# VERIFICATION OF THE STRESS RUPTURE WITHSTAND TEST
***Based on Appendix H in SAE J2579 Revision 3 Post-Ballot Draft Dated 2017-03-21***

## OBJECTIVE

The current version of the Global Technical Requirement (GTR) for hydrogen and fuel cell vehicles uses only a prescriptive requirement of initial burst ratio to protect against rupture of containers in the Compressed Hydrogen Storage System (CHSS). Such a prescriptive approach as the following draw-backs:

- Causes in unnecessary over-design that increases weight and cost of the container (and the vehicle).
- Is difficult to enforce from a regulatory standpoint since the initial burst ratio requirement is a function of the container materials which may or may not be apparent to the test agency.
- Hinders the development of new materials and material-blends and new container construction designs that were not considered as part of the prescribed requirements.

To avoid the problems cited above, the automotive industry typically defines performance-based requirements that can used to verify the vehicle system or component without need for prescription. Such a performance-based method for stress rupture withstand is included with SAE J2579 to demonstrate adequacy without need for prescription, and the methodology is currently being refined in the latest revision of SAE J2579.

The objective of the proposed development is to demonstrate proof-of-concept of the methodology being developed by SAE and verify the test method in the SAE J2579 draft revision.

## DESCRIPTION OF THE APPROACH IN THE SAE J2579 DRAFT REVISION FOR VERIFICATION OF CONTAINER STRESS RUPTURE WITHSTAND

Appendix H in SAE J2579 provides an alternative to the use of prescribed initial burst pressure ratios using a performance-based methodology.

The stress rupture capability needed for a container to meet the worst-case demands of road service is estimated, and test conditions for the *Durability (Hydraulic) Performance Test in Extreme Conditions and Extended Usage* are adjusted from the standard protocol in the GTR and Section 5.2.2.3 of SAE J2579. By so doing, the adjusted test protocol in Appendix H of SAE J2579 fully address stress rupture requirements for road-service along with other conditions such as cycle fatigue, chemical exposures, and extreme thermal/pressure that can limit the useable life of the container and possibly result in failure.

Appendix H actually provides two stages of development and verification of stress rupture:

1) In Appendix H.2. the minimum initial acceptable burst pressure ratio container is determined by producing containers in a weakened state and then demonstrating that these containers can meet the performance-based stress rupture for road service based on the adjustment to the *Durability (Hydraulic) Performance Test in Extreme Conditions and Extended Usage* test protocol.
2) In Appendix H.3, production (or pre-prodution) containers are verified to meet the *Durability (Hydraulic) Performance Test in Extreme Conditions and Extended Usage* test protocol as defined in Appendix H.2.

While the second stage as found in Appendix H.3 of SAE J2579 is more appropriate as a basis for future regulatory purposes, the test methodology in Appendix H.2 is more appropriate for verification of the overall approach as it is more technically challenging and revealing.

## DESCRIPTION OF THE PROPOSED TEST PROGRAM

The proposed test program is conducted in two phases:

1. The first phase demonstrates proof of concept by testing small (subscale) Type 4 containers.

   Both carbon-fiber and glass fiber composites should be constructed so that the proof-of-concept spans the likely range of fiber characteristics expected for road service.

   In order to expedite testing and lower program cost, subscale Type 4 containers are used for these tests. All containers are designed and manufactured to the same pressure capability of 35-50 MPa. The pressure capability is intentionally below the maximum of 70 MPa so that the stress ratio on the composite structure and fibers can be evaluated by simply adjusting the assumed NWP rating of the containers. *NOTE: The container necks and end bosses should be designed in anticipation of higher level testing.*

   At least 50 subscale containers should be fabricated for both carbon and glass fiber COPVs. The tanks are then divided into groups of 10 for each fiber.

   The first group of ten for each fiber is subjected to initial burst testing (as defined in Appendix H.2 of SAE J2579) in order to establish the baseline capability for the production lot.

   Subsequent groups of containers for each fiber are tested to the modified *Durability (Hydraulic) Performance Test in Extreme Conditions and Extended Usage* test protocol (as defined in Appendix H.2) at progressively higher pressure levels, simulating containers designed to higher NWPs, until the highest pressure level is determined at which all containers in the group can pass. (See the detailed test description below for guidance).

In addition to providing proof-of-concept, this testing will also demonstrate the minimum burst pressure of the containers for each fiber type (as defined in Appendix H.2). These results can be compared to current prescribed levels to quickly understand potentially how much embedded margin exists in current prescribed levels for initial burst ratio.

2. The second phase demonstrates that the pressure hold at 1.5xNWP/85C can detect if the liner of Type 3 container is imposing additional stress on the composite and thereby reduces the stress rupture life.

   At least 20 small (subscale) Type 3 containers should be produced with both carbon and glass fibers. The composite structure should be designed to produce the minimum capability demonstrated in the first phase of testing for the Type 4 containers. The liner should be designed and autofettaged to impose a “meaningful” additional pressure on the composite structure. As before, the tanks are divided into groups of 10 for each fiber.

   The first group of ten is subjected to initial burst testing (as defined in Appendix H.2 of SAE J2579) in order to establish the baseline capability for the production lot.

   The second group of 10 containers for each fiber are tested to the adjusted *Durability (Hydraulic) Performance Test in Extreme Conditions and Extended Usage* test protocol (as defined in Appendix H.2) at the pressure deemed acceptable for Type 4 containers.

   Assuming the liners of the Type 3 containers are producing a significant additional stress on the composite, some or all the containers in the group should fail the test, depending on the amount of additional stress compared to the possible 20% span in initial burst pressure.

   The additional stress on the composite structure can be estimated by comparing the percentage of failed tanks to additional initial burst pressure required to be above that percentage.

**<u>ESTIMATED COST OF TEST PROGRAM</u>**

A rigorous “bottoms up” cost estimate has not been developed, but the following estimates were developed to scope the cost of this program.

If we assume that at least 50 subscale Type 4 containers and 20 subscale Type 3 containers are produced for both carbon and glass fibers at roughly $2000 per container, the estimated material cost for the program is about $280,000.

Furthermore, if we assume that materials is typically 20 - 33% of overall program cost. and overall cost for the proof-of-concept phase is $850,000 - 1,400,000.

**DETAILED DESCRITION OF THE PROOf-OF-CONCEPT TEST FOR PHASE 1**

***Definition of COPVs to be Used for Proof-of-Concept***

- As a minimum, glass and carbon COPVs should be part of the verification to demonstrate likely extremes of stress rupture capability.
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- Type 4 vessels are preferred as the composite over-wrap clearly carries the pressure-bearing loads and there is no "sharing" with liners.

- The NWP of containers should be nominally 35-50 MPa with all samples targeted to the same NWP. The burst pressure of the vessels shall meet the values prescribed for $BP_{min}$ based on the particular fiber material and the design NWP of the container.

  The end bosses and tanks of the tank should be designed for 70 MPa so that testing may be conducted on containers to this rating using the procedure defined below.

  *Note: Limiting the NWP of the Type 4 containers provides the capability to increase the stresses by simply raising the pressure to simulate design margins.*

- The test containers may be significantly smaller than containers used on vehicles as long as the materials of construction and the fabrication approach are the similar.

- At least 50 containers of each fiber type should be produced for testing.

***Test Procedure For Each Fiber Type***

1. The qualification batch shall be divided into (at least) 5 groups with (at least) 10 containers in each group.

2. The first group of containers shall be burst tested to establish the representative distribution of the verification batch per Appendix H2.2.

   a) The burst pressure of all vessels in the first group should be greater than or equal to the minimum allowable burst pressure ($BP_{min}$ as defined above).
   b) The burst pressure of all vessels in the first group should be within ±10% of each other.

3. The second group of tanks are subjected to the *modified* test protocol in H.3.1 following the procedure in H.3. One additional modification to the test in H.3 might be to allow adjustment of the cut depth for corrosion damage if the thickness of the composite is significantly less than planned production.

   The tanks in this second group should pass the adjusted test protocol (as defined in H.2), given the presumed conservatism of the prescribed burst pressure ratio. If this is not the case, then the appropriateness of continuing verification with this batch of containers should be considered.

4. The third group of containers is tested like the second group except that the pressure level for all pressure cycles and pressure holds is raised by 10% to increase stress in the pressure-bearing composite and thereby simulate a group of tanks that is “rated” 10-15% higher than the prescribed value.  See the procedure in H.2.3.2 for details in applying the pressure corrections.

   If all the containers in third group pass the adjusted test protocol, then the pressure level for all pressure cycles and pressure holds is raised by another 10-15% to increase stress in the pressure-bearing composite and thereby simulate a group of tanks that is “rated” 20% higher than the prescribed value.

   The process is repeated in until a group experiences a failure.

5. After one or more failures are experienced, test a group of containers that is part-way  between the group with a failure and the last group that did not fail.  The amount of pressure adjustment can be estimated based on the percentage of tanks that failed in the last group compared to the increase in initial burst pressure required to produce that percentage improvement.

6. Having completed the testing, one can then determine the production targets based on a very low probability of producing a container with a burst pressure of $BP_{min}$.  See Appendix H.2 for guidance.