ... NWP X 125%

SAE J2579

	1st Group (250cycles)		2nd Group (250cycles)
25cycles (5%)	Stabilize environment : ≤-40℃ ▷ Tank conditions ... First 10cycles, ≥NWPX80% ... remnants, ≥NWP X 100% ▷ Gas conditions ... First 5cycles, ≥20℃ ... Next 5cycles, ≤-35℃	25cycles (5%)	Stabilize environment : ≥50℃, 95% RH ▷ Tank conditions ... ≥NWP X 125%
25cycles (5%)	Stabilize environment : ≥50℃, 95% RH ▷ Tank conditions ... ≥NWP X 125% ▷ Gas conditions ... First 5cycles, ≤-35℃	25cycles (5%)	Stabilize environment : ≤-40℃ ▷ Tank conditions ... ≥NWP X 80% (first time) ... ≥NWP X 100%
200cycles (40%)	Stabilize environment : 20±5℃ ▷ Tank conditions ... NWP X 125%	200cycles (40%)	Stabilize environment : 20±5℃ ▷ Tank conditions ... NWP X 125%

▣ Research Contents_Test Concept

ISO 19881:2018 "Gaseous hydrogen — Land vehicle fuel containers"

17.3.13.2 Procedure

The hydrogen gas cycling test shall be performed in accordance with the following procedure.

The container shall be pressure cycled using hydrogen from 2 MPa ± 1 MPa to 125 % of the nominal working pressure for 1 000 cycles. The end boss at the valve end (the end where the fill/discharge occurs) may be grounded. Each cycle shall consist of filling and venting of the container. The fill rate shall not exceed 60 g/s and the maximum allowable gas temperature shall not be exceeded. The defueling rate shall be specified by the container manufacturer.

The first 500 cycles shall be conducted at the ambient temperature, followed by a static hold at 115 % of the nominal working pressure (±1 MPa) at 55 °C for a minimum of 30 h. The second 500 cycles shall be conducted with the container at an ambient temperature of −30 °C (250 cycles) and at 50 °C (250 cycles).

Subscale specimens may be used for this test with diameters reduced by as much as 20 % and lengths reduced by as much as 50 %.

Save time and cost using subscale specimens

ISO/FDIS 19884 "Gaseous hydrogen — Cylinders and tubes for stationary storage"

8.3.3 Pressure vessel tests

8.3.3.2 Use of subscale units

Where indicated, tests may be performed on full scale diameter pressure vessels of shorter length; however, the L/D ratio of sub-scale units shall be greater than 2,5. If the full scale cylinder L/D ratio is less than 2,5, a full scale cylinder is required. The winding pattern of the sub-scale unit shall be the same as the full scale pressure vessel.

Full-scale pressure vessels containing a filler material to reduce the internal volume may also be used.

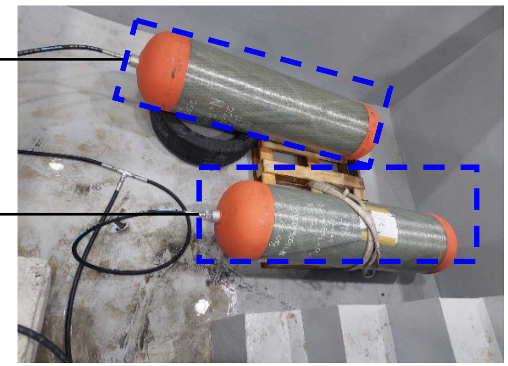
Save time and cost using containing a filler → **Our choice**

▣ Research Contents_Test process

Comparison of the volume reduced storage container(40% filler inserted, 70L) and the normal storage container by brief test

Internal insertion filler
(Liner-like material)

Container (filler O)	Container (filler X)
Volume 105L (175*0.6)	Volume 175L



Validation of the volume reduction method for reducing test time
Verification of the durability of the storage container through repeated hydraulic cycling test

Sample	Volume	-	GTR No.13			-	EC 79/2009	GTR No.13	-
		Leak test	Permeation test	Pressure cycling Test (Gas/Brief)	Permeation test	Internal inspection	Pressure cycling Test (Hydraulic)	Permeation test	Internal inspection after cutting
Container (filler O)	105L (175L*60%)	▪ 10 Mpa to 87.5 Mpa	▪ High temperature (55℃) ▪ First permeation rate① measurement	▪ Ambient(20±5℃) High(55℃) Low(-40℃) temperature Perform 5 times each	▪ High temperature (55℃) ▪ Middle Permeation rate② measurement	▪ Physical Damage Check	▪ Ambient temperature (20℃) ▪ 125% NWP ▪ 5,000 cycles	▪ High temperature (55℃) ▪ Final permeation rate③ measurement	▪ Physical Damage Check
Container (filler X)	175L								

▣ Research Contents_Test result and Proposal

The filler method test time reduction verification (up to 77%), No internal damage caused by fillers

Sample	Volume	Leak test	First permeation rate ⓐ (cc/hr/L)	Average test time	Middle Permeation rate ⓑ (cc/hr/L)	Internal inspection	Pressure cycling Test (Hydraulic)	Final permeation rate ⓒ (cc/hr/L)	Internal inspection after cutting
Container (filler O)	105L	No leak	4.57 (9.9% compared to the limit)	54min/cycle (@20℃) 67min/cycle (@55℃) 224min/cycle (@-40℃)	6.37 (13.8% compared to the limit)	No damage	▪ Pass	6.34 (13.8% compared to the limit)	No damage
Container (filler X)	175L		2.09 (4.5% compared to the limit)	109min/cycle (@20℃) 91min/cycle (@55℃) 979min/cycle (@-40℃)	5.52 (12% compared to the limit)			5.28 (11.5% compared to the limit)	

1. Depending on the container manufacturing deviation, the first permeation rate is different, and the middle permeation rate after the pressure cycling(Gas/Brief) test both satisfies the GTR No.13 (values ⓐ and ⓑ)
2. Check the test method for shorter time, lower temperature means higher effect (@20℃ 50%, @-40℃ 77%)
3. There is little effect on leakage even if the pressure cycling test(Hydraulic) is carried out with fillers in it (small difference in values ⓑ and ⓒ)
4. Checked the inside of the container and found no physical damage

[GRSP]

Proposing methods to shorten verification test times of expected on-road performance and performance durability for Compressed Hydrogen Storage System under GTR No.13

[Second topic] A Research for reducing High temperature static pressure test time for hydrogen storage containers

Korea Gas Safety Corporation

2023.05

KOREA GAS SAFETY CORPORATION

▣ Outline

▣ Background and purpose of research (Hydraulic)

Verification Test takes a lot of time

High temperature static pressure test (HTSPT)

To reduce test time, We are looking for ways to shorten a test method that takes 1,000 hours for one test

GTR No.13

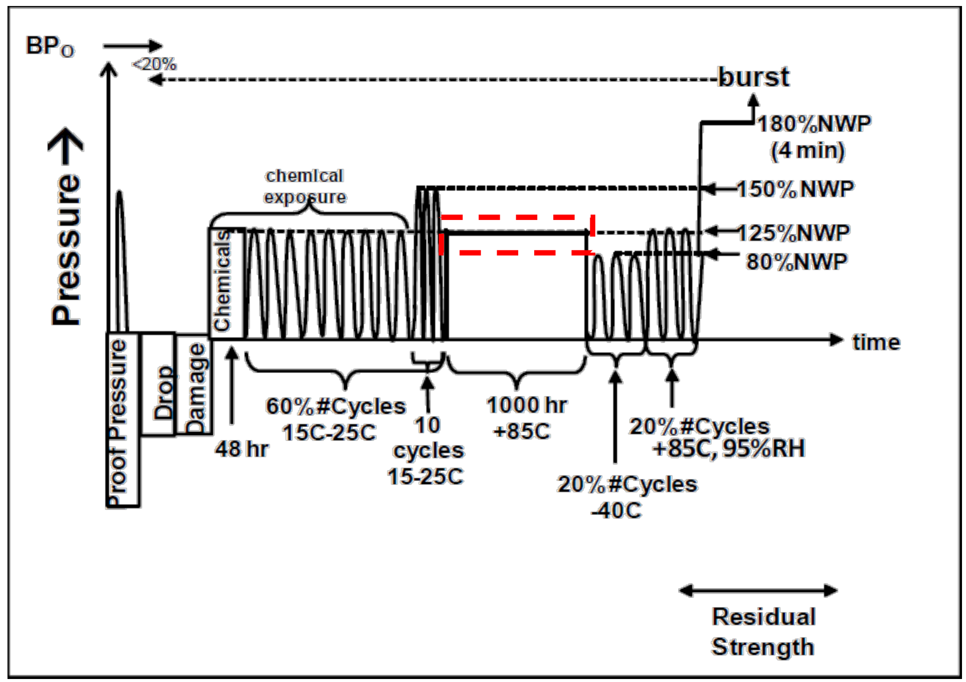
Test procedure

- Test time : 1,000 hour
- Fluid temperature : +85℃
- Fluid Pressure : 875 bar
- Fluid type : Non-corrosive fluid
- Stabilize environment for at least 24 hours

- Before High temperature static pressure test
  - Proof Pressure test
  - Drop test
  - Damage test
  - Chemical exposure and ambient-temperature pressure cycling test

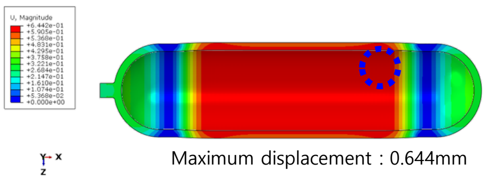
- **High temperature static pressure test**
  - test time : 1,000 hour
  - minimum test time : almost 42 days

- After High temperature static pressure test
  - Extreme temperature pressure cycling test
  - Hydraulic residual pressure test
  - Residual burst strength test



▣ Research Contents_Test process and result

Hydrogen Storage Container structural analysis for high temperature static pressure test



Maximum displacement : 0.644mm

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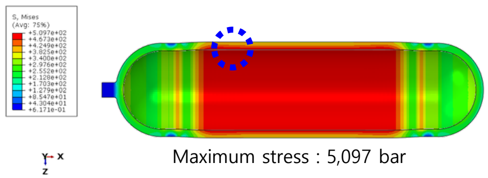
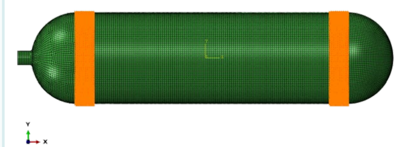


Maximum stress : 5,097 bar

< Maximum stress >

- **Hydrogen Storage Container information**
  - Weight : 120 kg
  - Length : 1.8 m
- **Analysis method**
  - Input : material properties (600h, 800h, 1000h)
  - Pressure : 875 bar



Result of structural analysis according to properties

No.		1(BASE)	2	3	4
CFRP material	Hour	-	600	800	1,000
	Temp (℃)	20	85	85	85
Result	Max. Stress (MPa)	509.7	508.5	508.6	509.7
	Max. Displacement (mm)	0.644	0.608	0.620	0.622

CFRP Properties according to temperature and test time

No.		1(BASE)	2	3	4
CFRP material	Hour	-	600	800	1,000
	Temp (℃)	20	85	85	85
Result	Tensile Strength (MPa)	2,671.25	2,535.10	2,539.67	2,582.93
	Elastic Modulus (GPa)	149.06	157.54	154.42	154.42
	Poisson's ratio	0.31	0.32	0.32	0.31

→ In the structural analysis of the container material and the tensile test that simulated in, it was confirmed that the hydrogen sotorage container for 600 and 800 hours were more vulnerable than the high-temperature static pressure for 1,000hours.

▣ Research Contents_Test process and result

Comparison of demonstration tests for actual hydrogen Storage Container

Bus Hydrogen Storage container
Before HTSPT

Bus Hydrogen Storage container After HTSPT (600h)

Bus Hydrogen Storage container After HTSPT (1,000h)

Bus Hydrogen Storage container
Residual burst strength test

Validation of the test time reduction method for reducing test time

Sample	Test Time (hour)	GTR No.13				
		Before HTSPT	HTSPT	After HTSPT	Residual burst strength test	Burst pressure (Mpa)
Container (decrease)	600	-	Temperature : 85℃ Pressure : 875 bar (125% NWP)	-	0 MPa to burst pressure	The test In progress
Container (general)	1,000					187.5

→ Based on findings of the research, we would like to propose initiating a discussion on reducing the duration time of the high temperature static pressure test.

Thank you.

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