SGS 6 17

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Comparison of hydrogen containers requirements

Prepared by ISO

Picture at a glance

JARI S001

Covers types 3 & 4 fuel containers up to a maximum filling pressure of 35 Mpa and a max. internal capacity of 360 l

ISO 15869

Covers types 1, 2, 3 & 4 hydrogen containers up to the WP specified by the manufacturer

EC Regulation 79/2009

Covers types 1, 2, 3 & 4 hydrogen containers up to NWP specified by the manufacturer

SAE J2579

Covers the hydrogen system and container requirements up to a NWP of 70 Mpa (no type of containers are defined)

OICA proposal

Covers hydrogen system and container requirements (no type of containers are defined)

Recommendations

- **Types of tanks**: Keep the types 1, 2, 3 and 4 to avoid performing tests that may not be necessary on some types of tanks.
- **Definitions:** Nominal working pressure (NWP): settled pressure of compressed gas at a uniform temperature of 15° C in a full container
- **NWP**: To be specified by the manufacturer.

Recommendations

- **Maximum filling pressure**: The maximum filling pressure is used to guide the designer of the container. This concept is covered by the testing program and does not need to be defined in the GTR.
- **Internal capacity:** No need to specify an upper limit.
- **Design temperature**: -40 ºC to 85 ºC

Service life and number of filling cycles
Comparison

- **All vehicles**
  - 15 000 filling cycles (EC Directives and JARI)
  - 11 250 filling cycles, representing a 15-year life of use in commercial heavy-duty vehicles (ISO and SAE)
  - 5500 cycles (OICA)
- **Exceptions**
  - 5500 filling cycles if a counter system is used (ISO)
  - 5500 filling cycles for personal vehicles (SAE)
  - 3000 filling cycles if a counter system is used or components are replaced before they exceed their specified service life (EC)

Service life and number of filling cycles

Recommendations

All vehicles

- The OICA paper allows 5500 cycles for all categories of vehicles, which represent a safety concern for vehicles that will be used in commercial service.
- The GTR text should be aligned with the ISO and SAE recommendation of 11 250 cycles for commercial use.

Service life and number of filling cycles
Recommendations

Exceptions

- The SAE approach to allow for 5500 cycles for personal vehicles will require that vehicles designed for personal use are identified as such and that measures are put in place to make sure that these vehicles never get into commercial use or that they are removed from service once the maximum number of filling cycles is reached as suggested by the EC.
- The ISO and EC approach also allows a reduced number of filling cycles (5500 cycles for ISO and 3000 for the EC) provided that a counter system is used.
- We therefore recommend that in the GTR a reduced number of cycles of 5500 be allowed with either one of the above conditions. The regulators should determine what will be easier for them to enforce.

Burst pressure
Comparison

	EC Regulation and ISO				JARI	SAE	OICA
Construction	**Type 1**	**Type 2[b]**	**Type 3**	**Type 4**	**Type 3 and 4**	**All types**	**All types**
All-Metal	2,25				2,25	**1,8**	**1,8**
Glass		2,4	3,4	3,5			
Aramid		2,25	2,9	3,0			
Carbon (NWPs less than 35 MPa)		2,25	2,25	2,25			
Carbon (NWPs greater than or equal to 35 MPa)		**2,25 (EC)** **2,0 (ISO)**	**2,25(EC)** **2,0 (ISO)**	2,25(EC) 2,0 (ISO)			

Burst pressure

Recommendations

- Use the ISO and EC directives approach where the burst pressure ratio varies with the fibres and type of tanks.
  - The burst pressure of a composite container is based directly on the stress in the fibre.
  - Different fibres have different stress rupture characteristics, therefore the safety factor should be adjusted accordingly.
  - Carbon fibre has the best stress rupture characteristics. Glass fibre has the poorest stress rupture characteristics while Aramid fibre has intermediate stress rupture characteristics
  - The burst pressure ratio specified in ISO and in the EC paper have been established based on the 40 years of experience of use of composite containers. They should not be discarded without serious considerations.

Burst pressure

Recommendations

The SAE and OICA approach should not be used for the following reasons:

- The SAE's basic approach is to define maximum possible load and then show that a container despite maximum expectable ageing/degradation, will withstand this load.
- The problem with SAE's "black box approach" is that the test procedure will have to produce all the ageing that you could see over the life-time of any type of cylinder.
  - To do that, you have to understand all the possible degradation mechanisms sufficiently well to be able to relevantly "accelerate" the ageing so that it takes less time to perform the test than the expected life-time. If the test only reproduces the ageing in part because it doesn't adequately simulate all the ageing factors, you may qualify a tank that will eventually fail before its end of life.
  - The difficulty with such an approach is that you must also you must also factor-in the variability due to manufacturing of initial strength, and also the variability of the degradation rate, parameters which also depend of container type.
  - Finally, measured BP is not necessarily representative of the state of degradation: state of degradation may be advanced without significant reduction of BP – the container is simply closer to the state of instability, i.e. a state beyond which the rate of degradation increases very rapidly, eventually leading to burst.
- For all the above reasons, it is therefore not practicable to define a single test procedure and a single end-of test BPR.

Stress ratio

Comparison and Recommendations

- Only ISO has a a criteria on both BPR and Stress Ratio. The issue is that with a BPR of 3 for instance, the stress ratio (stress at rupture/stress at nominal pressure) may be less than 3 meaning that the container is closer to the rupture limit at NWP than the BPR suggest.
- To avoid excessive degradation over time, you need the stress level (SR) to be below a certain specified value throughout the composite.
- WG 24 of ISO/TC 58/SC 3 is currently investigating these safety factors.
- We therefore recommend that the GTR include the stress ratio requirements and be revisited once the ISO/TC 58/SC 3 work on ISO/TR 13086 *Factors of safety for composite cylinders* is completed.

Material Comparison and Recommendations

- Except for the OICA paper, all the documents specify material requirements. The ISO, the EC and the SAE requirements are the same.
- Since material properties are essential requirements for the safety of containers, we recommend that they be incorporated in the GTR text.

First series of qualification tests
Comparison

- **ISO, JARI, EC**
  - Extreme temperature pressure cycling
    - ISO: 11250 hydraulic pressure cycles or 5500 hydraulic pressure cycles
    - EC: 15000 hydraulic pressure cycles or 3000 hydraulic pressure cycles
  - Hydrogen gas cycling
  - Accelerated stress rupture
  - **Permeation**
    - ISO: 2,00 cc/h/l of water capacity at 35 MPa and 2,8 cc/h/l of water capacity at 70 MPa
    - EC:6,00 cc/h/l of water capacity
  - Residual burst strength

- **SAE and OICA**
  - Extreme temperature gas cycling
    - SAE: 1000 pneumatic pressure cycles for commercial vehicles and 500 pneumatic pressure cycles for personal vehicles
    - OICA: 500 pneumatic pressure cycles
  - Static gas pressure exposure at extreme temperature
  - **Leak/Permeation**
    - SAE and OICA: 150 cc/min for standard passenger vehicles
    - A leak localized test shall be conducted to confirm that localized leakage, if any, is not capable of sustaining a flame.
  - Proof pressure
  - Residual burst strength

- In SAE and OICA, the extreme temperature gas cycling, the static gas pressure exposure at extreme temperature, the leak/permeation tests are pneumatic tests that are done in a sequence followed by a proof pressure and residual burst pressure tests

First series of qualification tests
Comparison

- All the documents require that the container or the hydrogen storage system be subjected to extreme temperature pressure cycling, hydrogen gas cycling, accelerated stress rupture test as well as permeation tests.
- The SAE and OICA papers required that these tests be carried out in a sequence and that they should be performed on the hydrogen storage system using hydrogen gas.
- The number of pneumatic pressure cycles is quite lower than the number of hydraulic pressure cycles specified in ISO and in the EC papers. The OICA paper also does not make a distinction between vehicles for personal use and commercial use as it is done in the SAE.
- Except for the hydrogen gas cycling test, the ISO, Japanese and EC tests are hydraulic tests to be performed on the container. They can be performed in parallel.

First series of qualification tests
Recommendations

- Considering that OICA and Japan are looking at alternate ways of testing to reduce the testing time and that they are both considering going back to an approach that is similar to the ISO, Japanese and the EC papers where the tests are hydraulic tests supplemented by material tests, we recommend that the tests should be hydraulic tests done in parallel.
- Further discussion should be considered for the maximum permeation rate allowed by the permeation test. The acceptance criteria for this test vary from one document to the next.

Second series of qualification tests
Comparison

- **ISO, JARI, EC**
  - Impact damage
  - Chemical exposure
  - Composite flaw tolerance
  - Ambient temperature pressure cycling
  - Leak-before-break (LBB)
  - Boss torque

- **SAE and OICA**
  - Drop Impact
  - Surface damage and chemical exposure
  - Extended pressure cycling
  - Ambient cycling test (under consideration by OICA only)

Second series of qualification tests
Recommendations

- All the documents require that the container be subjected to an impact damage (drop) test, a surface damage, a chemical exposure, and an ambient temperature extended pressure cycling test.
- The test procedures are similar and the acceptance criteria vary slightly.
- The SAE and OICA propose that these tests be done in a sequence.
- Considering that OICA and Japan are looking at alternate ways of testing to reduce the testing time, we recommend that the tests be authorized to be done in parallel and that the ISO acceptance criteria that have the highest level of consensus be used.

Second series of qualification tests
Recommendations

- **LBB**:
  - Both ISO and the EC are looking at leak-before-break requirements (the container may fail by leakage after an acceptable number of filling cycles, but not rupture).
  - OICA is also considering this approach.
  - It is important to keep the LBB concept. We could however remove the LBB test since it can be demonstrated through the ambient pressure cycling test.
- **Boss torque test**:
  - This test is covered in ISO, the Japanese and the EC papers for type 4 containers. We recommend that it be included in the GTR text.
  - It should be determined if the test should be done at 2 times (JARI and EC) or at the torque specified by the manufacturer (ISO).

Third series of qualification tests
Comparison and recommendations

- **ISO, JARI, EC**
  - Bonfire
  - Penetration
  - Hydrostatic burst
- **SAE and OICA**
  - Engulfing fire
  - Penetration
  - Hydrostatic burst

All the document require a bonfire test. It should be included in the GTR and be performed on the hydrogen storage system (container with thermally activated PRD).
Except for the Japanese documents, all papers require that a penetration test be performed on the container. This test should be included in the GTR text.
All papers require that a penetration and hydrostatic burst test be performed on the container. These tests should be included in the GTR text.

Sampling (batch) test

Comparison and recommendations

- **Sampling/Batch tests (ISO, JARI, EC and SAE)**
  - Hydrostatic burst
  - Periodic ambient temperature pressure cycling
  - Material tests
- Except for OICA, all the papers require the container be subjected to sampling (batch) tests.
- Batch tests are specified when the manufacturing process is a special process (process, the results of which cannot be entirely verified by a non-destructive test of the product such as welding, painting, etc)
- These tests are required to make sure that the manufacturing process is maintained under control and that the containers that are produced have not deviated from the design that has been approved as part of the qualification (type) tests.
- The test procedures and acceptance criteria are very similar. They should be included in the text of the GTR.

Routine (production) test

Comparison and recommendations

- Routine (Production) tests (ISO, JARI, EC and SAE)
  - Dimensional inspections, NDE and hardness test of metallic containers and liners, Inspection of plastic liners
  - Hydraulic test
  - Leak test
- Except for OICA, all the papers require the container be subjected to the routine (production) tests.
- The ISO, Japanese, the EC and the SAE test procedures and acceptance criteria are very similar. They should be included in the text of the GTR.

Conclusion

- All the papers that are being looked at by the HFCV SGS for defining the requirements that apply to the storage containers have similarities that facilitate their comparison.
- The ISO and the EC approaches are almost identical.
- The SAE and the OICA paper use a similar approach except that the OICA paper is further reducing the level of safety of the container by:
  - specifying a number of pressure cycles for the expected service performance tests and the durability tests that do not take into account that vehicles could be in commercial use;
  - not specifying any material tests
  - not specifying any batch tests
  - not specifying any routine (production tests).

Conclusion

- We have shown that it is not practicable to define a single test procedure and a single end-of test BPR as suggested by SAE and OICA and to rely only on an end of life BPR of 1,8 irrelevant of the fibre and type of tanks.
- It is instead safer to use the ISO/EC approach where the safety margins on the expected possible loss of strength is larger on type of containers that are known to be subject to a degradation mechanism that can substantially reduce their strength over life-time, as with glass-fiber/epoxy, than with composites that are known to be subject to much less degradation (e.g. Carbon/epoxy).
- Also OICA and Japan recognize that the first series of qualification test (systems-level pneumatic tests done in sequence) are quite extensive and too lengthy. They are looking at alternate ways of testing that revert back to the ISO/EC approach of using hydraulic tests performed on the containers supplemented by material tests.
- For all the above reasons, we recommend that the GTR text be extracted from the ISO paper, which represents the higher level of consensus among all the papers being looked at by the HFCV SGS.

Thank you