Influences of Hydraulic Sequential Tests on The Burst Strength of Type-4 Compressed-Hydrogen Containers

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Introduction: Revision deliberation of GTR13

◆ The Global Technical Regulation No. 13 (GTR13) for hydrogen and fuel cell vehicles is now under discussion for revision.

◆ GTR13 has a basic policy that guarantees the strength of the compressed-hydrogen containers throughout the lifetime. For this policy, it is specified to ensure 180% NWP in the residual burst pressure at the End-of-Life (EOL) of the containers.

◆ The current GTR13 also specifies the minimum burst pressure requirement of 225% NWP for new containers.

◆ The initial burst pressure requirement needs to be revised to an appropriate value. The value should correlate with 180% NWP of EOL burst pressure.

NWP : Nominal Working Pressure

Cost reduction and weight reduction of containers

Conventional requirement
Introduction: Revision deliberation of GTR13

Purpose

Experiment Method

Test Results
- Example results of Burst test.
- Initial and End-of-Life burst pressures

Discussion
- Factors for the deterioration of the burst strength
- Method of how to prescribe initial burst pressure

Conclusions
Purpose

To propose a provision for an appropriate initial burst pressure.

I. (Main study) To confirm the correlation between initial burst pressure and End-of-Life burst pressure, we investigated the influence of the hydraulic sequential tests on the burst pressure of compressed hydrogen containers.

II. (Only discussion) After reviewing the results, we will propose a provision for an appropriate initial burst pressure.
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Experiment Method

- **Test Container**: 70MPa, Type-4 Container for vehicles
- **Test Method**: Evaluating any deterioration and variations of burst pressure due to the hydraulic sequential tests

*Hydraulic sequential tests*
1. Drop test
2. Surface damage test
3. Chemical exposure + Ambient temperature pressure cycling test
4. High temperature static pressure test
5. Extreme temperature pressure cycling test
6. Residual strength burst test
(1) Drop test

- Each container was dropped in three directions.

High speed camera video

Horizontal Position

> 1.8m

End plug side

Vertical Position

> 488J (about 1.5m)

Valve side

45° angle Position

> 1.8m

End plug side

Valve side
High speed camera video: Horizontal drop test
(2) Surface damage test

- Surface flaw generation
- Pendulum impacts (5 places)

Surface flaw generation

<table>
<thead>
<tr>
<th>Flaw A</th>
<th>Flaw B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>1.25mm</td>
</tr>
<tr>
<td>Length</td>
<td>25mm</td>
</tr>
</tbody>
</table>

Container surface after surface flaw generation

Dome Part Cylindrical Part Dome Part

Pendulum impacts

Dome Part Cylindrical Part Dome Part

30J

Specimen

Container surface after pendulum impacts
(3) ~ (5) Pressure cycling tests

(3) Chemical exposure + Ambient temperature pressure cycling test
(4) High temperature static pressure test
(5) Extreme temperature pressure cycling test

◆ Setting the test containers in the thermostatic chamber and pressuring the containers with the intensifier.

Thermostatic chamber

Test container

120MPa intensifier
(6) Residual strength burst test

- The container was pressurized to 180% NWP and held for 4 minutes.
- The container was pressurized again until burst.

![Example of pressure curve for residual strength burst test](image)

NWP : Nominal Working Pressure
Burst test video
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Example results of Burst tests

◆ A result of the initial burst test

◆ A result of the End-of-Life (EOL) burst test
Rupture from the cylindrical part of the container

high speed camera video: Rupture from the cylindrical part
Rupture from the dome part of the container

high speed camera video: Rupture from the dome part
Comparison result of Initial and EOL burst pressure

- The End-of-Life burst pressure decreased by about 5% from the initial burst pressure.
- The variations of the End-of-Life burst pressure were increased from that of the initial burst pressure.
Rupture point

- All the rupture points of new containers at the Bigginig of life were located in the cylindrical part.
- The rupture points of the containers at the End-of-Life were located either in the cylindrical part or in the dome part.

### Test Condition

<table>
<thead>
<tr>
<th></th>
<th>BOL</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOL</td>
<td>Initial burst pressure at the beginning of life</td>
<td>End-of-life burst pressure after the hydraulic sequential tests</td>
</tr>
<tr>
<td>EOL</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

### Rupture point

<table>
<thead>
<tr>
<th></th>
<th>Cylindrical part</th>
<th>Dome part (End plug side)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOL</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>EOL</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>
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Factors for the deterioration of the burst strength

- **Surface damage test (surface flaw and pendulum)**
  - The surface of the CFRP in the cylindrical part was directly damaged by saw cuts and by pendulum impacts.
  - It is considered that the surface damage test is the main factor for the deterioration of the burst pressure in the cylindrical part.
  - FEM analysis also assumed that a burst pressure decreased by about 5% due to the surface flaw damage.

- **Drop impact**
  - The dome part on the plug side was damaged by vertical drop test.
  - It is considered that the damage caused by the vertical drop is the main factor for the deterioration of the burst pressure in the dome part.
  - In order to clarify the influence of the drop test, we investigated the damage of containers using the non-destructive inspections.
Method of how to prescribe initial burst pressure

- setting the initial burst pressure to an appropriate value correlated with the provisions of the End-of-Life burst pressure.

The deterioration rate:
- about 5%

The variation of initial burst pressure: \( BP_0 \pm 10\% \)

The variation of EOL burst pressure: \( BP_{EOL} + 10/-15\% \)

Initial burst pressure

\( BP_0 \)

\( BP_{min} = 200\% NWP \)

EOL burst pressure

\( BP_{EOL} \)

180\% NWP

If the minimum initial burst pressure is 200\% NWP or more, the End-of-Life burst pressure of 180\% NWP will be ensured. Therefore, it is possible to lower the minimum initial burst pressure from the current 225\% NWP to 200\% NWP.
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Conclusions (1/2)

I. The hydraulic sequential tests were conducted using 70MPa compressed hydrogen containers. As a result,

- The End-of-Life burst pressure decreased by about 5% from the initial burst pressure.
- The variations of the End-of-Life burst pressure were increased from that of the initial burst pressure.
- All the rupture points of new containers were located in the cylindrical part.
- The rupture points of the containers at the End-of-Life were located either in the cylindrical part or in the dome part.

From the results, it is considered that the drop test and surface damage test are the main factors for the decrease in the burst pressure and increase of the burst pressure variation by the hydraulic sequential test.
II. Judging from the results about the deterioration and variations of the test container, it is possible to lower the minimum initial burst pressure from the current 225% NWP to 200% NWP. 200% NWP is correlated with the provisions for the residual burst pressure at the End-of-Life.
Thank you for your attention.

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This study is summarizes part of the results of "research and development of technology for hydrogen utilization - research and development on improvement and international harmonization of compressed hydrogen container regulations for FCV" consigned by the new energy and industrial technology development organization (NEDO).