



BSI Standards Publication

Gaseous hydrogen — Land vehicle fuel containers

National foreword

This British Standard is the UK implementation of ISO 19881:2025. It supersedes BS ISO 19881:2018, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/6.

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© The British Standards Institution 2025
Published by BSI Standards Limited 2025

ISBN 978 0 539 17075 7

ICS 43.060.40; 71.100.20

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 June 2025.

Amendments/corrigenda issued since publication

Date	Text affected



**International
Standard**

ISO 19881

Gaseous hydrogen — Land vehicle fuel containers

*Hydrogène gazeux — Réservoirs de carburant pour véhicules
terrestres*

**Second edition
2025-06**

Reference number
ISO 19881:2025(en)

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Foreword

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This document was prepared by Technical Committee TC 197, *Hydrogen technologies*.

This second edition cancels and replaces the first edition (ISO 19881:2018), which has been technically revised.

The main changes are as follows:

- harmonization with UN GTR 13 Phase 2 with focused modifications to the fire test;
- fire test pre-test conditions included as Annex material.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The purpose of this document is to promote the implementation of hydrogen powered land vehicles through the creation of performance-based testing requirements for compressed hydrogen fuel containers. The successful commercialization of hydrogen land vehicle technologies requires standards pertaining to fuelling stations, vehicle fuel system components and the global homologation of standards requirements for technologies with the same end use. This will allow manufacturers to achieve economies of scale in production through the ability to manufacture one product for global use.

This document is based on the CSA Standard ANSI/HGV 2-2014 and UN GTR No. 13.

Gaseous hydrogen — Land vehicle fuel containers

1 Scope

This document specifies requirements for the material, design, manufacture, marking and testing of serially produced, refillable containers intended only for the storage of compressed hydrogen gas for land vehicle operation. These containers:

- a) are permanently attached to the vehicle;
- b) have a capacity of up to 1 000 l water capacity;
- c) have a nominal working pressure that does not exceed 70 MPa.

This document is applicable only to fuel containers containing gaseous hydrogen according to ISO 14687 for fuel cell and internal combustion engine land vehicles. This document specifies requirements for hydrogen fuel containers acceptable for use on-board the following types of land vehicles: light-duty vehicles, heavy-duty vehicles and industrial powered trucks, such as forklifts and other material handling vehicles. Requirements for other types of land vehicles such as rail, off-road, etc., can be derived with due consideration of appropriate service conditions.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 148-1, *Metallic materials — Charpy pendulum impact test — Part 1: Test method*

ISO 306, *Plastics — Thermoplastic materials — Determination of Vicat softening temperature (VST)*

ISO 7866:2012, *Gas cylinders — Refillable seamless aluminium alloy gas cylinders — Design, construction and testing*

ISO 9809-1:2019, *Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 1: Quenched and tempered steel cylinders and tubes with tensile strength less than 1 100 MPa*

ISO 9809-2:2019, *Gas cylinders — Design, construction and testing of refillable seamless steel gas cylinders and tubes — Part 2: Quenched and tempered steel cylinders and tubes with tensile strength greater than or equal to 1 100 MPa*

ISO 11363-1, *Gas cylinders — 17E and 25E taper threads for connection of valves to gas cylinders — Part 1: Specifications*

ISO 11439:2013, *Gas cylinders — High pressure cylinders for the on-board storage of natural gas as a fuel for automotive vehicles*

ISO 11926-1, *Connections for general use and fluid power — Ports and stud ends with ISO 725 threads and O-ring sealing — Part 1: Ports with O-ring seal in truncated housing*

ISO 19882, *Gaseous hydrogen — Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*

ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

ASTM D2344/D2344M, *Standard Test Method for Short-Beam Strength of Polymer Matrix Composite Materials and Their Laminates*

ASTM D3359, *Standard Test Methods for Rating Adhesion by Tape Test*

ASTM D3418, *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry*

ASTM D4138, *Standard Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross Sectioning Means*

ASTM D7091, *Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals*

ASTM E8/E8M, *Standard Test Methods for Tension Testing of Metallic Materials*

ASTM E23, *Standard Test Methods for Notched Bar Impact Testing of Metallic Materials*

ASTM G154, *Standard Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Materials*

CGA C-1-2009, *Methods for Pressure Testing Compressed Gas Cylinders and Tubes*

ECE/TRANS/180/Add.13/Amend.1 UN GTR No. 13, UN Global Technical Regulation on Hydrogen and Fuel Cell Vehicles

SAE J2579, *Standard for Fuel Systems in Fuel Cell and Other Hydrogen Vehicles*

SAE J2601, *Fueling Protocols for Light Duty Gaseous Hydrogen Surface Vehicles*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

autofrettage

pressure application procedure, used in manufacturing composite containers with metal *liners* (3.15), which strains the *liner* (3.15) past its yield point sufficiently to cause permanent plastic deformation that results in the *liner* (3.15) having residual compressive stresses and the fibres having residual tensile stresses at zero internal pressure

3.2

burst pressure

highest pressure reached in a container during a burst test

3.3

composite

filament and resin system

3.4

compressed hydrogen storage system

CHSS

system designed to store compressed hydrogen fuel for a hydrogen-fuelled vehicle, composed of a container, container attachments (if any), and all primary closure devices required to isolate the stored hydrogen from the remainder of the fuel system and the environment

3.5

container category

unique class of containers that are intended for a specific usage

3.5.1

Category A

class of containers that are intended to be used in light-duty and heavy-duty land vehicle applications, regardless of the potential for further qualification to the UN GTR No. 13 for hydrogen and fuel cell vehicles

3.5.2

Category B

class of containers of 70 MPa nominal working pressure that are intended to be further qualified in accordance with the UN GTR No. 13 for hydrogen and fuel cell vehicles

3.5.3

Category C

class of containers that are intended to be used on hydrogen powered industrial trucks

Note 1 to entry: For examples of industrial trucks, see ISO 5053-1.

Note 2 to entry: Requirements for fuel cell power systems for electrically powered industrial trucks, where Category C containers can be used, can be found in IEC 62282-4-101.

3.5.4

container

pressure-bearing component on the vehicle that stores the primary volume of hydrogen fuel in a single chamber or in multiple permanently interconnected chambers

3.5.5

container attachments

non-pressure bearing parts attached to the container that provide additional support and/or protection to the container and that may be only temporarily removed for maintenance and/or inspection only with the use of tools

3.6

container type

classification of container design as a function of its constituent parts

3.6.1

Type 1

metal container

3.6.2

Type 2

container which contains a metal *liner* ([3.15](#)) reinforced with a resin impregnated continuous filament (*hoop-wrapped* ([3.12](#)))

Note 1 to entry: See [3.12](#).

3.6.3

Type 3

container which contains a metal *liner* ([3.15](#)) reinforced with a resin impregnated continuous filament (*fully-wrapped* ([3.11](#)))

Note 1 to entry: See [3.11](#).

3.6.4

Type 4

container which contains a resin impregnated continuous filament with a nonmetallic *liner* ([3.15](#))

Note 1 to entry: See [3.3](#).

3.7

design family

group of containers consisting of one fully qualified design and variations on that design that comply with [Table 11](#)

3.8

destroyed

in a state of alteration making a container physically unusable for its purpose

3.9

dry hydrogen

hydrogen that meets or exceeds the quality level in ISO 14687

3.10

fold

place where two material flows meet in such a manner as to create a sharp visual groove

3.11

fully-wrapped

reinforced by a *composite* (3.3) material applied over the entire *liner* (3.15) including the domes

3.12

hoop-wrapped

reinforced by a *composite* (3.3) material applied in a substantially circumferential pattern over the cylindrical portion of the *liner* (3.15) so that the filament does not transmit any significant stresses in a direction parallel to the container longitudinal axis

3.13

leakage

release of contents through a defect or crack

3.14

leak test gas

gas for testing leaks that consists of *dry hydrogen* (3.9), dry helium or blends that contain these gases at a detectable level

3.15

liner

inner container or gas container to which the overwrap is applied

3.16

maximum fuelling pressure

MFP

maximum pressure applied to a compressed system during fuelling

Note 1 to entry: The maximum fuelling pressure is 125 % of the *nominal working pressure* (3.19).

3.17

minimum required burst pressure

minimum *burst pressure* (3.2) that is to be met during a burst test and which is needed to demonstrate the required *stress ratio* (3.27)

3.18

normal cubic centimetres

Ncm³

dry gas that occupies a volume of 1 cm³ at a temperature of 293,15 K (20 °C) and an absolute pressure of 101,325 kPa

3.19

nominal working pressure

container pressure, as specified by the container manufacturer, at a uniform gas temperature of 15 °C and full state of charge

3.20

permanently attached

intended to remain fixed to a particular vehicle for the lifetime of the container or vehicle, whichever comes first

3.21

permeation

diffusion of the gaseous contents to the atmosphere at a molecular level, by means of pores or molecular gaps

3.22

pressures

forces applied perpendicular to the surface of an object per unit area over which that force is distributed

3.22.1

autofrettage pressure

pressure to which a container is taken with the intent of yielding the *liner* (3.15) or inner surface of the container

Note 1 to entry: The autofrettage operation is considered to be part of the manufacturing operation and is conducted prior to proof testing.

3.22.2

fill pressure

pressure attained at the actual time of filling

Note 1 to entry: Fill pressure varies according to the gas temperature in the container, which is dependent on the filling parameters and the ambient conditions. The maximum fill pressure should not exceed 125 % of the *nominal working pressure* (3.19).

3.22.3

hydrostatic pressure

pressure to which a container is taken during acceptance testing

3.23

pressure relief device

PRD

device that, when activated under specified performance conditions, is used to vent the container contents

3.24

rejectable damage

damage as outlined in CGA C-6.4 and in agreement with the container manufacturer's recommendations

3.25

rupture

sudden and unstable damage propagation in the structural components of the container resulting in loss of contents

3.26

settled temperature

uniform gas temperature after any change in the temperature caused by filling has dissipated

3.27

stress ratio

minimum ultimate strength of the fibre, as determined in pressure container burst tests, divided by the stress in the fibre at the *nominal working pressure* (3.19)

3.28

thermally-activated pressure relief device

non-reclosing PRD that is activated by temperature to open and release hydrogen gas

4 Service conditions

4.1 General

4.1.1 Standard service conditions

The standard service conditions specified herein are provided as a basis for the design, manufacture, inspection, testing and approval of containers that are to be permanently attached on vehicles and used to store compressed hydrogen for use as a fuel on-board the vehicles. Containers are intended to be installed on vehicles based on SAE J2578, SAE J2579, IEC 62282-4-101, or UN GTR No. 13. Other equivalent standards and applicable regulations can exist.

4.1.2 Container category

Category A, Category B and Category C containers are intended to provide a sufficient level of safety for the intended application, but test methods and records are different.

4.1.3 Service life

The service life for the containers shall be specified by the container manufacturer. The specified life shall not be less than 10 years or greater than 25 years as defined in [4.3](#).

4.1.4 Periodic in-service inspections

Any requirements and procedures for periodic re-qualification by inspection or testing during the service life shall be specified by the container or vehicle manufacturer on the basis of use under the service conditions specified herein. For containers that require periodic re-qualification by inspection or testing, the container label shall identify this requirement according to [Clause 15](#). Guidance on periodic inspection is included in [Annex A](#).

NOTE National legislation that override the requirements of this document can exist.

4.2 Pressures

4.2.1 Nominal working pressures

This document applies to containers that have a nominal working pressure, as specified by the container manufacturer, of 35 MPa or 70 MPa at 15 °C, hereinafter referred to in this document as the following:

- a) “H35” — 35 MPa;
- b) “H70” — 70 MPa.

4.2.2 Maximum pressures

Containers are designed to be filled to a pressure not exceeding any of the following conditions.

- a) A pressure that would settle to the nominal working pressure at a settled temperature of 15 °C. The fill pressure shall be temperature compensated to prevent pressures from exceeding the maximum pressures that are defined.
- b) Normally up to 125 % of the nominal working pressure immediately after filling, regardless of the gas temperature, and infrequently up to 150 % under dispenser fault conditions.

4.3 Maximum number of filling cycles

Containers are designed to be filled to pressures not exceeding the requirements of [4.2.2](#), as follows:

a) Category A:

For a maximum of 750 times the service life of the container in years for a minimum of 10 years and a maximum of 25 years.

b) Category B:

For a maximum of 7 500 cycles, or 11 000 cycles for a service life of 25 years or less.

c) Category C:

For a maximum of 1 125 times the service life of the container in years for a minimum of 10 years and a maximum of 25 years.

NOTE 1 Refer to [E.3](#), [E.4](#) and [E.5](#) for the rationale on container fill cycles.

NOTE 2 Containers are expected to be removed from service when the service life used in the design qualification has expired, consistent with the labelling requirements in [Clause 15](#).

4.4 Temperature range

4.4.1 Settled gas temperatures

Settled temperature of the gas in containers may vary from -40 °C to 85 °C .

4.4.2 Container temperatures

The temperature of the container materials may vary from -40 °C to 85 °C . The manufacturer may choose to test beyond these temperatures.

4.4.3 Extreme gas temperatures

Gas temperatures beyond the limits described in [4.4.1](#) during filling and discharge are permissible for fault tolerance justification.

Safe Type 4 container operation is assured if subjected to transient gas temperature excursions below -40 °C per the liner ductility requirement to -50 °C in accordance with [6.7](#). Caution should be exercised regarding the low temperature performance of container primary closure devices such as shut-off valves, check valves, and thermal pressure relief devices (TPRDs).

Safe Type 4 container operation is assured if subjected to transient gas temperature excursions above 85 °C per the liner softening temperature requirement of 95 °C in accordance with [6.7](#), and the resin T_g requirement of 105 °C in accordance with [6.6](#). Caution should be exercised regarding the elevated temperature performance of container primary closure devices such as shut-off valves, check valves, and TPRDs.

Containers qualified to meet this document shall be capable of being filled safely utilizing SAE J2601 series fuelling protocol(s) or an equivalent fuelling protocol.

4.4.4 Test temperatures

Unless otherwise specified, all tests shall be conducted at ambient temperature ($20\text{ °C} \pm 15\text{ °C}$).

4.5 Gas composition

Containers made according to this document are designed to be used with hydrogen fuel complying with ISO 14687 or SAE J2719. Containers made according to this document can also be used for hydrogen road vehicles with hydrogen fuel (Type I Grade A) complying with ISO 14687.

4.6 External surfaces

The external surfaces of the container shall be designed to be resistant to environmental conditions outlined in [17.3.3](#).

4.7 Installation requirements

The container manufacturer shall provide information to the vehicle manufacturer or system integrator as necessary to support proper installation in the vehicle.

The vehicle manufacturer or system integrator shall be responsible for the protection of the container, container valves, pressure relief devices and connections as required.

If this protection is mounted to the container, the design and method of attachment shall be approved by the container manufacturer. Factors to be considered include the ability of the container to support the transferred impact loads and the effect of local stiffening on container stresses and fatigue life.

Containers are intended to be protected from accidental cargo spillage and from mechanical damage. This document contains no requirements for container integrity in a vehicle collision. Container locations and mountings should be designed to provide adequate impact protection to prevent container failure in a collision.

5 Conformance

Conformance to the design and test requirements shall be required, without exception. If there is evidence of a fault in carrying out a test or an error in measurement, another test shall be performed. If the results of this test are satisfactory, the results of the prior test shall not be a basis for rejection.

6 Material qualification tests and requirements

6.1 General

All structural materials shall be traceable to their original manufacturer's certified test reports. The materials shall meet performance quality, as specified and controlled by the container manufacturer. Materials not in conformance with the original manufacturer's design specifications are not authorized.

[Table 1](#) summarizes specific material tests that are required herein subsequently.

Table 1 — Material tests

Material tests	Clause	Material type	Container type			
			1	2	3	4
Impact test	6.3.2	Steel	•	•	•	•
Tensile test	6.3.3	Metals	•	•	•	•
Sustained load cracking test	6.3.4	Aluminium	•	•	•	•
Corrosion test	6.3.5	Aluminium	•	•	•	•
Ultraviolet resistance test	6.4	External coatings	•	•	•	•
Shear strength test	6.6	Resins		•	•	•
Glass transition temperature test	6.6	Resins		•	•	•
Tensile test	6.7	Nonmetallic liners				•
Softening temperature test	6.7	Nonmetallic liners				•
Tensile test	9.3	Nonmetallic liner welds				•

6.2 Material requirements

Materials in constant contact with hydrogen shall be determined to be acceptable in hydrogen service, without any concern for hydrogen embrittlement and hydrogen accelerated fatigue. The performance tests cannot guarantee that all cases and conditions of hydrogen service will be validated, so it is still incumbent on the container manufacturer to carefully screen materials of construction for their intended use. The materials and design shall be such that there will be no significant change in the functioning of the container, deformation or mechanical change in the container, and no harmful corrosion, deformation or deterioration of the materials when subject to the service conditions provided in [Clause 4](#).

NOTE Material performance data and/or acceptance criteria in hydrogen environments can be found in ISO/TR 15916, ANSI/CSA CHMC 1, ASME B31.12, and SAE J2579, Appendix B.

Nonmetallic materials normally in contact with hydrogen shall be verified to be acceptable in hydrogen service. Consideration shall be given to the fact that hydrogen diffuses through these materials more easily than through metals; therefore, the suitability of materials shall be verified under prolonged hydrogen exposure. Nonmetallic materials shall retain their mechanical stability with respect to strength (e.g. fatigue properties, endurance limit, creep strength, elasticity) when exposed to the full range of service conditions and lifetime as specified by the container manufacturer. Materials shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation. The chemical and physical properties necessary for operational safety shall not be significantly affected within the scheduled lifetime of the equipment unless a replacement is foreseen; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, aging resistance, the effects of temperature variations, the effects arising when materials are put together (for example, galvanic corrosion), the effects of ultraviolet radiation and the degradation effects of hydrogen on the mechanical performance of a material.

6.3 Metal containers and metal liners

6.3.1 Material properties

Steels shall be aluminium killed and produced to predominantly fine-grained structure. The container manufacturer shall demonstrate that exposure to high-pressure hydrogen under the service conditions provided in [Clause 4](#) does not cause any harmful corrosion, deformation, or deterioration of the material. The chemical composition of all steels shall be declared and defined at least by:

- a) carbon, manganese, aluminium and silicon content in all cases;
- b) nickel, chromium, molybdenum, boron, vanadium or any other elements that are deliberately added.

Aluminium alloys shall be specified in accordance with specifications and guidelines of the Aluminum Association practice for the given alloy system. The impurity limit for lead and bismuth in any aluminium alloy shall not exceed 0,003 % each. Aluminium alloys 6351 and 6082 shall not be used.

6.3.2 Impact test for steel

The impact properties of the steel in the finished container or liner shall be determined in general accordance with ISO 148-1 or ASTM E23. The impact test pieces shall be taken from the wall of the container in the transverse direction. The notch plane orientation shall be in the direction perpendicular to the circumference and along the length. Test pieces with a width of less than 5 mm shall be taken from the longitudinal direction. If the wall thickness does not permit a final test piece width of 10 mm, the width shall be as near as practicable to the nominal thickness of the container wall. All impact tests shall be conducted at ≤ -40 °C. Impact values shall not be less than that indicated in [Table 2](#).

Table 2 — Impact Values (See [6.3.2](#))

Width of the test piece	(mm)	$5,0 \leq \text{width} < 7,5$	$7,5 \leq \text{width} < 10,0$
Impact strength	(J/cm ²)	35	40

- a) Impact values for test pieces of width less than 5 mm shall be based on special studies of particular materials and particular specimens.
- b) Required average results of three specimens.
- c) Not more than one specimen shall break at less than the average value required, and no single specimen shall break at less than 80 % of the average value.

6.3.3 Tensile tests for metals

Test methods to determine tensile strength for metals shall be carried out in accordance with ISO 9809-1 for steels, and ISO 7866 for aluminium. Alternatively, tensile tests shall follow the guidelines of ASTM E8/E8M and shall meet the requirements of the designs.

6.3.4 Sustained load cracking (SLC) test for aluminium alloys

The resistance of aluminium to SLC shall be determined in accordance with ISO 7866:2012, Annex B and shall meet the requirements therein.

6.3.5 Corrosion tests for aluminium alloys

Corrosion tests for aluminium alloys shall be carried out in accordance with ISO 7866:2012, Annex A and shall meet the requirements therein.

6.4 Ultraviolet resistance of external coatings

Protective coatings required to meet [17.3.3](#) shall be evaluated for resistance to ultraviolet effects using a minimum 1 000 h exposure using a UVA 340 lamp in accordance with ASTM G154. Evidence of blistering, cracking, chalking or softening shall be a cause for rejection.

6.5 Fibres

Structural reinforcing filament material types in the composite overwrap shall be glass fibre, aramid fibre, carbon fibre or mixtures or hybrids thereof. If carbon fibre reinforcement is used, the design shall incorporate means to prevent galvanic corrosion of metallic components of the fuel container.

6.6 Resins

The matrix material used for impregnating the fibres in the composite overwrap may be thermosetting or thermoplastic resin. Examples of suitable matrix materials are epoxy, modified epoxy, polyester and vinylester thermosetting plastics, and polyethylene and polyamide thermoplastic material. Resin system materials shall be tested on a sample test panel, representative of the composite overwrap, in accordance with ASTM D2344/D2344M. Following a 24 h water boil, the composite shall have a minimum shear strength of 13,8 MPa.

Resin system materials shall have a glass transition temperature (T_g) of at least 20 °C above the maximum container temperature (i.e. ≥ 105 °C). The glass transition temperature of resin materials shall be determined in accordance with ASTM D3418.

NOTE There is safe container operation experience at T_g at least 20 °C above the maximum container temperature. At temperatures less than this value, viscous flow phenomena can have an effect, resulting in stress concentration and damage accumulation in the laminate.

6.7 Nonmetallic liners (Type 4)

The nonmetallic liner material shall be compatible with the service conditions specified in [Clause 4](#).

The liner melt temperature shall be sufficiently high to allow gas release only through pressure relief devices during fire tests. See [17.3.8](#) for further details.

The tensile yield strength and ultimate elongation shall be determined in accordance with ASTM D638. Tensile or impact testing shall be conducted on samples of the nonmetallic liner material to demonstrate that the material fails in a ductile, rather than brittle, mode at temperatures down to $-50\text{ }^{\circ}\text{C}$.

The liner softening temperature shall exceed $95\text{ }^{\circ}\text{C}$ and shall be determined in accordance with the method described in ISO 306 or using an equivalent method.

6.8 Bosses for Type 4 containers

Materials shall be compatible with the liner and intended environment and shall meet the requirements of [6.2](#), [6.3.1](#), [6.3.2](#), [6.3.3](#), [6.3.4](#), and [6.3.5](#) as applicable.

7 Wall thickness

7.1 Type 1 containers

The minimum wall thickness shall be sufficient to comply with all applicable qualification tests within this document.

7.2 Liners for Type 2, Type 3, and Type 4 containers

Minimum thickness of the liner shall be such that the qualification test requirements of this document are met.

For Type 2 designs, the unreinforced metal liner shall have a minimum burst pressure of 125 % of the nominal working pressure.

7.3 Composite reinforcement for Type 2, Type 3, and Type 4 containers

7.3.1 Stress analysis

The stress analysis is applicable to Category A, B, and C containers.

Stresses in the liner and composite reinforcement shall be computed using suitable analysis techniques to adequately predict the stresses and strains in both the liner and the composite overwrap at the following pressures: autofrettage pressure (Type 2 and 3 only), zero-gauge pressure (after autofrettage for Type 2 and Type 3), nominal working pressure, hydrostatic test pressure, and minimum burst pressure.

7.3.2 Composite reinforcement stress ratios

NOTE 1 It is important to accurately calculate stresses in order to ensure stress ratio requirements are met, particularly when a metal liner is thick or autofrettage pressure is significantly greater than the hydrostatic test pressure. See ISO/TR 13086-1 and ISO/TR 13086-3 for information and guidance regarding stress ratios and their calculation.

The composite overwrap shall be designed for high reliability under sustained loading and cyclic loading. This reliability shall be achieved by meeting or exceeding the following composite reinforcement stress ratio values shown in [Table 3](#).

Table 3 — Composite reinforcement stress ratio values (See [7.3.2](#))

Material	Type 2	Type 3	Type 4
E-Glass	2,65	3,5	3,5
S-Glass	2,65	3,5	3,5
Aramid	2,25	3,0	3,0
Carbon	2,25	2,25	2,25

NOTE 2 For guidance on the calculation of stress ratio values, see ISO/TR 13086-1.

7.3.3 Modified stress ratio test

At the option of the container manufacturer, or for designs in which the required minimum container burst pressure is not sufficient to cause tensile failure in the fibre, a modified burst test procedure may be used to verify that the fibre stress ratio at the nominal working pressure is achieved. The stress ratio requirements (2,65) for E-glass and S-glass, reinforced Type 2 containers, may be demonstrated by meeting a minimum hold time at a specified pressure during the burst tests conducted under [12.5](#) or [17.3.5](#). Acceptable alternative combinations of hold times and pressures are as follows:

- a) 1 min at 250 % of the nominal working pressure;
- b) 1 h at 225 % of the nominal working pressure.

As an alternative, the strength of the fibre may be verified by the testing of containers, with the composite thickness reduced by no more than 50 %, to cause failure initiation in the composite.

7.3.4 Hybrid designs

Hybrid construction (using more than one type of reinforcing fibre) shall be permitted. The strength of the individual types of fibres used in a hybrid construction may be verified by the testing of containers reinforced with a single type of fibre. In a hybrid construction, the applicable stress ratio requirements shall be met in one of the following ways:

- a) if load sharing between the various fibre reinforcing materials is considered a fundamental part of the design, each fibre shall meet the stated stress ratio requirements;
- b) if load sharing between fibres is not considered as a fundamental part of the design, one of the reinforcing fibres shall be capable of meeting the stress ratio requirements even if all other fibre reinforcing materials are removed.

7.4 External loads on containers

Containers with greater than 450 l water capacity and all containers employing integral mounts or valve protection shall consider the external loads imposed on the container as a function of the service conditions and mounting provisions. This includes bending and torsional stresses.

8 Threaded openings

All threads shall comply with a recognized international or national standard, including ISO 11926-1 for straight threads and ISO 11363-1 for tapered threads.

Threads shall be clean cut, even and to gauge.

Tapered threads are only permitted on steel containers, steel liners and steel bosses.

9 Manufacture

9.1 General

Manufacturing processes shall be the same as those used to produce the containers subjected to design qualification tests and shall be specified by the container manufacturer in sufficient detail to produce consistent product. No defect shall be acceptable that is likely to cause failure within the lifetime of the container.

9.2 Metal containers and metal liners

Surfaces shall have dirt and scale removed, as necessary, to afford proper inspection. A reasonably smooth and uniform surface finish shall be required. No interior folding shall be permitted. Smooth gathering of

the material, in the neck or dome area in which there are no sharp rooted folds, shall be acceptable. If not originally free from such defects, the liner or container surface may be machined or otherwise treated to eliminate these defects provided the required minimum wall thickness is maintained. The liner or container end contour shall be concave to pressure.

9.3 Nonmetallic liners

Nonmetallic liners shall be free of contaminants as necessary to afford proper inspection. Interior folds, laps or sharp surface indentations, inclusions, voids, and clusters of voids that are detrimental to the product are not permitted. If not originally free from such defects, the liner surface may be reworked to eliminate these defects provided the liner then meets all design requirements. Welded construction of nonmetallic liners shall be permissible.

Liner weld processes, particularly time, temperature and joining force, shall be monitored during the welding process and controlled within the parameters established by the container manufacturer. Tensile tests of liner weld specimens shall be conducted on samples manufactured at the extreme limits of the process within which the container manufacturer controls the weld process.

Tensile testing of liner weld specimens shall be conducted during qualification of the weld process at $\leq -40\text{ }^{\circ}\text{C}$, at an ambient temperature and at $\geq 85\text{ }^{\circ}\text{C}$.

Tensile specimens shall fail either outside the weld joint or with a ductile failure, if the failure is within the weld.

9.4 Composite containers with metallic liners

The container shall be fabricated from a metal liner overwrapped with resin impregnated continuous filament windings or using an equivalent method. The winding pattern shall be in the “hoop” direction for “hoop-wrapped” containers, or in the “helical or in-plane” and “hoop” directions for “fully-wrapped” containers. The windings shall be applied under controlled tension to develop the design composite thickness. After the winding is complete, composites using thermoset resins shall be cured by a controlled temperature process that does not compromise the performance of the liner.

9.5 Composite containers with nonmetallic liners

Type 4 composite containers shall be fabricated from a nonmetallic liner overwrapped with resin impregnated continuous filament windings or using an equivalent method. The winding shall be applied under controlled tension to develop the design composite thickness. After the winding is complete, composites using thermoset resins shall be cured by a controlled process that does not compromise the performance of the liner.

Composite containers with nonmetallic liners shall be designed such that if, when pressurized, the liner is susceptible to creep and flow, no leakage will occur during the prescribed lifetime. Composite containers with nonmetallic liners shall also be designed such that during depressurization, the liner is not susceptible to failure from elastic instability or buckling.

The softening temperature for the liner may be exceeded during processing if the qualification testing verifies that the completed container passes all required tests.

9.6 Brazing

Brazing for any purpose whatsoever shall not be permitted.

9.7 Welding

Welded construction of metal containers, liners, and bosses shall not be permitted.

9.8 End closing by forming

The ends of aluminium containers or liners shall not be closed by a forming process. The base ends of steel containers or liners which have been closed by forming, except those containers or liners designed in accordance with ISO 9809-1, shall be inspected using non-destructive examination (NDE). Metal shall not be added in the process of closure at the end. Each container or liner shall be examined before end forming operations for thickness and surface finish.

9.9 Mounting and protection

If mounting provisions and/or valve protecting shrouds are required, they shall be permitted to be manufactured as part of the container, provided they are not detrimental to the performance of the container. If manufactured as part of the container, structural integrity shall be demonstrated by conformance with qualification tests specified in [Table 5](#) or [Table 6](#), as applicable.

9.10 Batch definitions

9.10.1 The batch definitions shall be as follows.

- a) Metal liners and containers only. A “batch” shall be a group of metal liners or containers successively produced having the same design, specified material of construction, process of manufacture, process of heat treatment, equipment of manufacture, equipment of heat treatment and conditions of time, temperature and atmosphere during heat treatment as the batch acceptance sample, with the only variation being the length up to ± 50 %.
- b) Nonmetal liners only. A “batch” shall be a group of nonmetal liners successively produced having the same design, specified material of construction, process of manufacture and equipment of manufacture as the batch acceptance sample, with the only variation being the length up to ± 50 %.
- c) Composite container only. A “batch” shall be a group of containers successively produced from liners having the same design, specified materials of construction, process of manufacture and autofrettage process as the batch acceptance sample, with the only variation, applicable to Type 2 containers only, being the length up to ± 50 %.

9.10.2 In no case shall a “batch” be permitted to exceed 200 units plus destructive test units, or one shift of production, whichever is greater.

9.11 Design qualification tests

Prior to initialling the in-service usage of any specific container design, qualification tests as prescribed in [Clause 17](#) shall meet all applicable requirements.

10 Production tests and examinations

10.1 General

Production examinations and tests shall be carried out by the following means on all containers produced in a batch:

- a) through non-destructive examination that flaws in metal containers and liners do not exceed the container manufacturer's specified limits;

NOTE Guidance for the determination of the container manufacturer's specified limits can be found in [Annex B](#).

- b) through visual or non-destructive examination that nonmetallic liners are free of flaws exceeding the container manufacturer's specified limits (see [9.3](#) for types of flaws);

- c) verification that the critical dimensions and parameters specified by the manufacturer of the completed container and of any liner and overwrapping are within design tolerances. Statistical sampling of critical dimensions shall be acceptable provided that the process is demonstrated capable of maintaining a process capability index (Cpk) of 1,33 or more;
- d) verification of the conformance with specified surface finish with special attention to deep drawn surfaces and folds or laps in the neck or dome area of forged or spun end closures or openings;
- e) verification of the coating quality (if required);
- f) verification of markings;
- g) verification of strength (heat treatment) of metal containers, liners and bosses. For Type 1 containers and Type 2 liners, a hardness test or equivalent shall be required.

A summary of critical production inspection requirements to be performed on every container is provided in [Table 4](#).

Any container not meeting the specifications in [Table 4](#) shall be rejected.

Table 4 — Production inspection requirements (See [10.1](#))

Production verification requirement(s):	Provision	Container type			
		1	2	3	4
Dimensions	10.1 c)	X	X	X	X
Flaws	10.1 a) and b)	X	X	X	X
Strength (heat treatment) of metal containers, metal liners and metal bosses	10.1 g)	X	X	X	X
Hydrostatic proof and volumetric expansion test	10.2	X	X	X	X
Leak test	10.3	a	a	a	X
Coatings (where required)	10.1 e)	X	X	X	X
Surface finish	10.1 d)	X	X	X	X
End closing by forming (steel)	9.8	X	X	X	
Markings	10.1 f)	X	X	X	X
^a Leak tests shall be conducted on those container types that are closed by forming.					

10.2 Hydrostatic proof and volumetric expansion test

Each finished container shall be hydrostatically tested to at least 150 % of the nominal working pressure. The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure. Measuring systems for pressure and expansion shall meet the accuracy and periodic calibration requirements of CGA C-1-2009, or ISO 11439:2013, A.11. Hydrostatic or pneumatic pressure shall be maintained for 30 s or sufficiently longer than 30 s to produce complete expansion. If the test pressure cannot be maintained due to failure of the test apparatus, it shall be permissible to repeat the test at a pressure increased by 0,69 MPa minimum.

When a proof test is conducted, the cylinder shall be rejected if there are leaks, failure to hold pressure or visible permanent deformation after the cylinder is depressurized.

The container manufacturer shall define the appropriate limit of elastic and permanent volumetric expansion for the test pressure used. The container manufacturer shall record all actual test results. Any container that does not meet the defined acceptance criterion for elastic expansion or volumetric expansion shall be rejected.

10.3 Leak test

All containers shall be leak-tested using the procedures in items a) and b) or an acceptable alternative method. The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure. Containers with multiple sealing connections shall be leak-tested at each connection. Permeation through the wall shall not be considered to be leakage.

- a) Containers shall be thoroughly dried and then pressurized to the nominal working pressure with leak test gas. If the manufacturer can demonstrate and document that leaks are detectable at a lower pressure than the nominal working pressure, then the lower pressure shall be used for the leak check procedure.
- b) Containers shall be placed in an enclosure to permit the detection of any leaks.

Any gas detected beyond the allowable permeation rate shall be a cause for rejection.

WARNING — Extreme care should be taken not to create explosive mixtures of gases within the container or test area (enclosure) when using combustible gases. Precautions should be taken in consideration of the potential for the release of combustible gases.

11 Batch tests

11.1 General

Batch testing shall be conducted on finished containers or liners that are representative of the normal production and are complete with identification marks. The test containers and liners, as appropriate, shall be randomly selected from each batch. If more containers are subjected to the tests than are required by this document, all results shall be documented.

When the test results fail to meet the requirements, the container or liner batch shall be rejected. One retest of a rejected batch may be authorized if the test result identifies the presence of a defect in the container or liner and the batch is 100 % inspected to remove defective containers or liners from the batch. A second sample shall then be permitted to be selected from the batch and tested. The batch shall be considered acceptable if the second sample meets the batch criteria. Applicable national legislation that overrules these requirements can exist.

11.2 Batch material tests

The container or liner shall meet the requirements of the design when subjected to the following tests.

- a) Check the dimensions against the design.
- b) For metal containers and liners, subject two specimens to the tensile test in accordance with the appropriate method specified in [6.3.3](#).
- c) For steel containers and liners, subject three specimens to the impact test in accordance with the method specified in [6.3.2](#).

11.3 Coated containers

When a protective coating is a part of the design, the following tests shall be performed (in order) on a finished container or a representative test panel from each coating batch.

- a) Coating thickness tests shall be in accordance with one of the following appropriate test methods:
 - 1) ASTM D7091;

2) ASTM D4138.

- b) Containers that do not meet the container manufacturer's specified coating thickness requirement may be recoated after appropriate surface preparation without prior re-stripping.
- c) The coating adhesion test in accordance with ASTM D3359 shall provide a minimum rating of 4 when measured using either test method a) or b), as appropriate.

Repair of tested surfaces shall be permitted to a container manufacturer's approved procedure.

Where the coating fails to meet the requirements, the batch shall be 100 % inspected to remove similarly defective containers. The coating on all defective containers may be stripped, using a method that does not affect the integrity of composite wrapped containers, and re-coated. The coating batch test shall then be repeated.

11.4 Burst test

11.4.1 Batch burst test

One container selected from each batch shall be hydrostatically pressurized to burst in accordance with the test procedure described in [17.3.5.2](#). The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure. Rupture may occur in any region of the container. The burst pressure shall meet or exceed the minimum required burst pressure; otherwise, the batch shall be rejected.

The container used for the cycle test in [11.5](#) may be used for the burst test. If the burst pressure of the cycled container is less than the minimum required burst pressure, an additional burst test shall be conducted on another container selected from the batch. The burst pressure on the additional container shall meet or exceed the minimum required burst pressure; otherwise, the batch shall be rejected.

11.4.2 Periodic burst test

11.4.2.1 The requirement in [11.4.1](#) to burst a container from each batch may be replaced by periodic burst testing. For the first five sequential batches of a design family (i.e. similar materials, processes and stress levels, but allowing different sizes), one container from each batch shall be burst-tested in accordance with the requirements of [11.4.1](#). If the container from any batch fails to meet the minimum required burst pressure, the batch shall be rejected.

11.4.2.2 If five sequential batches pass the burst test, subsequent burst tests are only required on every tenth batch manufactured. If more than three months have passed since the last batch of containers was burst-tested, a container from the next batch of containers manufactured shall be burst-tested.

11.4.2.3 If a container fails to meet the minimum burst test requirement, the batch shall be rejected and a sample from every batch manufactured since the previous periodic burst test shall be tested. Any failure to meet the minimum burst test requirement shall also cause rejection of the corresponding batch. A representative container from each of the next ten batches shall be burst-tested.

11.5 Ambient cycle test

11.5.1 Batch cycle test

One container selected from each batch shall be pressure cycle tested in accordance with the following. The container attachments, if any, shall also be included in this test, unless the manufacturer can demonstrate that the container attachments do not affect the test results and are not affected by the test procedure.

11.5.2 Periodic pressure cycling test

11.5.2.1 The container shall be pressure cycle tested in accordance with the following procedure.

- a) Fill the container to be tested with a non-corrosive fluid such as oil, inhibited water or glycol.
- b) Cycle the pressure in the container between 2 MPa and ≥ 125 % of the nominal working pressure for a total number of cycles equivalent to 750 times the service life of the container in years for Category A containers, or to 7 500 cycles or 11 000 cycles as appropriate for Category B containers, or to 1 125 times the service life of the container in years for Category C containers. The maximum pressurization rate shall be 2,75 MPa per second.
- c) Leakage may occur in any region of the container. The number of cycles attained before failure shall meet or exceed the number specified above; otherwise, the batch shall be rejected.

11.5.2.2 The first five sequential batches of a design family shall be tested as follows.

- For Category A containers: The total number of cycles is equivalent to 750 times the service life of the container in years.
- For Category B light duty containers: The total number of cycles is equivalent to 7 500, or 11 000 cycles, as appropriate.
- For Category B heavy duty containers: The total number of cycles is equivalent to 11 000 cycles.
- For Category C containers: The total number of cycles is equivalent to 1 125 times the service life of the container in years.
- The cycling rate shall not exceed 10 cycles per minute. If the container from any batch fails to meet this requirement, the batch shall be rejected.

11.5.2.3 If five sequential batches pass the cycling test, subsequent pressure cycling tests shall only be required on every tenth batch manufactured. If more than three months have passed since the last batch of containers was cycle tested, a container from the next batch of containers manufactured shall be cycle tested.

11.5.2.4 If a container fails to meet the cycle requirement, the batch shall be rejected and a representative container from each of the next 10 batches shall be cycle tested.

12 Rejected containers and liners

12.1 Physical test

In the event of failure to meet the physical test requirements, retesting or reheat treatment and retesting shall be authorized as follows to the satisfaction of the Inspector.

- a) If there is evidence of a fault in carrying out a test or an error of measurement, a further test shall be performed. If the result of this test is satisfactory, the first test shall be ignored.
- b) If the test has been carried out in a satisfactory manner, the cause of test failure shall be identified.
 - 1) If the failure is considered to be due to the heat treatment applied, the manufacturer may subject all the cylinders implicated by the failure to a further heat treatment, e.g. if the failure is in a test representing the prototype or batch cylinders. A test failure shall require reheat treatment of all the represented cylinders prior to retesting. One additional heat treatment shall be allowed for aluminium and two additional heat treatments are allowed for steel. Additional heat treatments require the validation by material properties testing ([6.3.2](#) and [6.3.3](#)) for steels.

This reheat treatment shall consist of either re-tempering or a complete reheat treatment.